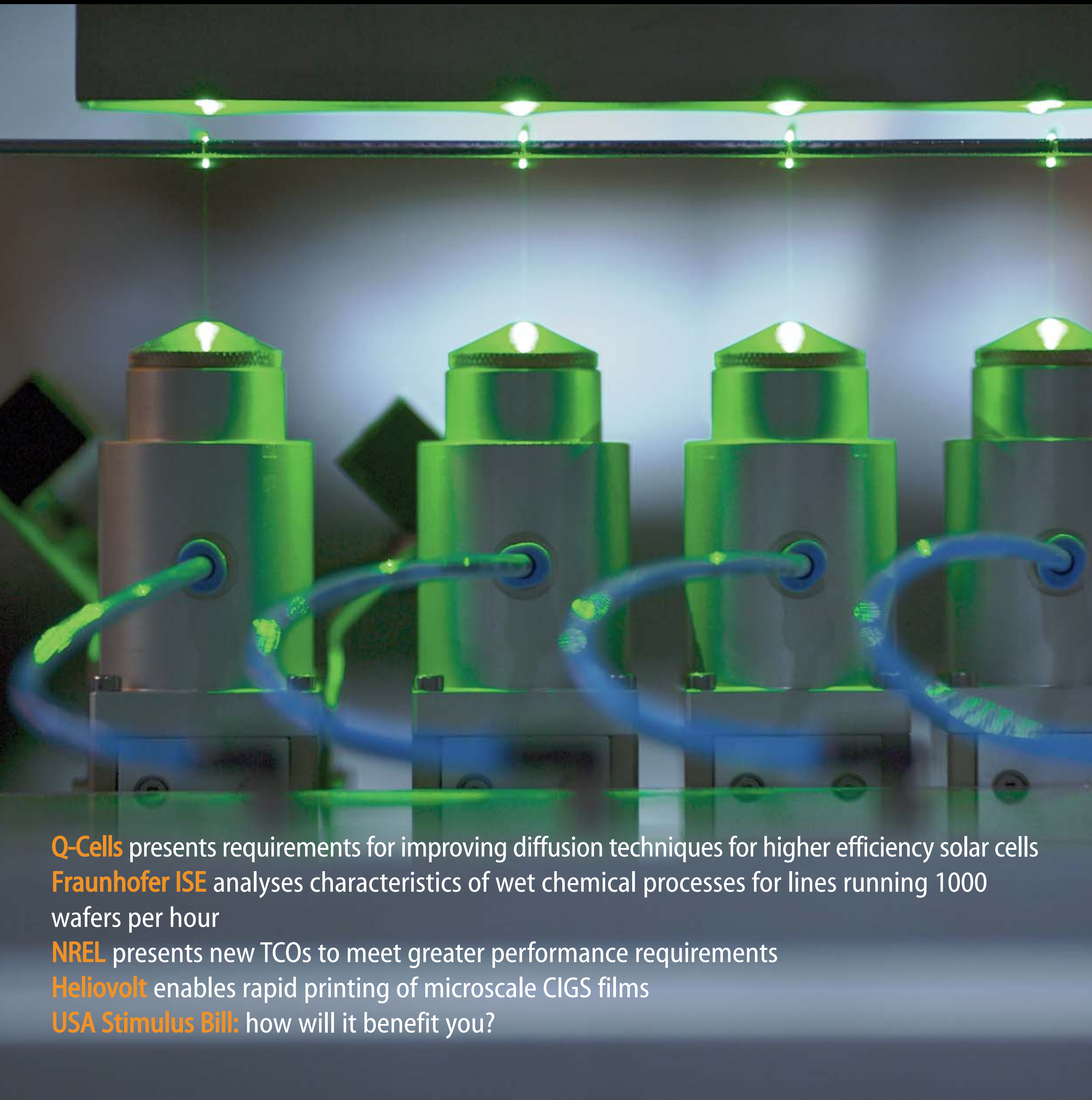
Third Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS



Q-Cells presents requirements for improving diffusion techniques for higher efficiency solar cells

Fraunhofer ISE analyses characteristics of wet chemical processes for lines running 1000 wafers per hour

NREL presents new TCOs to meet greater performance requirements

Heliovolt enables rapid printing of microscale CIGS films

USA Stimulus Bill: how will it benefit you?

First Quarter 2009

Photovoltaics International

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Front cover shows high-speed laser scribing of thin-film silicon modules.
Picture courtesy of Oerlikon Solar Ltd., Trübbach, Switzerland.

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Publisher's foreword

The first quarter of 2009 is drawing to a close and we are starting to achieve some clarity regarding global credit issues. Although timing is uncertain, it looks like demand could start to pick up through the second half of 2009, with most analysts anticipating that the renewable energy sector will be one of the first industries to bounce back from the global recession currently in place.

In February, Germany's new economy minister Karl-Theodor zu Guttenberg announced that he expects to see an upturn in the German economy no later than autumn. Coupled with KfW's bank loan offerings and aleo Solar's already announced 50MW of projects in the EU for 2009, the situation from a demand perspective is starting to look less grim.

All eyes now turn to the USA as the stimulus bill takes effect this year. The bill will mean 30% tax breaks for manufacturers, helping them maintain profits even through the worst of the module oversupply situation. In fact, demand for modules in the USA remains strong in key state markets driven by strong subsidies. When our own Tom Cheyney caught up with installers at the recent 'Go Green Expo' in Los Angeles (p. 172), the story they painted was a stark contrast to the pervading feeling of unease in the solar industry.

The respite from end-market demand could come as a blessing for solar manufacturers allowing them more time to focus on important cost-saving and efficiency improvements throughout the supply chain.

Silane is used predominantly in PV manufacturing to treat wafers and for depositing amorphous silicon on glass substrates. As a pyrophoric substance it can be extremely hazardous to handle and use. Our article on innovative materials looks at Sixtron's efforts to replace SiH_4 with gasses that will not affect overall cell efficiency (p. 44).

Louay Eldada, CTO of Heliovolt, gives us an exclusive look at a manufacturing approach that enables the rapid printing of microscale CIGS films with p- and n-type nanodomains, critical for achieving the highest efficiencies possible (p. 86).

Q-Cells helps us understand the characteristics of emitter doping profiles and the diffusion process to contribute toward higher cell efficiencies. In addition, an overview of industrial diffusion technologies is provided as a guide for future production strategies (p. 60).

There are new and innovative ways to market solar panels today. We take a look at SunPower's solar employee purchase program whereby HP has met corporate sustainability goals and SunPower dealers have benefited from an additional 200kw of installations (p. 155).

This year, *Photovoltaics International* will be leading the charge to recognise the importance of process, project and equipment development through the inaugural Cell Awards. I encourage everyone to get involved by nominating their particular favourites in the solar technology realm at www.cellaward.com.

Companies that continue to invest and innovate during these tough times will come out ahead as the underlying need for solar energy transcends fiscal and political imperatives. The need for clean, cheap and renewable energy remains at the heart of how our society functions and thus demand will rebound. The extent of this rebound will be determined by the efficiency of the steps taken by the industry of today to constantly improve processes.

Sincerely,

David Owen
Photovoltaics International

Photovoltaics International

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

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

Editorial Advisory Board

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

Gerhard Rauter

Chief Operating Officer, Q-Cells AG

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

Takashi Tomita

Senior Executive Fellow, Sharp Solar

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

Rodolfo Archbold,

Vice President of Operations, Evergreen Solar

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

Dr. Kuo En Chang

President of Solar Division, Motech Industries, Inc.

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

Professor Eicke R. Weber

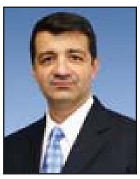
Director of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg

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

Dr. Zhengrong Shi

Chief Executive Officer, Suntech

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



Dr. John Iannelli

Chief Technology Officer, Emcore Corp

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

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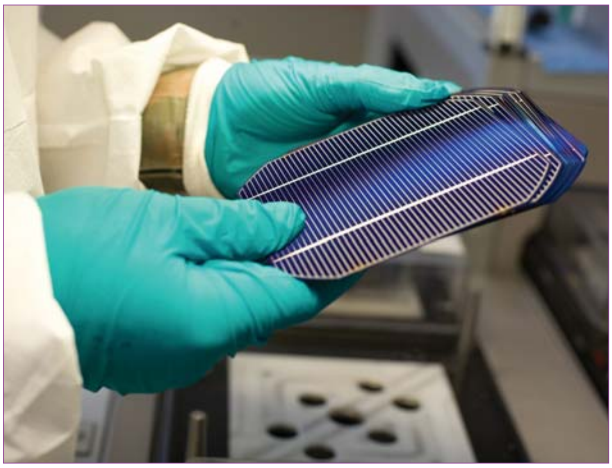

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Photovoltaics International

Fab and Facilities

News

Suntech celebrates 1GW and prepares for 2009 production milestone and new HQ

Suntech Power Holdings celebrated realizing its stated goal in 2008 of reaching its production target of 1GW in both solar cell and module capacity, claiming to be the first to achieve both milestones. Suntech also announced the opening of a new Headquarters in Wuxi, China, its centre for manufacturing, which employs what it claims is the largest building integrated solar façade, producing a grid-connected 1MW.

"We are very proud to become the world's first PV solar company to achieve 1GW of solar cell and module production capacity," said Dr. Zhengrong Shi, Suntech's Chairman and CEO. "Since our inception, we have focused on rapidly building world-class manufacturing facilities that can meet the burgeoning global demand for green energy. This milestone is a credit to all Suntech employees that have tirelessly worked towards the common goal of making cost-effective solar energy systems available on a global scale."

Suntech's new HQ uses 2,552 PV modules.

Late last year, Suntech revised its capacity expansion plans in response to slowing demand, which will see the company hold capacity at 1GW through 2009. Previous plans were to expand capacity to 1.4GW in 2009. The new HQ is said to employ 2,552 semi-transparent 'Light Thru' Suntech solar panels installed by Suntech's in-house system integration team.

Following the announcement of becoming the first comany to reach 1GW of solar cell and module production capacity, Suntech Power Holdings Co., Ltd. cancelled plans to recruit an additional 2,000 staff, choosing instead to cut 800 jobs, or 10% of the company's current workforce as a seasonal adjustment. Dr. Shi blamed the current financial crisis for the change in plans.

Capacity News Focus

Advanced Solar Photonics schedules 40MW thin-film module production facility

Florida-based Advanced Solar Photonics (ASP) plans to break ground on its SolarFab this year following its expansion to a 318,000 sq ft facility. The SolarFab, a thin-film module production plant is scheduled to ramp up production to 40MW by late 2010, with the capability to expand capacity further down the line. The new production facility will focus on development of ASP's thin-film SunPanels, which are scalable and are expected to be able to reach grid parity by 2011 due to ASP's patented manufacturing process and technologies.

ersol triples manufacturing capacity with Bosch Group's €530 million investment

ersol Solar Energy will undergo a major expansion in terms of production following the announcement of a planned €530 million in investment from parent company the Bosch Group, which acquired 50.45% of ersol's shares in June 2008. The investment will be spent on construction of a new manufacturing facility for crystalline solar cells adjacent to the existing research facility in Arnstadt, Germany, a module manufacturing 'shop,' and a new administrative building and expansion of the research facility, all of which are expected to generate an estimated 1,100 new jobs.

ersol's planned expansion in Arnstadt, Germany

The expansion will see the near-tripling of crystalline manufacturing capacity to a nominal capacity of around 630MWp. The investment will inject close to €530 million in the company from now until 2012, and will help to further the company's growth. Sales for 2008 are expected to exceed €300 million, while projections for 2009 show an expectation of over €400 million.

Sharp shuffles new thin film plant production schedule

Sharp Corporation will bring forward the planned production of its next-generation solar thin-film plant, based in Sakai City, Osaka Prefecture, Japan. Sharp had planned production to start at the 1GW capacity facility in March 2010, but cited an increase in demand for the revised start, expected by the end of 2009.

Citing growing demand as the reason for the production being brought forward could be a moot point. Sharp had already announced in December 2008 that it would be bringing forward production of its next-generation TFT-LCD production at the

Sharp's next-generation solar thin-film plant, based in Sakai City, Osaka Prefecture, Japan.

jointly located facility. The move to improve its competitive position in an over-supplied LCD market by employing larger Gen 10 panels to cut production costs is seen as a key cost reduction strategy.

According to market research firm iSuppli Corp., large-sized TFT-LCD panel prices have continued to decline since the beginning of 2008 with prices reaching cash-cost levels. Should the revised start materialise, Sharp would possibly need to revise upwards capital spending plans for FY2009 and FY2010, to take into account the earlier than expected ramp.

BP Solar capacity falls

BP Solar reported a production capacity decline for the 4Q 08. The reasons for this were a combination of the running down and expected closure of its 50MW photovoltaic cell and module manufacturing plant in Australia, as well as a fire at its joint venture production plant in India, Tata BP Solar. BP detailed the production disruption and decline in MW capacity in its latest quarterly financial filings.

Nominal capacity in the 3Q 08 was 277MW, but fell to 213MW in the fourth quarter, due in particular to the fire at Tata BP Solar plant, which disrupted production. Nominal capacity in 2008 was therefore below 4Q07 levels of 228MW, indicating an overall decline in MW capacity in 2008.

Evergreen Solar consolidates facilities, stays on track with solar manufacturing plans

Evergreen Solar said it shipped 8.5MW of its proprietary String Ribbon photovoltaic modules from its Devens, Massachusetts, factory and an additional 3.7MW from its Marlboro, Massachusetts, pilot manufacturing facility during the 4Q 08, numbers that are in line with its announced expectations in October.

The company – which manufactures wafers, cells, and modules at its sites – also received its certificate of occupancy for the second phase of the Devens facility on December 19 and expects to reach the planned full capacity of about 40MW per quarter from that factory in the second half of 2009.

Evergreen Solar module production.

Tool Order News Focus

CaliSolar selects Eyelit manufacturing software for new PV cell facility

CaliSolar chose Eyelit to provide its factory automation, manufacturing execution, quality, and asset management software suite to support the upgraded metallurgical-grade silicon (UMG-Si) solar cell company in its production ramp of a new fully integrated facility in Sunnyvale, California.

Eyelit said that its solutions will be used to track, monitor, and provide product visibility of material, starting with raw silicon and including ingot, brick, wafer, and PV solar cell production, along with control over CaliSolar's equipment and other key assets.

CaliSolar will utilize Eyelit's FactoryConnect middleware for factory automation and direct tool connectivity, while the vendor's asset management offering will provide tool monitoring, management of calibration, and preventive maintenance, as well as built-in warnings, alerts, maintenance operations, and tasks all focused on higher equipment utilization. The solar company also plans to implement Eyelit's quality software for real-time statistical process control and deviation management.

Air Products wins turnkey gas supply contract with Spanish thin film start-up

Gadir Solar selected Air Products to supply turnkey gas systems as well as bulk and speciality gases to its new a-Si thin-film manufacturing plant, supplied by Oerlikon Solar. The contract includes the long-term supply of nitrogen, hydrogen, argon, oxygen, and specialty gases such as silane, NF3 (nitrogen trifluoride), and dopant gases as well as the installation and operation of the complete gas distribution system from the source containers to the point of use.

Sanyo's Nishikinohama Factory, Kaizuka City, Osaka, Japan.

Sanyo targets 600MW HIT solar cell production with new plant

Sanyo Electric Co., Ltd has officially announced the construction of a new solar cell manufacturing plant at its Nishikinohama Factory, Kaizuka City, Osaka, Japan. Groundbreaking took place on February 17th, 2009 with the new facility expected to be completed in October 2009.

The new facility will be dedicated to the production of Sanyo's Heterojunction with Intrinsic Thin layer (HIT) solar cells. The company also announced that HIT production at its Shimane Plant in Unnan City, Shimane Prefecture, Japan will also be expanded to meet demand for its HIT solar cells in Japan and Europe.

Sanyo said that the combined current capacity of the two plants would reach 340MW by the end of its FY2008 and reach 600MW at the end of FY2010 when the newly announced expansion plans reach full capacity.

However, according to *Photovoltaics International's* 2008, capacity expansion forecast for Sanyo, the expansion plans are approximately one year behind previous projections. This could be attributed to Sanyo's financial problems and subsequent planned acquisition by Panasonic Corporation.

Other News Focus

Signet Solar picks New Mexico for company's first U.S. thin-film PV factory site

Signet Solar chose Belen, New Mexico, as the site for its first North American thin-film-silicon solar PV module manufacturing facility. The first phase of the plant, set to have an annual 65MW production capacity, is scheduled to start operations in 2010 and will create 200 high-wage jobs.

Signet has long-term plans for expansion. The company plans to increase annual capacity to 300MW, hiring as many as 600 more workers, for a 600,000 sq-ft facility at Rancho Cielo area about a half-hour south of Albuquerque. The community says it plans to build a 700 acre solar farm which will employ Signet's large-area TFPV glass panels. The amount of Signet's investment or details of incentives offered by New Mexico have not yet been disclosed.

Day4 Energy to cut jobs at Burnaby production facility

Day4 Energy, Inc. announced the planned cut of approximately 95 people from its workforce in an attempt to improve the company's cost structure. The Canadian solar module manufacturer said that the cuts would affect the company's Burnaby, BC production facility, and would incur restructuring costs of approximately US$0.7 million. The affected employees would be offered severance and human resource support, according to the company.

South Korean Government bestows export award on Edwards for fourth year running

Vacuum and abatement company Edwards is the recipient of the South Korean Government's "Export Tower Award" for the fourth year in a row. The award celebrates the company's reaching of US$70 million in exports for the year, having met incremental targets of US$10M in 2004, US$20M in 2006 and US$50M in 2007. Presentation of the award took place during South Korea's "45th Annual Day of the Export," which event celebrates companies that have contributed to the Korean economy.

Adept sees decline in revenue for the 2Q 09

Adept Technology, Inc. announced its financial results for the 2Q 09, ending December 27, 2008. Revenues were down to US$11 million, compared to US$14.4 million in the same period last year and US$14.3 million in the 1Q 09.

This decrease is due to a decline in orders and service business, which can be attributed to the current weakening economic climate as well as a decline in capital spending relating to Adept's industrial and automotive business in Germany. The company suffered a GAAP net lost of US$4.6 million, including restructuring costs of US$1.9 million, US$1.4 million of which came as the result of the write down of service inventory related to the discontinuation of remanufactured robots. This compares to a net income of US$1.5 million and a net loss of US$1.6 million for the 1Q 09.

Adept's gross margin also decreased to 42.2% of revenue in the 2Q 09 from 50.4% of revenue in the same period last year and 46.2% in the 1Q 09. The company's gross margin in the 2Q 09 suffered due to the weakening of the euro and strengthening of the Yen compared to the dollar, in addition to a decline in their higher margin service business.

At December 27, 2008, Adept's cash and short-term investment balance was US$11.0 million, compared to US$12.3 million at September 27, 2009 and US$15.2 million at June 30, 2008.

TÜV Rheinland PTL opens solar PV testing, certification facility in Arizona

TÜV Rheinland PTL, a new private venture between TÜV Rheinland and Arizona State University, opened January during ceremonies held in Tempe, Arizona. The photovoltaic lab is touted as one of the world's most comprehensive and sophisticated facilities for testing and certification of solar energy equipment.

The organization upgrades the technology and know-how of the former ASU Photovoltaic Testing Laboratory (established in 1992) and moves from the old ASU PTL testing grounds in Mesa to a more strategic, centralized location in Tempe.

The 40,000-sq-ft facility more than doubles its previous capacity and provides a one-stop source for clients to get full testing and certification for a wide range of safety and performance standards in use by the global industry, according to TÜV PTL.

The lab is equipped with state-of-the-art solar simulators and temperature-humidity environments. Clients can benefit from full system testing for all photovoltaic system components, including inverters, grid-tied electronics, controllers, motion and tracking devices, and wireless control electronics. In addition, technical direction and testing on standards for emerging technologies such as concentrating PV, concentrating solar power, and building-integrated PV are provided.

Supported by both the federal and state governments, the ersol Board of Management, who proposed this investment initially, have also applied for government subsidies that could total a tenth of the €530 million. The subsidies are subject to European Commission approval.

Design for fab scalability

Konstantin Konrad, **Fabian Böttinger** & **Joachim Seidelmann**, Fraunhofer Institut für Produktionstechnik und Automatisierung (IPA), Stuttgart, Germany

ABSTRACT

Owing to the huge demand for photovoltaic products, the market is still very attractive for investments in production facilities. Nevertheless, the increasing number of competing photovoltaic manufacturers and the decrease in governmental subsidies require substantial and continuous cost reductions. Whilst existing facilities can save costs by enhancing cell efficiency, optimizing production processes or reducing material costs and other resources, for new manufacturing sites there is a great potential in making efficient use of economies of scale. This also holds true - to some extent – for expanding existing fabs. This paper presents the logistics behind and the benefits of implementing economy of scale in a PV manufacturing facility.

A considerable amount of research has been carried out regarding the economy of scale for large-sized manufacturing sites, targeting output values of gigawatt dimensions and above. For all stakeholders, the necessity of a well-planned ramp-up and implementation strategy seems to be obvious for large-scale factories. However, in the case of existing factories and factory layouts, most stakeholders are unaware of the unused potential in their production capabilities.

The extent of the investments needed for such facilities is one of the main reasons for there to be reluctance in this scaling implementation. Therefore, a commonly used approach is to achieve full production capacity step-by-step by using proven standard fabs with lower output capacities. The advantage of replicating these fabs is that lessons learned from one fab can easily be transferred to subsequent projects.

Some useful synergies that can typically be achieved are:

- Large-order quantities and supplier agreements
- Lower personnel costs through reducing the number of specialists and administration staff
- Common supply of materials and other resources, e.g. power or gas supply, and

The limitations of this approach are mainly experienced in the field of inter–fab production optimization. The separation of material flow systems does not allow inter-line balancing, thus resulting in unused potential.

The lack of a higher-level IT system capable of coordinating and gathering data from multiple production lines makes sustainable fab analysis and control impossible (e.g. flexible material routing). Typical IT systems are not designed to be extended to multiple production lines.

Frequent instances of equipment down-time, maintenance as well as qualification and engineering lots can lead to disturbances in production which may result in the starvation of bottleneck equipment. Other equipment invariably has additional capacity available that remains unused, resulting in suboptimal output.

The approach explained detailed in this paper is intended to overcome this obstacle and set up an intelligent and flexible production by:

- optimizing the utilization of bottleneck equipment
- ensuring balanced Work In Progress (WIP)
- minimizing material waiting times
- reducing cycle times, and
- making use of redundancy.

IPA approach – Design for Scalability

In order to achieve optimal throughput, the extension of production capacities must be considered right at the start of the first planning and design phase. Smaller adjustments and improvements can still be made during the implementation phase.

Company	City/Country	MW
Sontor GmbH	Solar Valley Thalheim/Germany	24
Moser Baer	Indien	40
Auria Solar Co.	Taiwan	60
Pramac SpA	Switzerland	30
Sunwell	Taiwan	60
Sontor GmbH	Bitterfeld-Wolfen/Germany	25
Solibro	Solar Valley Thalheim/Germany	30
Würth Solar	CISfab Schwaebisch Hall/Germany	30
CMC Magnetics	Taiwan	46
Wacker Schott	Jena/Germany	50
Odersun AG	Fuerstenwalde/Germany	30
Schott	Jena/Germany	33
SolarWorld	South Korea	150
SolarWorld	Camarillo/USA	100
Signet Solar	Dresden/Germany	120

Figure 1. Breakdown of currently (2008) installed production capacity based on authors' research.

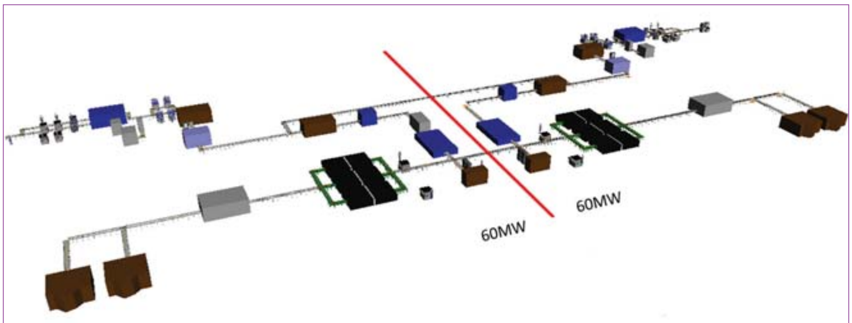

Figure 2. Schematic of IPA's Design for Scalability approach (2 x 60MW > 120MW).

However, this results in increased expenses and can lead to a limited outcome due to the actual layout restrictions.

Therefore, the basis of an integrated, modular and efficient factory has to be designed and implemented in the first production line. A well-designed logistic and IT approach is fundamental for an efficient production site.

Logistic system

In current extended factories, the logistic connection between different components is either not assured at all or not optimal. Usually there are two almost independent production lines that make very little use of the increased redundancy potential. The factory footprint is not laid out for the additional equipment and materials; even the buffer space or storage locations are often unsuitable for the extended capacity. Therefore, considerable effort is necessary just to ensure efficient production of the two separate lines.

Design for Scalability – logistic approach

The goal of extending the factory needs to be considered in the design phase. Specified transfer stations for extension (extension points) are defined in the first phase. These extension points are used to transfer material smoothly between the different production lines. The specific location of the decoupling points varies from company to company, and depend on facts such as equipment costs (usually the most expensive pieces of equipment are the ones targeted to be improved) and the logistic effort for integration. This ensures improved equipment utilization and enhanced line balancing in the case of tool-downs, maintenance, etc.

At this point, additional space requirements for the extended production capacity are taken into consideration and can be easily adjusted or linked with extra space. By taking these two aspects into account, transfer between separate production lines is ensured efficiently. This guarantees the necessary flexibility regarding changing material flow requirements (qualification lots/research & development lots/process improvements concerning tact times, etc.). The most important benefit is that such a scalable solution makes full use of economies of scale. If this is taken into consideration in the planning phase, there should be no problem in connecting the production lines even if they are housed in different buildings. Transport systems (e.g. conveyors) transporting batches or single-wafer substrates can easily be installed in tunnels or housings.

IT infrastructure

There seems to be a lack of comprehension of the level of IT integration needed for PV factories. More often than not, the IT system is not efficient enough for the extended capacity and unable to make full use of the increased redundancy. It can have trouble efficiently integrating and operating additional components that are required when production capacity is extended.

Design for Scalability – IT approach

The IT roll-out/implementation takes place in two steps.

In the first step, an efficient scalable backbone for the IT system is implemented. Important features at this point in time include:

- Rapid and uncomplicated integration of equipment. Where several equipment types with highly varying interfaces are implemented, an equipment integration layer is generally used. Now that the first standard for IT interfaces in the PV industry is under way, interoperability will be significantly facilitated and integration effort considerably reduced.
- Component tracking to trace materials.
- Rapid integration of external software.
- Resource management.
- Collection of process data, reporting, analysis and more.

Special care is taken regarding the later addition of supplementary components, which are necessary to manage larger production sites efficiently. Components that are not necessary for the operation of one manageable production line can easily be added and integrated at a later stage. Some may be more useful in cases where processes have reached a higher level of maturity (fault detection and classification, statistical and advanced process control, etc.); others are directly related to the extended capacity (scheduling and dispatching, material management, maintenance management, etc.).

This approach minimizes the effort required to extend capacity as all of the business logic and features (e.g. reports or master data management) keep working in the same way as before. By combining the Logistic and IT approach, a flexible system is realized for production capacity, equipment requirements and changing logistic demands where new software and hardware components can easily be integrated.

Procedure

The Design for Scalability procedure consists of five phases in which the factory concept is developed. In the preliminary survey, a *feasibility study* is carried out where the potential risks are evaluated, and the scope, deployment of resources and the timeframe for realization are all outlined. Additionally, an adapted *cost-benefit analysis* is performed where the monetary aspects are reviewed. In this phase, the project potential is estimated and a decision made by the project managers as to whether further investigations are justified. .

Requirements are then gathered in a structured way and aligned with the business strategy. The production processes are initially described with the aid of *business process modelling*. Based on the process sequence, a *use case analysis* is carried out in which the core use cases are described and examined. Subsequently, the *technical requirements/restrictions* for each process step are considered and listed in a document. Again, special emphasis is placed on the extension phase during the factory lifecycle.

Armed with the familiarity of the use cases and requirements, the factory layout can then be designed. Starting with an idealistic layout, the gathered knowledge is considered and the layout gradually redesigned. This is achieved using a top-down approach, which takes the most important requirements into account (extension points, transfer routes, footprint for additional equipment, etc.), resulting initially in major layout changes and in optimization (short routes, etc.) at a later stage. This phase realizes a flexible, adaptable material flow and an optimized footprint for further factory improvements.

Material flow simulation studies are carried out with the aid of discrete event simulation software to verify and further enhance the layouts. This enables the dynamic behaviour of the production system to be modelled and different layout versions to be evaluated. Aspects such as buffer capacity, optimal throughput, improved equipment utilization and enhanced line balancing (in case of down events) are considered. Different scenarios with research & development lots, re-qualification lots or dummy substrates can be examined and evaluated without difficulty. The whole structure of the simulation model is based on a modular approach. Building the simulation model in this way reduces the effort involved in modifications that are essential in order to test different scenarios and finally enhance overall factory performance. For example, the position of extension points can be changed without difficulty.

At the end, a final report and implementation plan are prepared. A total cost of ownership is drawn up in which all costs for the initial investment and later operation of the PV factory are listed and considered.

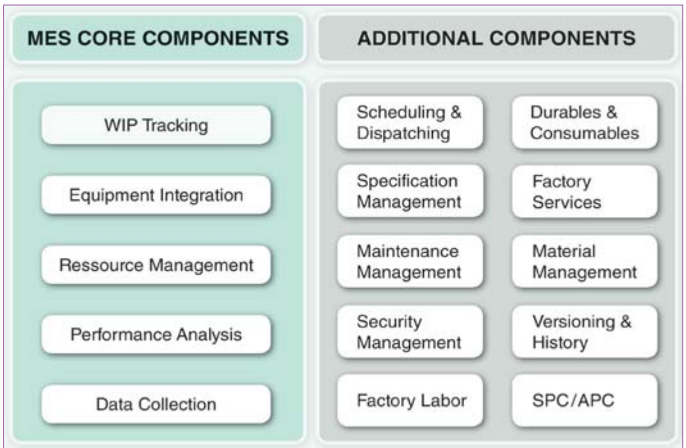

Figure 3. Suggested MES core components for the first stage and additional components that can be integrated in a second step.

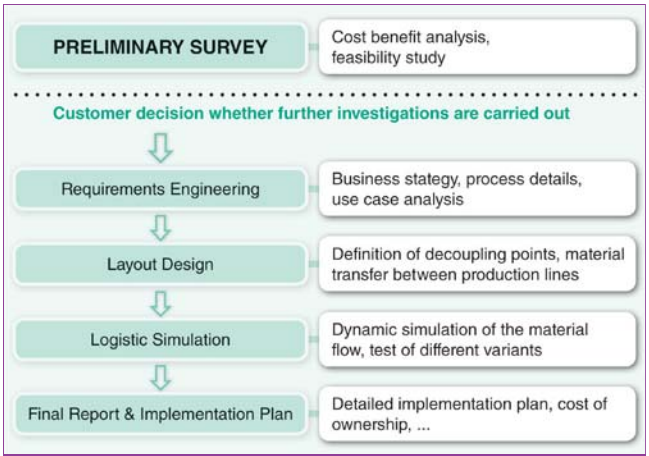

Figure 4. The five phases of the Design for Scalability procedure.

Limits and summary of the approach

As the state-of-the-art extension approach for PV production lines lacks both efficiency and effectiveness, this new scalability approach has been introduced. It considers the logistic and IT requirements and optimizes overall factory performance and effectiveness when extending production capacities.

One limitation of the approach is obvious for all stakeholders. The initial investment for the first production line fulfilling the requirements for an easy and efficient extension at a later stage is bigger compared to that of a standard production line. Another important obstacle for the Design for Scalability approach is the turnkey business in the thin-film photovoltaics market. Turnkey suppliers can often be reluctant to adapt their standard fab concept to specific customer requirements. In the event that they are willing to customize their automation and IT system according to the client's needs, they tend to charge high amounts for specifications and limit their warranty for the production system.

Nevertheless, the extension concept of PV factories will become more important and consequently more enhanced in time.

About the Authors

Konstantin Konrad is project manager and senior scientist at Fraunhofer IPA, which he joined in 2007. He has a Master's degree in cybernetics engineering from the University of Stuttgart. He has sound knowledge in the field of factory logistics and manufacturing IT, as well as experience in software and hardware projects.

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PV fab managers' wish list: achieving an efficient supply chain

Eddy Blokken, SEMI, Belgium

Featuring insights from **Sovello AG**, **Solland Solar**, **Scheuten Solar**, **Deutsche Cell**, **Solarwatt** and **ersol Solar Energy**

ABSTRACT

The PV industry has seen some incredible growth in the last five to eight years. This growth is essential in order to fulfill the challenging targets this industry has set itself to ensure it becomes an economical viable alternative energy source. A negative result of this growth, however, is the inefficient supply chain, where there is a lack of balance between demand and supply. The industry is going from one bottleneck to another. What is the impact of such inefficiencies on the supplier/manufacturer relationship? In this article, we collect information from short interviews of a number of fab managers in the wafer, cell and module domain, and try to answer this question.

Introduction

The relation between customer and supplier goes through different phases: lead prospection, contract negotiation, delivery, installation, interfacing, debugging, modifications, buy-off, maintenance, and eventually the removal of obsolete equipment to restart the cycle. The most challenging of these phases currently seems to be delivery, installation, commissioning and maintenance, which topics will be further developed throughout this paper. This does not suggest that the other phases are problem-free, but they interfere less today with the efficiency of the manufacturers.

"Huge volumes of material move through the production line, but the added value available from the processes is limited."

Where are the challenges situated? Most manufacturers refer to maintenance services as the issue that most urgently requires collective fixing, closely followed by the need for standards. Challenges are also present in the need for consistent quality management of some material supplies and the need for much shorter lead times. This is especially true for ramp-up of the production and to get to stable manufacturing processes, if that state is ever reached. Each of these complaints is discussed in turn in the coming sections.

Maintenance services

Many of the people active in the PV industry today come from other industries, particularly the semiconductor industry. This industry, which holds many similarities to the PV industry from a technology perspective, generated some steps that brought so much added value


SEE WHAT YOU'VE BEEN MISSING

to the product that an outage had to be avoided at all costs. This expression has to be taken literally. In the photovoltaics industry, however, it is a different story. Huge volumes of material move through the production line, but the added value available from the processes is limited.

This difference is the main reason why some of the services that are normally available in the semiconductor industry are out of reach for the PV industry, such as 24/7 support by the supplier on site. But does that mean that no support needs to be provided? Equipment suppliers were reluctant until recently to be creative in alternative ways such as, for example, having a hotline and remote support, which would immediately solve more than 95% of all problems. This is all dependent on a support system being available, such as staff of the PV manufacturer that are well trained in the required skill set. But this set-up as a solution in itself presents the next challenge, namely, training of the production engineers and experts of the manufacturer's technologies. It all too often happens that the staff are not trained to the level that the customer would want.

An additional demand is the need to get insight into all information regarding machines that are custom made, or machines that were developed in collaboration with the equipment maker. "Why should we not have access to the source code of the control of equipment if we have paid for the development of the equipment?" asked Mr. Baumheuer of Sovello, indicating a clear unbalance in the relation between customer and supplier.

As a facility manager, if it happens that you are not able, for whatever reason, to have your own people well trained, the problem is further compounded if you do not have access to trained representatives of the supplier company. If it is a case that this absence of trained staff is due a lack on the part of your supplier, it is unlikely that a crisis at your facility will be met with a fast and effective intervention. "It's often the case that the same people are responsible for the installation and maintenance of the systems, with the result that sometimes an engineer comes straight from an installation at a competitor in order to help you fix an urgent problem in your production line," said Mr. Koerselman of Solland. This lack of experienced, sufficiently trained technical staff is causing bottlenecks in the organisations of the suppliers, in turn resulting in projects interfering with each other unnecessarily.

Maintenance is also related to the availability of spare parts at a reasonable cost. Today this cost is perceived as being higher than needed, as every supplier uses its own types of motors, valves, and other spare parts. The fast succession of new versions of the same equipment also contributes further to this problem. It has been discussed that a potential solution to this problem would be to establish a form of 'pool' of spare parts, but this suggestion has never been taken up and developed by any of the concerned parties. This idea could potentially reduce the costs associated with expensive components such as vacuum pumps, for example. The introduction of standardization would be a significant factor in reducing the cost of ownership in this case.

Standards

Streamlining the manufacturing process is especially difficult if each equipment supplier has its own individual interface for getting material in and out of the machine. "If we could agree on the height and the direction (horizontal or vertical) of flow of the wafers or panels in or out of a machine, and on the carriers to be used, this would be a significant improvement," indicated Mr. Stock of ersol.

Standardization can also help in less obvious situations in a fab, such as with the position, look and feel of an operator terminal. Consistency in this regard can prevent mistakes and consequently time-wasting, as well as reduce the training time of tool operators. Evidence to support this claim is close at hand: most workers today are familiar with the look and feel of the Mac and Windows platforms, which, had the companies not standardized the appearance and workability of the programs, would have ended up as a mess of interfaces for different programs.

"Standards are sorely needed in relation to materials, their properties and measurement."

Another area that needs standardisation in order to bring about an improvement in discussions between suppliers and manufacturers are measurement procedures of supplies, the performance of the equipment (e.g. MTBF, MTTR,...), and the overall economic performance of the system (cost of ownership). A common sentiment in this regard is that usage numbers of gases and chemicals of the different machines are often over-estimated, making it difficult for the PV manufacturer to plan its logistics in preparation of the ramp-up of the new equipment. As cost of ownership will become a significant sales argument when shortage of equipment is resolved in the future, it would be beneficial for the equipment makers to provide much more accurate data.

Standards are sorely needed in relation to materials, their properties and measurement. These include basic properties of these materials such as the dimensions of the glass, screens for screen printing, types of pastes, etc. "If we had less quality variation on screens for screen printing, it would improve efficiencies in the order of percentages," said Dr. Schitthelm of Deutsche Cell. Another example was given by Dr. Prünte of Scheuten Solar: "If we could agree on specific measurement methods and characteristics of the basic materials that are needed for production, we would be able to reduce buffer stocks significantly, and we would be able to trust the quality checks of suppliers without the need to redo the same tests".

PV manufacturers often do not have access to information regarding their process window, hence the quality variations acceptance criteria of their supplies are also unknown. To compensate, the manufacturers often over-spec their supplies, and as a result receive an inefficient trade-off between supply cost and output improvement. As quantities of certain gases and chemicals required for PV manufacturing are currently low relative to other industries, there is still reluctance on the part of the materials manufacturers to invest in specific PV-grade chemicals, as there is no consensus among manufacturers as to what the standard quality levels should be.

Equipment lead- and ramp-up times

Given the strong growth of the PV industry, many suppliers have had problems keeping up with growth, some finding themselves unable to grow at the same pace as their order book. Research has shown that it is almost impossible to grow an organisation by more than 30% per annum without causing significant stress. Even if this were something that could be achieved without unnecessary hassle, there would still be a huge difficulty in finding staff with the required levels of experience to fill the newly-expanded organisation.

Standard overshooting of delivery lead times were the natural result of this inability to keep up with industry growth. But another, potentially more serious result was that people became rushed to try and keep up with the order books; as quite often happens in the harsh business world, people were forced to do first, and think later. Too little attention was paid to the all-important quality assurance in the manufacturing process, meaning that, in turn, too much time was lost in correcting errors after installation, absorbing resources that were scheduled to be spent on the next customer. Having experienced staff and quality assurance systems in place is vital in this industry. An organisation that lacks these elements runs the risk of being classed as sub-par.

Other examples clearly illustrate how fluidly a process such as installation and plant set-up can run. A supplier of thin-film equipment, starting from a green-field installation, succeeded in installing and ramping production within 15 months.


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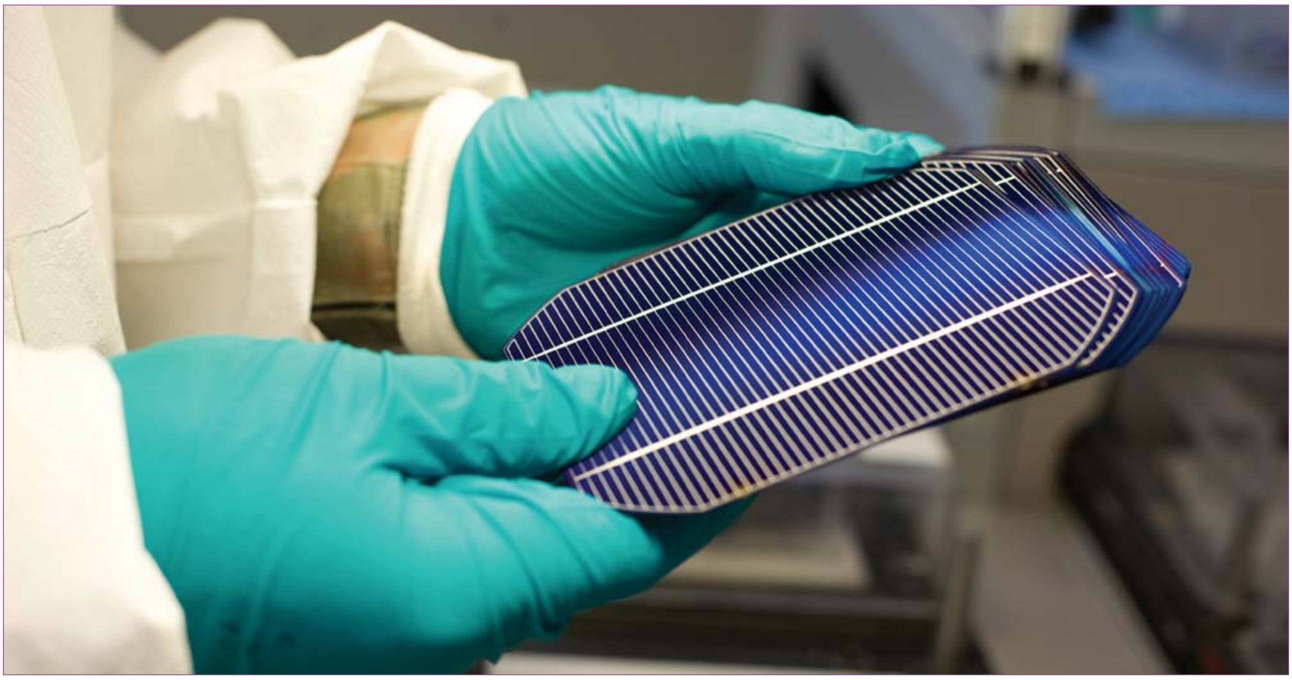

Courtesy of SolarWorld AG.

Suppliers that have their roots in other industries such as the car manufacturing industries are much less susceptible to these long delays: "Suppliers that also work for the car industry are often just in time with their equipment, installing and bringing them in to service almost without you noticing," said Mr. Schomann of Solarwatt.

> "Having experienced staff and quality assurance systems in place is vital in this industry."

These companies were able to source from their experienced staff to service the PV industry, and they were used to very strict order fulfillment processes with well-established procedures for quality assurance. It will be interesting to see how speedy a knowledge transfer will be possible between both industries in order to obtain equivalent quality levels in the PV industry. Given the sluggish market for the car industry, this could happen faster than many would hope for.

Another element that requires attention is the build-up of process know-how on the part of equipment suppliers. This would help in two areas. Quite often it is not clear who owns certain IP when equipment improvements are developed in collaboration between an equipment supplier and a PV manufacturer, and it often takes too much time for an equipment supplier to ramp-up and stabilize the production on a new installation to an operational level. The first element, ownership of new developments, has been an element of frustration for the PV manufacturers, who invested resources and know-how to improve a specific equipment, but then saw 'their' improvements also implemented on the machines of their competitors, without any compensation for their input. Were the equipment supplier to have better know-how of the processes involved, they would be able to arrive at these improvements themselves without help from the PV manufacturers. This scenario would also prevent leakage of knowledge from one PV manufacturer to another.

Making this idea a reality, we would see huge improvements in new installation ramp-ups.

Another likely outcome would be a more stable process after ramping, less susceptible to system outages, and as a result, less dependent on support activities. And so we find that the issue has come full-circle – support facilities and sufficient access to trained technical staff are vital to prevent the supply bottlenecks we are currently experiencing in the industry.

Conclusion

As the current economic situation allows the market to stabilize a little, it is a good time to prepare for the next rush when grid parity is reached in more and more regions. It is also a perfect opportunity to correct any dysfunction in the supply chain. Several problems could be addressed by increasing the number of new process experts entering the industry, bringing fresh ideas for both the equipment and materials suppliers, as well as for the PV manufacturers. For this to become a reality, the education system needs to be stimulated to increase the amount and output of its photovoltaics-based courses, without sacrificing on the quality of the people.

Furthermore, the industry needs to invest in discussions on standards. This cannot be carried out by third parties; it must be done by the industry itself, with organisations such as the PV Group, the International SEMI Standards Program and standards group Deutsches Institut für Normung eV (DIN) actively supporting such initiatives. As long as the situation remains the same, with unresolved standards and resources issues, all parties should communicate to bridge the gap. Expectations of both parties must remain realistic, however, taking the lead from other industries' benchmarks. The semiconductor and FPD industries, the automotive and telecommunications industries – the solutions are there for the taking for the PV manufacturing industry.

Acknowledgements

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Eddy Blokken received an engineering degree in microelectronics from the University of Leuven in 1987, and went on to receive a degree in industrial management in 1993. He joined SEMI in 2006 as Director of Technologies and Standards, and is segment owner for the photovoltaic industry in Europe. Before SEMI, Eddy was Business Development Manager at IMEC, prior to which he held several management positions in the telecom industry.

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Global overview of current and future manufacturing capacities for crystalline solar cells and thin-film PV panels

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ABSTRACT

This review is based on primary research of global solar cell and thin-film manufacturing companies that are currently manufacturing, expanding manufacturing, building facilities for manufacturing or progressing towards establishment of manufacturing facilities. The study looks at historical, present and future name-plate capacities for the global continental regions and also for specific countries with large existing capacity or rapid capacity growth and is based on approximately 600 companies and manufacturing facilities throughout the world. It addresses primary manufacturing technologies including monocrystalline silicon (sc-Si) & multicrystalline silicon (mc-Si) wafer based solar cells, thin-film silicon panels (amorphous, amorphous/micro-crystalline, crystalline on glass), cadmium telluride (CdTe), copper indium (gallium) sulphide/selenide (CIS/CIGS/CIGSe/CIGSSe), dye sensitized solar cells (DSSC/DSC) and other organic solar cells/photovoltaics (OPV). The study acknowledges that there are manufacturers of multi-junction and concentrator solar cell and modules (Fresnell lenses or mirror reflectors) but does not include them in the review.

Introduction

The review details how the global manufacturing capacity has developed and grown from approximately 2GWp/year in 2005 up to almost 13GWp/year in 2008, and from the present figure of 24GWp/year to at least 50GWp/year in 2012 (based on current announcements, without further projection or extrapolation). The figures are taken from a continually updated database, begun in 2003, which collates data based on existing facilities and realistic future figures based on company announcements for development and growth. This paper discusses both the further growth projected past 2012 and the relevant considerations for raw materials availability both up and downstream of cell/thin-film production. The apparently high annual capacity values are more indicative of actual industry capacity growth and under-utilization due to materials shortages and other limiting factors, rather than potentially erroneous over-calculations, which may result from lack of either differentiation between cell and module manufacturing or from companies that utilize multiple marketing methods and strategies. Adjustments in the data to consider the current economic climate would provide an increase in values rather than a reduction, and so have not been performed. Other studies by well-established PV industry analysts and commentators have similarly indicated there will be sufficient future capacity to forecast 25GWp of cell/modules production in 2010 [1].

Industry capacity is increasingly beginning to exhibit growth properties similar to the semiconductor micro-

	2005	2006	2007	2008	2009	2010	2011	2012	Future	No. of Fabs
Capacity MWp/Year (Ex. Conc.)	2213	4534	7169	13009	24445	41173	49611	59115	98544	541

Table 1. Global annual cumulative production capacities MWp/Year (excluding concentrator cells).

electronics industry where Moore's Law postulates a doubling of device performance capability approximately every 18 months. The PV industry demonstrates a similar trend with respect to global cumulative power generation capability, megawatts peak (MWp) or, in recent years, gigawatts peak (GWp). This phenomenal capacity growth is not only produced through manufacturing facilities' expansion and the creation of additional factories, but also through the combined effects of both technological improvements to increase cell conversion efficiencies and greater materials and process equipment utilizations such as thinner wafers and faster or larger format processing. Wafer-based crystalline silicon solar-photovoltaic technologies have been easiest to scale in recent years production capacity-wise; however, along with the accompanying famine of low-cost polysilicon, the utilization of much of the new capacity has been essentially limited to those companies holding supply contracts with the original polysilicon producers. The industry has reacted accordingly to these materials supply bottlenecks and almost all of the existing polysilicon producers have implemented production capacity expansion programmes. There have also been announcements of polysilicon plant developments from a multitude of chemical companies, as well as from others such as producers of cheaper alternative solar grade silicon (SoG-Si).

"Thin-film technologies are increasingly providing a greater portion of production capacity; soon to approach and eventually exceed one-third of all installed manufacturing capacity in the near future."

Traditionally, the vast majority of manufacturing capacity has been provided by the wafer-based crystalline silicon solar technologies, but this trend is changing. Thin-film technologies are increasingly providing a greater portion of production capacity; soon to approach and eventually exceed one-third of all installed manufacturing capacity in the near future. This proportion will likely increase even more dramatically once the organic-photovoltaic (OPV) technologies become viable and production-ready, almost certainly employing high-volume roll-to-roll manufacturing technologies, as is the case with Konarka. This principle also applies to other materials technologies utilizing other high-volume film-forming techniques such as printing, spray, roller and slot coating.

In the last year or two, there has been a dramatic increase in the number of announcements for new facilities and production capacity for thin-film silicon photovoltaic technologies. Amorphous silicon and tandem cell structures together with microcrystalline silicon predominate due to relatively easy availability of production systems and increase of raw materials supplies, among other factors. Within the next three to five years, thin-film silicon technologies will likely equate to approximately 25% of all solar-photovoltaic production capacity, evidenced by the fact these technologies currently exhibit the fastest capacity growth rate of any solar production technology. It is also noteworthy that an increasing number of equipment fabrication companies are offering either component parts or turnkey systems for thin-film silicon PV production.

Methodology

The review does not include capacity values for proposed expansion projects where there have not been announcements specifically detailing initial or long-term capacity (e.g. Q-Cells Mexico); however, details are included for established solar companies with planned major future capacity increases (e.g. Sharp). The study does not take in to account details or figures for concentrating photovoltaic (CPV) cells and modules, and hence figures for the number of companies, manufacturing facilities and annual manufacturing capacity for those technologies are additional to the figures provided here. Details for CPV manufacturers are published in the second edition of *Photovoltaics International* journal [2].

Each manufacturing facility at a distinct location is recorded, hence companies with multiple production lines in the same building or with production lines in multiple buildings on the same site are recorded as one location; similarly, a company with facilities in different locations on the same business park or facilities in different countries have them recorded separately.

There are several start-up companies that have failed to achieve manufacturing facilities status (e.g. CIS Solar Productions & API GmbH) and also some established manufacturing companies which have gone out of business either permanently or subsequently had the whole business acquired (e.g. Astropower to GE Energy). This study also takes into account that there have been mergers & acquisitions of successful companies (e.g. Ersol and Bosch); re-branding of a company when transitioning from the financing stages to becoming physical facilities (e.g. Next Solar to HelioSphera) and other name changes due to re-branding or other commercial considerations (e.g. EverQ to Sovello).

Capacity growth

The growth in global photovoltaic manufacturing capacity has thus far generally demonstrated a geometric level of growth and is set to continue similar expansion for at least several years to come. This sustained rate of industry expansion has in recent years been maintained by progressive growth in new markets (e.g. China, Germany

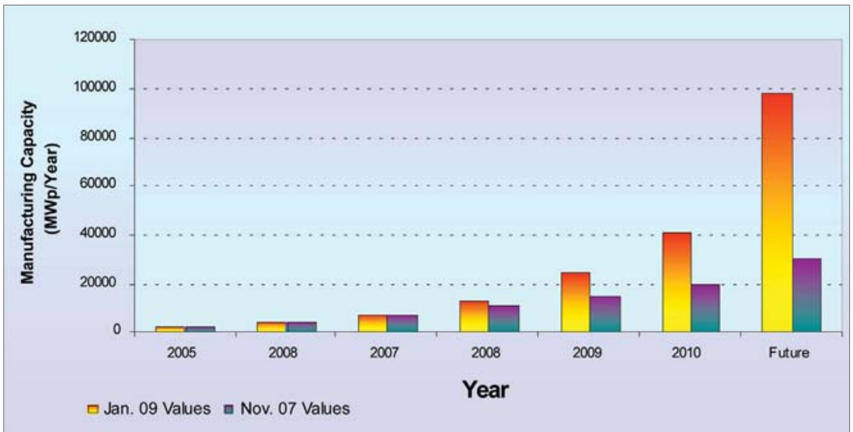


Figure 1. Global annual photovoltaic manufacturing capacities January 2009 vs. November 2007 (All technologies, excluding concentrator cells).

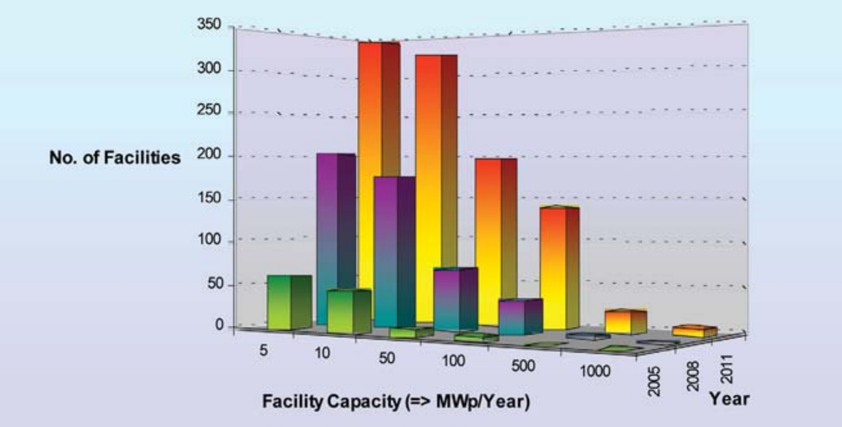


Figure 2. Number of production facilities vs. facility capacity (MWp/year) 2005 to 2011.

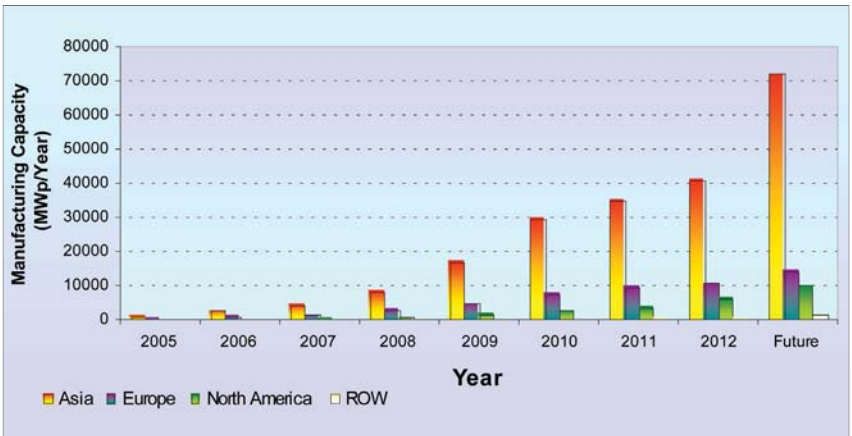


Figure 3. Annual global regional solar cell & thin-film PV manufacturing capacity.

and Taiwan) as others have at times had constraints limiting growth (e.g. Japan and USA). Experienced maturing companies are developing production capacity in more economically attractive areas of the world, from either a reduced cost of production perspective or via incentives supporting product installation and deployment (e.g. EPV Solar, First Solar and SunPower).

The historical figures for global production capacity, together with present and future values, are provided in Table 1. The figures detail the continued geometric growth of the industry globally, however what may be of greater interest is the rate of change of growth, which can be seen in Figure 1. Manufacturing capacity has increased dramatically within the last year, with figures indicating the industry capacity in 2010 will be double that expected from data compiled towards the end of 2007. Future (circa 2012-2015) capacity looks like being close to triple that expected previously at almost 100GWp/year, if not greater.

The growth of the photovoltaic industry global production capacity has seen the industry shift from comparatively small-scale manufacturing plants, with the vast majority of facilities being 10MWp/year or less, to a position where a large proportion have triple-figure manufacturing capacities, with several facilities planning on reaching at least 1GWp/year of production capacity, as detailed in Figure 2. It is relatively rare nowadays for a new production facility to have single-figure megawatt annual production capacity; those that are announced tend to be production development facilities for new technologies or pre-cursors to larger commercial production plants.

Asia

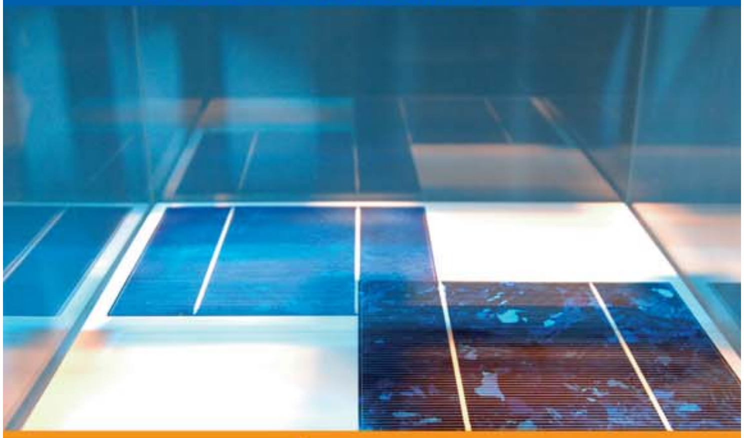
In recent years, Asia has been the leading photovoltaic manufacturing region of the world. This was primarily a result of early development of the solar industry in Japan being supported by national incentive programmes. However, in the last few years, the industry developed at a slower pace as those incentives were removed. Asia has maintained its status as the leading region by rapidly developing capacity, as detailed in Table 2 and presented in Figure 3. China, India and Taiwan are developing large capacities, principally as high-tech and lower-cost export-focused manufacturing nations as shown in Figure 4. These nations are set to become the forces that maintain Asia as the dominant manufacturing region in the future. Large levels of capacity are also being added in other nations such as Korea, Malaysia and the Philippines. The industry looks set to develop rapidly in Korea as a result of recently announced economic stimulation packages, coupled with climate change mitigation and renewable energy development programmes. Japan, once again, will also come to the fore due to similarly announced programmes and the reintroduction of a solar installation incentive scheme.

Europe

Europe has seen significant growth in recent years, driven initially by the German market and incentives, and more recently spurred on by expansion of similar renewable energy laws and incentives throughout Europe. The combination of further European nations introducing renewable energy deployment programmes and incentive schemes along with recent energy security issues will likely maintain the steady industry development within Europe.

Region	2005	2006	2007	2008	2009	2010	2011	2012	LT	No. of Fabs
Asia	1431	2957	4783	8796	17140	29889	35255	41154	71906	311
Australia & New Zealand	33	39	56	56	56	78	108	108	148	6
European Union	559	1182	1664	2999	4782	7631	9599	10459	14246	111
Europe Other	38	66	71	268	294	329	329	359	419	20
Middle East	19	19	49	51	54	181	366	366	1334	11
North America	131	269	545	839	2118	3024	3883	6597	10419	143
South America	2	2	2	2	2	42	42	42	42	3
Africa	0	0	0	0	0	0	30	30	30	1

Table 2. Global regional annual cumulative production capacities MWp/year (excluding concentrator cells).



Crystalline Silicon	2005	2006	2007	2008	2009	2010	2011	2012	Future	No. of Fabs
Monocrystalline Silicon	208	361	839	1578	2803	4189	4468	4468	6316	61
Multicrystalline Silicon	544	957	1170	1935	2925	4260	5990	7630	9675	30
Mono & Multicrystalline Silicon	1049	2483	3871	5506	9399	14646	16536	17391	22246	98
String Silicon	15	45	105	115	275	475	475	1450	1450	3
Silicon Spheres	0	20	20	32	32	32	32	32	32	3
Sliver Silicon	0	5	5	5	5	5	5	5	5	1
HIT-Si	105	165	165	260	340	650	1200	1200	4000	2
Unspecified / Unknown	117	223	278	920	2731	4087	4961	5836	12551	61
Total	2037	4258	6453	10351	18510	28344	33667	38012	56275	259

Table 3. Annual cumulative production capacities MWp/year for crystalline silicon technologies.

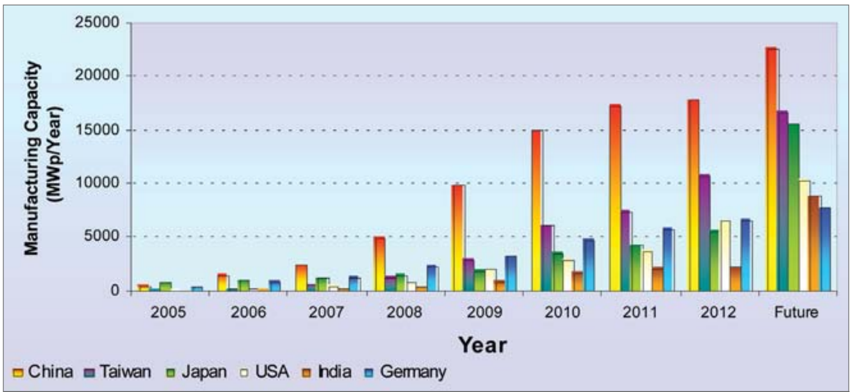


Figure 4. Selected nations annual solar cell & thin-film PV manufacturing capacities.

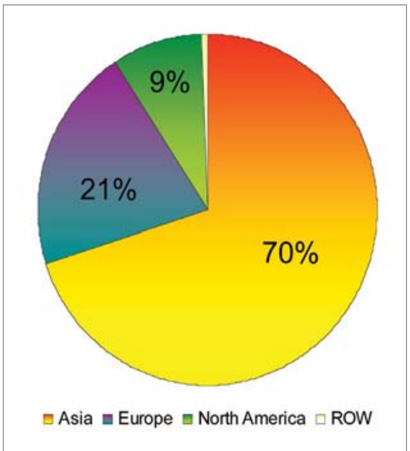


Figure 5. 2009 global regional capacity.

North America

The North American market is set to begin growing at a significant rate, following a period of relative dormancy in recent years, with the possibility of an extra growth impetus following the passing of the stimulus bill by U.S. President Barack Obama. Any significant policy change within the U.S. will likely have the effect of confirming the development of manufacturing capacity in Canada and Mexico.

Rest of the world

The rest of the world is showing significant levels of capacity developing in selected nations, specifically Australia and the United Arab Emirates. These nations have both introduced programmes to support and develop indigenous solar industries to provide products for installation in the high-insolation home markets. The other ROW nations will begin to develop and gradually increase manufacturing capacity and market share as grid-parity cost approaches and individual nations look to match energy security and climate change mitigation policies. The dynamics of global regional changes in the proportion of production capacity are presented in Figures 5 and 6, which indicate that the European proportion of manufacturing will diminish at the expense of the other global regions.

Technology focus

The photovoltaic industry has been dominated by the various crystalline silicon-based solar cell technologies and continues a high rate of capacity development, as can be seen from the data in Table 3. Collectively, these technologies hold the majority of global capacity throughout the foreseeable future. Thin-film technologies, having developed capacity relatively slowly until now, are currently set to achieve up to 40% of all manufacturing capacity within a few years.

Thin-film photovoltaic technologies have progressed over the last few years from small-scale developmental technologies, representing about 5% of annual production capacities, to a current

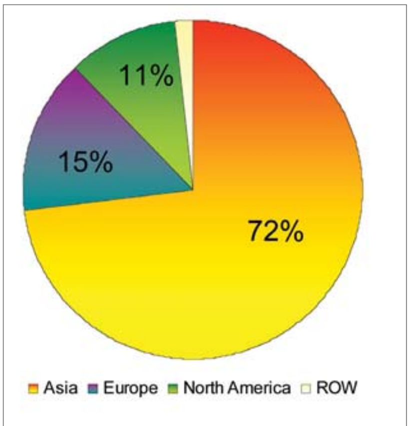


Figure 6. Future global regional capacity.

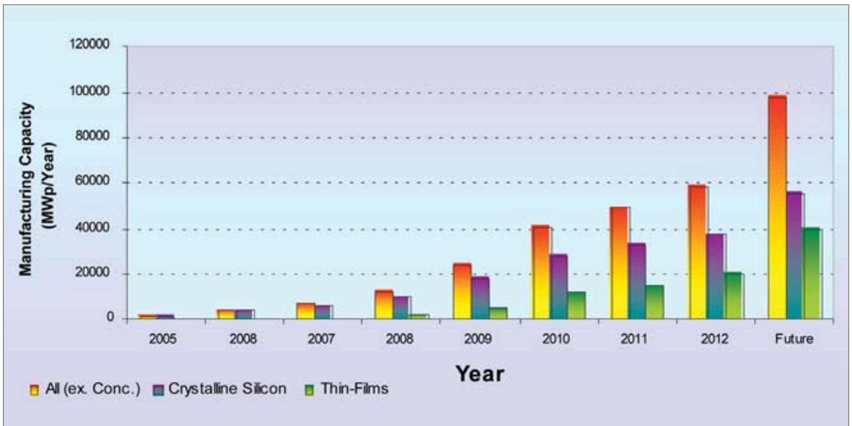


Figure 7. Annual global manufacturing capacity – All technologies, crystalline silicon & thin-films.

Thin-Film	2005	2006	2007	2008	2009	2010	2011	2012	Future	No. of Fabs
Amorphous/Microcrystalline Silicon	142	196	389	1670	4142	9218	11630	14380	30626	133
Amorphous Silicon & CIGS	0	0	0	6	6	25	25	25	100	2
Microcrystalline Silicon on Glass	0	12	15	20	30	130	130	130	130	3
Printed Silicon	0	0	0	0	10	10	10	10	10	1
CIS/CIGS/CIGSe/CIGSSe	6	15	179	378	781	1753	1963	3348	6773	46
Cadmium Telluride	28	51	118	265	615	1235	1517	1517	1517	15
Dye Sensitised Solar Cell	0	1	6	10	39	46	61	61	281	21
Organic Other	1	1	1	1	4	4	4	1003	1003	7
Unspecified / Unknown	0	0	0	0	30	155	531	555	1705	18
Total	176	274	706	2348	5626	12419	15338	20473	40439	221

Table 4. Annual cumulative production capacities MWp/year for thin-film technologies.

figure of around 20% of all capacity. If capacity continues to expand, at similar rates of growth, it will soon be heading towards 50% of all capacity, in both absolute terms & market share and thus reaching parity with the crystalline silicon technologies. Although the manufacturers of the CIS/CIGS and CdTe technologies have been exalted by the media for their rapid commercial development and progress, in reality it is the thin-film silicon PV technologies that are rapidly becoming the market segment leader. Thin film looks like becoming far more dominant from a capacity perspective, as illustrated in Table 4 and represented in Figure 8. The disproportionate growth of thin-film silicon PV is almost certainly a result of the number of companies offering key manufacturing systems and components, often based on standard platforms developed for FPD manufacturers.

Market drivers

There are numerous factors that positively influence the growth of the photovoltaic industry of which installation incentives in the form of grants, tax breaks or feed-in-tariffs are arguably most prominent. These types of incentives – some more generous than others – have in recent years spread throughout Europe and many countries, states and provinces elsewhere throughout the world. Many of the feed-in-tariffs based on the German EEG model have been shown to substantially increase the deployment of installed PV systems whilst assisting development of local PV manufacturing and installation industries.

In some areas of the world, the growth of the PV industries has enabled some technologies to reach grid-parity status. Compared to more traditional forms of power generation, this point becomes more evident when it is taken into account that in many instances grid parity for solar relates to retail power price, rather than wholesale, when the installation is located at the power user's location. There are also some utility-scale solar farm projects that have recently been claimed to have reached grid parity operation. The prevalence of grid parity projects will certainly increase as improvements in the various technologies develop and economies of scale manufacturing are achieved. Once grid parity becomes commonplace, the industry should become self-sustaining and should begin to provide PV systems with power generating capacity to replace existing base load generating capacity that is no longer viable from either an economic or an environmental perspective.

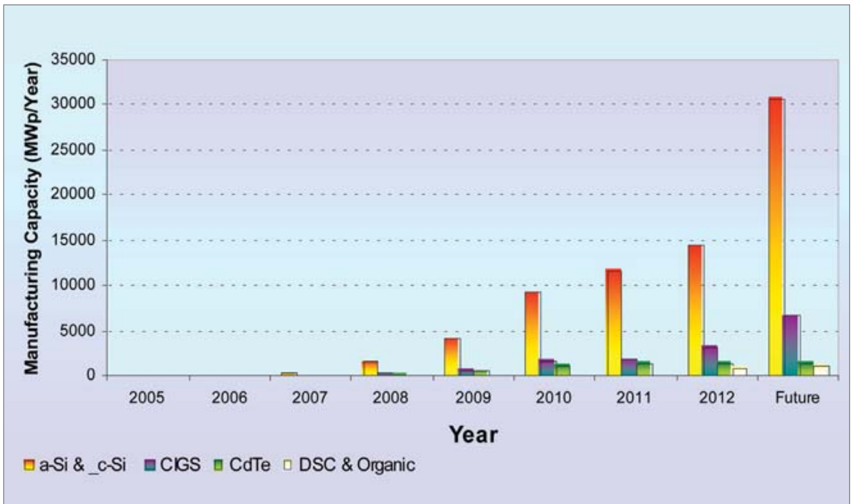


Figure 8. Annual global manufacturing capacity for thin-film technologies.

The creation of relatively large numbers of jobs in a comparatively short period of time is a potential boon for industry development – the EPIA recently estimated that the PV industry creates approximately fifty jobs per megawatt of production capacity [3]. This projection relates to cell and module manufacturing, research and development, and system integration and installation. The estimate does not include the additional jobs that would also be created in the raw materials manufacturing and supply industries. In these economically difficult times, it will likely be viewed positively that an industry exists that can provide rapid job creation coupled with increased renewable energy generating capacity deployment, utilizing a minimal carbon footprint technology.

PV technology is ideally suited to provide much of the power generating capacity that will be required to support other new technologies such as plug-in electric/hybrid vehicles or for hydrogen generation for use in both fuel cell and direct hydrogen combustion vehicles. It is also possible that PV technology could play a large part in powering the emerging inductive power supply/battery charging technologies. Finally, the versatility and variety of PV technologies and means of utilization and deployment provide a far greater level of opportunities compared to other alternative/renewable energy technologies.

Market limiters: materials availability

The PV industry's future rapid growth will likely have the ability to expand at an even greater rate with regard to nameplate production capacity as provided by factory buildings and production systems equipment. The actual use of those facilities will periodically become restricted due to other limiting factors.

Probably the most understood limiting factor within the solar industry thus far has been the availability of raw materials, specifically silicon of sufficient purity for use in solar cells, which was inherited from the microelectronics industry.

However, as the solar industry grew, its demand for raw materials exceeded supply, and, as the value added during microchip manufacture is considerably higher than that of solar cells, the microelectronics market could significantly out-price the solar industry for acquisition of these materials.

To alleviate this restriction in materials availability, the traditional polysilicon manufacturers announced large-scale production expansion plans. Approximately 200 additional refined silicon production projects have been announced throughout the world, which, if the majority come to fruition, could provide approximately one million metric tons of silicon suitable for solar cells. It should be noted that for 2008, the U.S. Geological Survey (USGS) mineral summaries estimate global production of metallurgical-grade silicon to reach about 5.7 million metric tons [4], of which approximately 80% is used directly for ferrosilicon manufacture and the remaining 20% for all other silicon-based applications, including manufacture of polysilicon and silane gases. Thus, it is conceivable that to maintain the use of solar energy in the future, there will be a requirement for additional metallurgical silicon production.

> "The most understood limiting factor within the solar industry thus far has been the availability of raw materials, specifically silicon of sufficient purity for use in solar cells."

The dramatic growth of thin-film photovoltaic production capacity presents further problems that need to be considered if this capacity is to be realised to its full potential. In addition to this availability of silane gases, which will see stellar demand, growth from the solar industry also has to provide significant quantities for the FPD industry. The CIS/CIGS/CIGSe/CIGSSe thin-film technologies are all reliant upon indium, requiring approximately 50 metric tons per gigawatt, and also gallium to a lesser extent. These minor metals are currently produced as by-products of base metal refining, with USGS mineral summaries estimating annual production to be comparatively low. Production for 2008 reached 568 metric tons for refined indium [5] and 135 metric tones for gallium [6], including both primary production and scrap refining. These metals being by-products of high volume primary base metals refining will most likely not see them becoming primary refined metals themselves, due to fundamental supply and demand characteristics. Fortunately, global reserves of indium are at present relatively plentiful, being reported as approximately 16,000 metric tons in 2007 [7] (more recent analysis has questioned the accuracy of this data [5]).

The vast majority of the current annual production of indium is utilized for the production of indium tin oxide (ITO) used primarily for TCOs in the FPD industry and also for joining materials (solders) and electronic components. It is also to some extent still utilized in the thin-film PV industry as the TCO front contact of glass superstrate modules. The cumulative production capacity for the CIS/CIGS type thin-film technologies may shortly begin to expand beyond the cost-availability constraints for materials supply for technologies and applications reliant upon unit cost per watt competitiveness. It is conceivable that in the event the FPD industry switches the preferred TCO technologies away from ITO to another suitable material or technology, then the lifespan of cost competitiveness of CIS/CIGS-based photovoltaic technologies would be significantly increased due to the more freely available supply of indium.

A consideration that currently affects both crystalline silicon and thin-film technologies is the availability of low-iron glass at reasonable cost. Although raw materials supply is not a significant factor, the cost and logistics involved in developing production facilities for this type of glass do influence development plans. Nevertheless, as the PV industry grows and ordinarily manufactures modules that provide power at or below grid parity cost, then it is conceivable that lower specification modules may be produced that use ordinary soda-lime float glass rather than high optical clarity glasses.

Construction materials such as those used for module lamination (EVA/PVB) and backing sheets will also need to be provided in significant volumes as the industry expands. Other items such as cables and connectors along with other systems components will also need to be made sufficiently available; however, many of these items are considered as retooling or alternate use applications of existing products and technologies.

The global economic slowdown and recession may have an effect on the availability of some components and materials or result in extended construction times and delays, which will likely be exasperated as companies choose to either postpone or cancel planned projects or even be forced to close businesses due to financial difficulties.

Conclusion

Finally, on a more positive note, there are indications that generally the PV industry as a whole will be actively supported as part of broader renewable energy strategies in efforts towards lifting economic activity in various countries with the aim of either preventing or alleviating recession. Hence, the rate of growth for solar cell and thin-film PV manufacturing capacity may experience a period of uncertainty, but this will likely be relatively brief, returning quickly to the Moore's law-style growth levels.

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About the Author

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Materials


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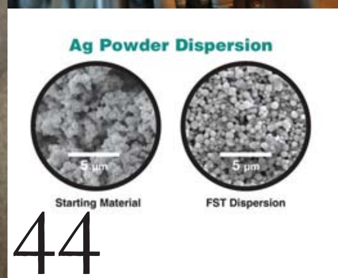
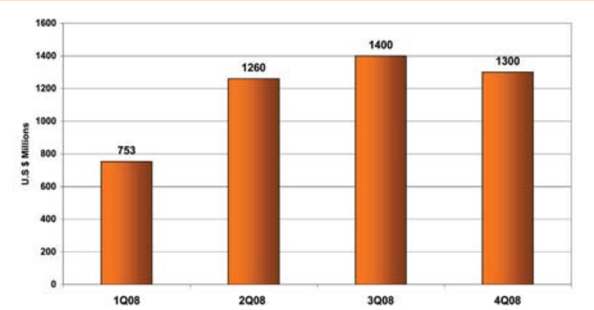

Ag Powder Dispersion
Starting Material
FST Dispersion
44

GT Solar sees order push out pressure ease as quarterly sales top US$200 million

GT Solar International, Inc. noted that its current backlog stood at US$1.3 billion after releasing its third quarter results that saw revenue reach US$205.2 million, a 46% increase over the previous quarter. Billings were boosted in the quarter with revenue recognition of a US$91.5 million contact for polysilicon reactors from major start-up DC Chemical.



Source: Photovoltaics International.

GT Solar order backlog.

Polysilicon and UMG News Focus

REC completes Moses Lake Plant III repairs

REC's announcement on December 15th, 2008 regarding the requirement of repair work on its Moses Lake Plant III has seen the work continue into the second week of February 2009. It seems there was close to double the expected amount of welding work to be done, leading to the unscheduled delay in preparing the plant for commercial polysilicon production, which has now been scheduled for the second half of March.

The final step in the preparation of the plant involves a process of systems checks and start-up procedures. If, as expected, the ramp-up goes without any issues, REC ASA is projecting production of 10,000-11,000MT of polysilicon for 2009, despite the extended delays. The company will provide an update with its interim results for the fourth quarter 2008, to be issued on February 18th, 2009.

KMA and Hyundai Heavy agree to US$600 million polysilicon deal

Korea Advanced Materials (KMA), a joint venture between Hyundai Heavy and South Korean paint maker KCC Corp., has closed a US$600 million deal to supply polysilicon to Hyundai Heavy Industries Co. from 2010 to 2015.

Hyundai Heavy, a large ship builder, also has a previous deal to purchase US$508 million of polysilicon from 2001 to 2015 from Woongjin Polysilicon, a subsidiary of Woongjin Holdings Co.

Hyundai Heavy has been vertically integrating its solar business and expects to finish construction of a solar cell manufacturing plant in 2010. In 2005 the company commissioned a solar module assembly line from Spire to produce 150,000 solar modules per year. It also has an ongoing wafer supply contract with LDK solar.

Timminco misses UMG-Si shipment targets

Timminco Limited said in an update to fourth quarter, 2008 financials that it had shipped 1,044MT of UMG-Si in 2008. The company had set a target in 3Q08 of achieving shipments in the range of 1,200-1,500MT for 2008. As part of its production capacity expansion plans at its subsidiary Becancour Silicon Inc, the company produced a total of 1,214MT in 2008. Production actually increased 62% compared with the previous quarter to 554MT.

Timminco had previously stated plans to expand capacity to 14,400MT by mid-2009, however the company did not provide any future guidance in a statement. It is not known whether Timminco's shipments were impacted by recent revised business outlook at Q-Cells, the largest PV manufacturer and Timminco's biggest customer, or whether delays existed in ramping new capacity, restricting shipments.

Timminco said that it had commissioned its fifth and sixth production lines in the last week of November and the third week of December 2008, respectively.

Yingli cements acquisition of Cyber Power; takes first steps in polysilicon production

Yingli Green Energy Holding Company Limited has completed acquisition of Cyber Power Group Limited, a development-stage solar-grade polysilicon producer, for approximately US$77.6 million. Yingli, the vertically integrated PV product manufacturer, marks its first venture into the polysilicon production industry with this acquisition, which was funded by available cash on hand and commitment to issue senior secured convertible notes due 2012 to Trustbridge Partners II, L.P.

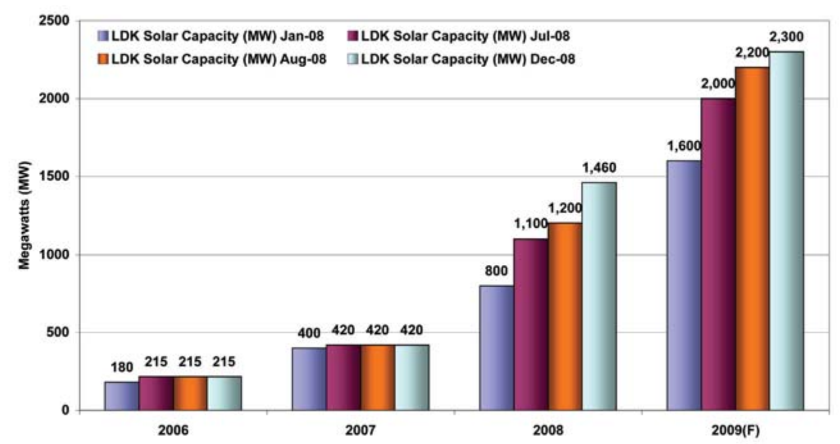
Yingli purchased 100% of the issued and outstanding share capital of Cyber Power, through Fine Silicon Co., Ltd., its principal operating subsidiary in China. Yingli entered into a share purchase agreement with Grand Avenue Group Limited, which is controlled by Yingli's CEO Liansheng Miao. Of the overall US$77.6 million cost, US$25 million had been paid in November 2008, with the final cost of the acquisition determined incorporating a 4% discount on Cyber Power's overall value as of November 30th, 2008.

It is expected that Yingli will use the recent acquisition to secure its polysilicon supply for its own PV products in the future. Prior to the acquisition, Cyber Power had planned to begin polysilicon production in the second quarter of 2009.

Wafer News Focus

LDK Solar revises capacity expansion plans amid slowing market demand

LDK Solar has succumbed to the slowing demand for solar wafers from its customer base that includes Q-Cells, Sharp and Suntech, having revised revenue estimates significantly downwards for its fourth quarter guidance. The revised revenue is between US$425 and US$435 million, compared to its previous projection of between US$555 to US$565 million. Wafer shipments were previously projected to be in the range of 260 to 270MW but are now expected to be in the range of 245 to 255MW. Gross margins have also been seriously affected, with guidance revised to between 10% and 13%, compared



LDK Solar's Wafer capacity expansion in 2008-2009.

Source: Photovoltaics International.

to gross margins of between 18% and 21%, issued previously.

"Late in the fourth quarter, we experienced a slowdown in our business related to the current global financial crisis," stated Xiaofeng Peng, Chairman and CEO of LDK Solar. "Despite a difficult operating environment, we remain focused on executing our growth strategy and believe that our competitive positioning as the largest and lowest-cost wafer producers in the solar industry will provide us with a competitive edge for navigating through these challenging times. We continue to have a solid cash position, with more than US$380 million, in addition to unused credit facilities totaling in excess of US$850 million and will continue to conservatively manage our resources. Our operations remain at full capacity, with contract backlog remaining strong for 2009."

LDK Solar noted that wafer capacity had reached 1,460MW at the end of 2008, compared to guidance given in August 2008 that capacity would reach 1,200MW in 2008. LDK Solar had originally forecasted in January 2008 that capacity would reach 800MW.

In August 2008, the company said capacity would reach 2,200MW by the end of 2009. In November 2008, LDK Solar revised capacity to 2,300MW for 2009. This figure is unchanged in its latest guidance.

LDK Solar now expects 2009 revenues to be in the range of US$2.3 billion to US$2.5 billion. Wafer shipments were guided in the range of 1,570MW and 1,670MW, with gross margins significantly better than current Q4 estimates at between 22% and 27%. A key aspect of this improvement even over previous fourth quarter guidance could be attributed to the markedly lower polysilicon costs and its ramp of the company's own polysilicon production in 2009, as well as greater economies of scale in its wafer manufacturing operations.

However, LDK Solar has also lowered its own polysilicon production targets. In July 2008, LDK Solar expected to produce between 100-350MT from its first 1,000MT polysilicon plant by the end of 2008. However, the company has now said that in the final stages of plant commissioning the optimization process has taken longer than expected. Although reiterating that the plant had started production, LDK Solar did not provide any production figures.

In its third quarter conference call, held in November 2008, LDK executives said that they expected polysilicon output in early December, 2008 would be between 15MT and 25MT. The plant is now expected to ramp up to its designed full capacity in mid-2009.

With respect to its larger, 15,000MT polysilicon plant, LDK Solar said in November 2008 that it expected production of between 5,000 and 7,000MT in 2009. However, in its latest revisions, the company has guided 'total' polysilicon production to be in the range of between 3,000 and 5,000MT in 2009, suggesting a significantly lower expectation from the larger plant.

LDK Solar plans to report full fourth quarter and fiscal year 2008 results in late February or early March 2009.

MEMC provides fourth-quarter revenue revisions

MEMC Electronic Materials, Inc. has revised downwards its revenue projections for the fourth quarter of 2008, owing to a slowdown in end demand in both the semiconductor and solar industries, according to the company. MEMC now expects to make between US$400 and US$425 million in the three-month period, compared to a previous guidance of US$500 million plus or minus US$25 million. Operating costs for the quarter are expected to remain unchanged at US$27 million.

REC to supply LG Electronics with US$340 million worth of multicrystalline silicon wafers

REC ASA has signed a long-term multicrystalline silicon wafer supply deal with Korea's LG Electronics starting in 2010 until 2014, worth US$340 million. The agreement is based on a take-or-pay contract with pre-determined prices and

volumes for the entire contract period. REC expects the prices to reduce over the time of the contract and is in line with earlier signed contracts.

ReneSola secures RMB800 loan for Sichuan polysilicon production facility

ReneSola Ltd. announced that its wholly owned subsidiary, Sichuan ReneSola Material Co. Ltd., has signed a RMB800 million (about US$117 million) 5-year project loan agreement with China Construction Bank, Sichuan Branch. This loan will contribute to the funding of construction of a polysilicon manufacturing facility in Meishan, Sichuan province and will provide ReneSola with a steady, inexpensive supply of polysilicon.

The company expects to begin the first phase of pilot production at the Sichuan facility late in the second quarter of 2009 and the second phase by the end of the third quarter of 2009. Each of the two phases will have a capacity of 1,500MT of polysilicon.

Other News Focus

Update: First Solar supplier reports record revenue

5N Plus Inc. reported record quarterly revenue of US$18.1 million on the back of strong demand in the photovoltaics market5N Plus, Inc., a major supplier of high purity cadmium telluride (CdTe) to First Solar, Inc., has reported record quarterly revenue of US$18.1 million on the back of strong demand in the photovoltaics market and increases in prices. In markets other than PV, 5N Plus saw sales flat to slightly down. The materials specialist also benefited from the ramp of its new refining facility in Germany, which delivered a full quarter of revenue for the company.

"We are pleased to report the results of the second quarter of our 2009 fiscal year which has been characterized by continuing growth and record level profitability," commented Jacques L'Écuyer, President and Chief Executive Officer. "This reflects the strong operational performance now at both of our facilities and the increasing demand for our products. In spite of the current financial world crisis, demand for our products remained strong during the quarter as we managed to increase sales and further strengthen our twelve month backlog of orders to a record level of US$54,722,363 as at November 30, 2008."

5N Plus had a backlog worth US$22.2 million in the same period of 2007, highlighting an increase in backlog of over 146%. At a cost of approximately US$14 million, the new refining facility in Germany is expected to double the production of CdTe for 5N Plus and enable the company to supply in excess of 200MT of CdTe per year.

The company said that it was considering future plans to increase capacity and R&D efforts, indicating that it expects demand to remain strong, despite the current economic conditions and concern over the growth projections of the PV industry in 2009.

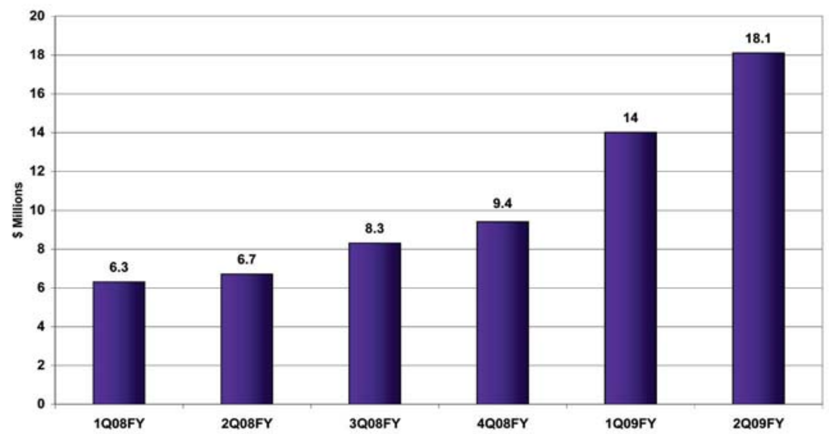
Update: 14th January

During the 5N Plus quarterly conference call, executives noted that First Solar accounts for 78% of sales. Current installed refining capacity of tellurium was 200MT per annum and was sufficient to meet customer demand in 2009.

Executives also noted that it estimated that it required a maximum of 25MT of tellurium to produce 200MW of thin film modules and could be as low as 5MT. Based on the higher quantity, 5N Plus could supply 1.6GW of CdTe thin film modules in 2009. First Solar has already guided capacity of 1GW is planned for 2009.

5N Plus is also building inventory. Currently the company has the equivalent of 1-years production of CdTe in storage, which has increases between 20-30% since the previous quarter.

The company noted that tellurium prices had declined slightly in response to



5N Plus Inc. revenue 2007-2008 FY.

Source: Photovoltaics International.

the current global economic downturn and was taking advantage of the lower demand for the rare metal to secure further sources of supply and build further inventory.

The new facility in Germany had a capacity of 100MT per annum and was currently at 50% capacity. Executives noted that further capacity expansions were not expected in the short-term and that to double capacity from the current 200MT capability would only require approximately US$5 million investment. The company also noted that improvements in capacity and production costs could be achieved without expansion due to continual focus on manufacturing improvements in 2009.

Taiwan Government to support PV materials infrastructure growth

According to Taiwan's Industrial Development Bureau, the PV industry in Taiwan is growing rapidly and requires the financial support of the Ministry of Economic Affairs (MOEA) to boost the supply of key materials required in the production of photovolatics. Assistance will be given to support the domestic production of low-iron glass, EVA (ethyl-vinyl acetate), silver/aluminum paste, solder and other raw materials that are not currently produced in Taiwan.

Various incentives, including tax relief, will now be offered by the MOEA to key Taiwan materials companies. In relation to polysilicon production, the MOEA will support Sun Materials Technology at the Letzer Industrial Park in Yilan, Taiwan, Polysilicon Corp and Muto Silicon Corp at the Pingtung Export Processing Zone Pingtung Export Processing Zone, and Top Green Energy Technologies Inc. at the Changpin Industrial Park.

Combined, the polysilicon producers are expected to invest NT$30 billion in planned expansions, the IDB said. Polysilicon output in Taiwan could reach 10,000 to 20,000 metric tons in 2010, should plans remain on track.

The MOEA will also provide assistance to Formosa Plastics, Taiwan Glass, Gigastorage, and Shenmao as their combined investments are expected to be in the range of NT$3.6 billion. Gigastorage has already started supplying silver/aluminum paste and the other companies are anticipated to bring related products to market from 2009.

The output from the planned capacity expansions is estimated to reach NT$40 billion and is hoped to meet the full demand of downstream PV producers in Taiwan through to 2015.

Auria Solar selects BOC Lien Hwa for thin film plant bulk gases

The Linde Group's, Taiwan joint venture BOC Lien Hwa (BOCLH) has been selected to provide a range of bulk and specialty gases for Auria Solar's new 60MW thin-film production facility in Tainan, Taiwan. Auria Solar is expected to start volume production in early 2009, using a-Si thin-film equipment and technology from Oerlikon Solar.

BOCLH was responsible for the turnkey installation of the gas supply systems as well as delivery of the production gases that include large volumes of silane and chamber cleaning gases.

AuriaSolar's 60MW plant, Tainan, Taiwan.

Meyer Burger wins CHF40 million wire saw order from SolarWorld

Meyer Burger Technology Ltd. has received an order for delivery of wire saws to the value of CHF40 million from SolarWorld. The wire saws will be shipped from the second quarter of 2009 onwards until the end of 2010. SolarWorld will use the high-tech wafer slicing tools in the expansion of its wafer fab in Freiburg, Germany, which it plans to expand to approximately 500MW by the end of 2010.

Product Briefings

CVD Equipment Corporation

CVD Equipment offers qualification for polysilicon and thin-film materials

Product Briefing Outline: CVD Equipment Corporation has introduced the EasyTube platform, a horizontal, silicon epitaxial chemical vapor deposition system designed to grow ultra-high purity (intrinsic) monocrystalline silicon layers on a monocrystalline silicon substrate for qualifying TCS and other chlorosilanes for polysilicon manufacturing facilities. The system is claimed to be adapted cost efficiently to a wide variety of thin-film process requirements needed to accelerate the commercialization of next-generation solar cell/modules and smart windows.

Problem: There is a growing need for quality control of the chlorosilane precursors used to manufacture polycrystalline silicon rods. By using the same precursor to deposit an epitaxial film that is measured for purity, the purity of the silicon precursor material can be determined.

Solution: The system is capable of meeting the exact criteria needed to produce quality silicon, and is intended to provide optimum control over processing of two 13mm round wafers per run at temperatures up to 1200ºC using RF induction heating. A water-cooled, high-purity quartz process tube is provided to minimize tube deposits and keep the quartz tube cool even during the long deposition runs.

Applications: Qualifying TCS and other chlorosilanes amorphous silicon, polysilicon, silicon nitride, high or low temperature silicon dioxide, silicon and silicon-germanium epitaxial, TCOs (SnO_2, ZnO, etc.), sulfurization, selenization, rapid thermal annealing, $POCl_3$ and other related diffusion-driven processes.

Platform: The system can be equipped with a wide variety of options, including a Loadlock, operation at high or low pressures, substrate rotation for deposition and composition uniformity, rapid heating and many others.

Availability: Currently available.

Alconox, Inc.

Alconox's 'Detojet' hard surface cleaner for large glass substrates

Product Briefing Outline: Alconox, Inc. has introduced Detojet hard surface cleaner for use in glass substrate and module in-process cleaning for large-scale glass photovoltaic modules. Detojet can be used in horizontal glass washers that clean the glass panels, followed by rinsing and drying prior to further processing.

Problem: Poor cleaning of thin-film solar modules during manufacturing can result in increased cost and reduced yield due to module faults from low electrical resistance between cells across laser scribe patterns; short circuits between cells in a module; and reduced steady-state efficiency after extended light exposure to a module. Substrates must be cleaned at the start of manufacturing as well as after each significant residue-creating process during manufacturing.

Solution: Large glass superstrates of transparent conductive oxide coated glass can be cleaned prior to manufacturing and during manufacturing using large horizontal conveyor washers with Detojet cleaner. The combination of dispersants and cleaning agents results in excellent particle control and debris free surface. The dispersants are able to lift particles into solution by overcoming the electrostatic attractions to the hard surfaces and by reducing the hydrophobic tendency of the surface of the particle, thereby rendering it more water dispersible. The cleaning agents remove hydrophobic oily films that can interfere with the particle removing action of the dispersants as well as lead to non-uniform layers during manufacturing.

Applications: Cleaning during the manufacture of glass panel photovoltaic modules with thin-film coating of amorphous and microcrystalline silicon layers.

Platform: Large horizontal conveyor washers.

Availability: Currently available.

Malvern Instruments

Malvern Instruments' particle image analyzer enables recycling of abrasive slurry

Product Briefing Outline: The Sysmex Flow Particle Image Analyzer FPIA-3000 from Malvern Instruments is used for monitoring the deterioration of abrasive slurries used in the wire saw cutting process in solar cell production. Fast, efficient quantitative particle analysis enables manufacturers to recycle slurry without compromising final product quality.

Problem: In solar cell production for the photovoltaic, semiconductor and microelectronics industries, the main technique for slicing silicon blocks into wafers is multi-wire sawing. In order to improve efficiency, reduce production costs and reduce waste, the industry is moving towards recycling of the abrasive slurry used in the wire saw cutting process. To do this it is necessary to carefully monitor the slurry for the presence of unwanted particles that build up during the sawing process and would reduce the quality of the final product.

Solution: The analyzer allows particle analysis of slurry samples in real time. Images of up to 360,000 particles are captured by a CCD camera and statistical results presented in terms of particle size, shape, distributions and particle count. With standard operating procedures, measurements that take just two minutes and with single-click initiation, the Sysmex FPIA-3000 provides high throughput, easy operation and reproducible results, according to the company.

Applications: With the ability to measure materials from 0.8µm to 300µm in size and to produce high quality particle images, the Sysmex FPIA-3000 is used for characterizing emulsions and suspensions.

Platform: Based on fully-automated top loading image analysis.

Availability: Currently available.

Glass for photovoltaics – a promising material for the future

Joachim Schmid, VDMA, Frankfurt, Germany

ABSTRACT

Glass plays an increasingly important role in photovoltaics. The rising demand for solar modules is pushing the glass industry to the fore. As a result, mechanical engineering companies around the world are working to meet the demands of the solar industry, with the tremendous potential of glass, especially in the thin-film sector, at the epicentre of this effort. This paper presents the beneficial properties of glass for use in the photovoltaics industry, and its potential for future applications.

Introduction

No matter where the source of their supplies, be it the United States, Europe, China or Australia, module manufacturers have had to face the same problem again and again. A considerable percentage of solar glass orders arrive unfit for production and can be classed only as waste. This waste glass would either have been shipped in defective packaging or damaged by humidity penetrating during intermediate storage, which can lead to surface corrosion, rendering the material incapable of being processed. In other cases, edges can be faulty, thickness or other dimensional tolerances agreed on with suppliers are off the mark. As experts are aware, this scenario is most common in cases where open-top containers are used. Waste quotas can reach 10% or higher quite often. Delivery problems can be a major factor in thwarting planning schedules of quite a number of companies. One of the main reasons behind these difficulties is that some parts of the international glass-making industry have not yet properly taken up the demands of the sector. But change appears to be on its way.

Much needed high-quality properties

Solar glass is indispensable both as a carrier material for thin layers of semiconductors and to cover modules. Glass of optimum quality, which is very much in demand, should have high transparency values, be break-resistant and should also readily accept anti-

Courtesy: Grenzebach Maschinenbau GmbH.

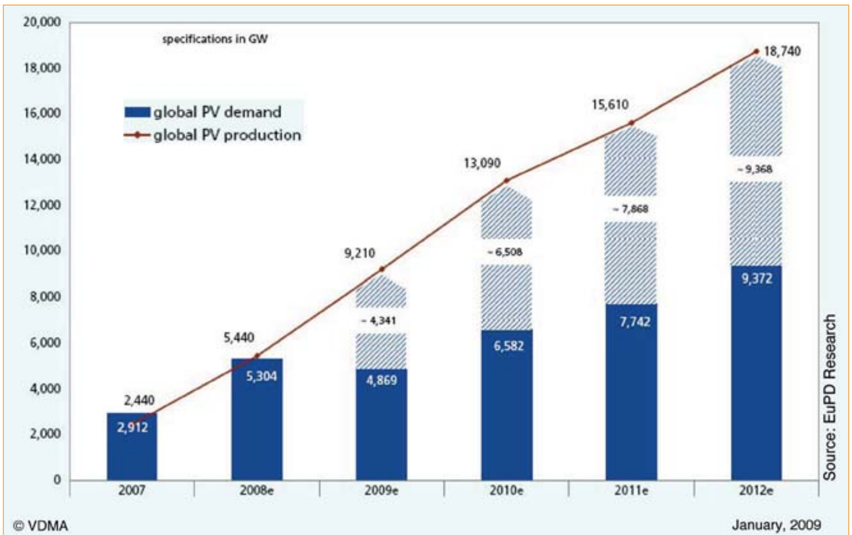
Figure 1. Robotic devices developed by Grenzebach, the German glass machinery manufacturer, take over contactless manufacturing of thin-film modules.

reflection blooming coatings. High-quality glass should be as thin and as cheap as possible and, very importantly, accurate to size. The international glass industry has so far not lived up to all of these challenges. A considerable number of glass manufacturers have viewed solar glass as a marginal phenomenon, at least until now. The main reason for this is the relatively small amount of glass being taken up by the photovoltaics sector to date.

Glass used in the PV industry is referred to as sheet glass, which may be produced using two different processes. For the so-called float glass process, red-hot and semi-liquid molten glass is poured on a bed of liquid tin, a process that is carefully controlled. Initially, glass will float on the tin surface like a thin layer, after which its temperature will be reduced with as little stress as possible. This type of manufacturing is used to make some 95% of sheet glass produced all over the world. Alternatively, rolled sheet glass is the result of glass being put through a series of rollers, which process the viscous mass and produce the desired shapes and dimensions.

Demand for solar glass

It would be quite a challenge to quote exact figures for the percentage of sheet glass taken up by the photovoltaic industry out of the total of about 45 million tons produced annually. Expert circles of the glass-making industry put that proportion at about 1%, leading us to believe that some 450,000 tons of sheet glass are used to make photovoltaic devices annually. Considering the total volume of the international glass-making industry, this is a fairly small percentage. Continuous glass-making units measuring several hundreds of metres in length are capable of making several hundred tons a day without running into any problems.



Courtesy: Grenzebach Maschinenbau GmbH.

Figure 2. Global PV demand vs. PV production and resulting oversupply.

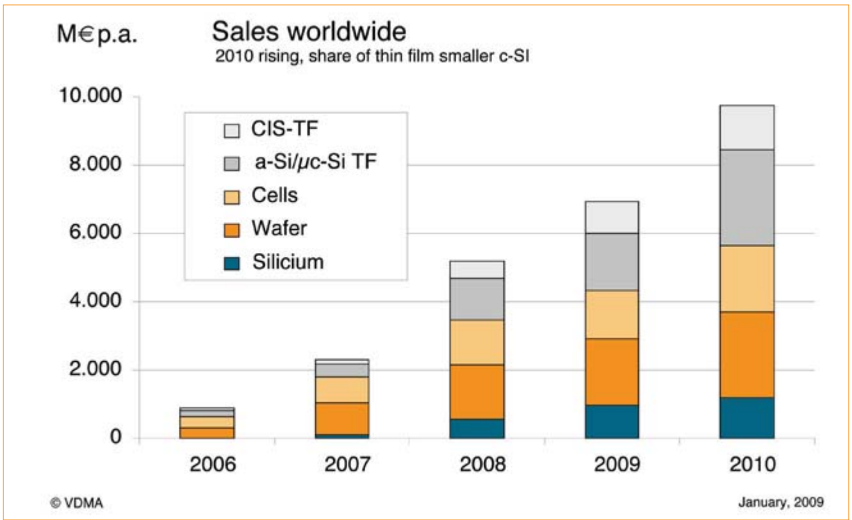
The recent strong increase in demand for solar modules, which in turn involves more demand for solar glass, however, has produced a different approach in at least some parts of the glass-making industries. Glass manufacturers expect strong growth not only for silicon wafer-based modules, but also in regard to the thin-film sector and its wide-ranging applications for the future. Nevertheless, it is open to speculation how high growth rates will eventually become. Estimates put the growth for thin-film cells at far above 50%. As far as the entire photovoltaics sector is concerned, there are experts who predict a market volume considerably above 40GW in 2012, requiring a close to tenfold increase in the amount of glass currently being used in the industry.

New float glass works for Germany

In order to help meet these future needs, Interpane, a German glass maker and finisher, and the Scheuten group from the Netherlands have launched a joint venture to set up a new float glass plant in Germany. The float glass-making section of the f I glass GmbH, to be commissioned in August 2009 by the two companies, will produce 700 tons a day. In addition to making base glass (float glass), the two companies will focus especially on the production of dedicated solar products, required in solar industry applications. Interpane AG, which will hold 49% of this joint venture, already operates one of Europe's largest float-glass operations in France. Both companies are also involved in the solar sector. A company spokesman for Interpane said that this investment had been made "with a view to the photovoltaics sector".

> "Glass of optimum quality, which is very much in demand, should have high transparency values, be break-resistant and should also readily accept anti-reflection blooming coatings."

Glass offers tremendous potential to the whole of the photovoltaics industry, particularly the thin-film sectors. The decisive criterion of light transmission is being increased all the time. Standard sheet glass panes, still in use today, for the most part consist of silicate glass with light transmission ratios ranging from only 85 to 88%. This is brought about by a high percentage of iron. People are therefore using more and more low-iron glass with light transmission ratios of up to 91%. This changeover from silicate glass – so-called 'green' float glass – to the 'lighter' low-iron float glass results in an increase in solar module efficiency



Source: LBBW.

Figure 3. Worldwide sales of materials used in the PV industry.

of about 2%. The latest available layer technologies may bring up light transmission by another 5%. Values up to 99% have been reached in laboratories.

Thin-film modules' structures

Demand for glass is not only increased via growth in the wafer-based field, but also by advances in the production of thin-film modules. There are already over one hundred companies employing this technology, with others just waiting to begin. Thin-film technology offers one decisive advantage over traditional modules based on silicon wafers: both cells and modules may be mass-produced on completely automated machinery. The structure of the modules is similar to that of laminated glass, in that they are made of two layers of glass put together. Simplifying matters to some extent, one might say that there is no organic substance but solar cells between these layers, as is the case with laminated glass.

German glass machinery builders realised the advantages of this new technology quite early. They modified their manufacturing technology to facilitate its use for the completely automated mass production of thin-film solar modules. 'Turnkey' solutions, which combine complete production lines and services from one supplier, are also on the market. Lenhardt Maschinenbau GmbH, a German glass machinery manufacturer affiliated to the Bystronic group, was the first company in the world to develop a laminate-free thin-film module as well as the technologies required for industrial mass production. Investors from all over the world are showing great interest.

Case studies: successful German companies

The German Engineering Federation (VDMA), Europe's largest industrial association, represents engineering companies based in Germany, serving the interests of over 80% of the German glass machinery industry. Two years ago, this organisation set up a working group for photovoltaics and solar thermal energy, as well as a body whose charter was to investigate the manufacture of photovoltaics tools. Both groupings wish to bring together the branches involved in this manufacturing chain to realise greater benefits from synergies.

Grenzebach, a German glass machine maker, developed plant and machinery encompassing all processing steps for manufacturing thin-film solar modules, irrespective of which type of solar cells make up the module in question. Such machines carry both the substrate and the glass cover along the whole processing line,

Courtesy: Interpane.

Figure 4. Sheet glass used for solar cells is manufactured on several float glass units, each of which is one hundred metres long.

starting with sheet glass and ending up with the finished module. The advantage in this case is that separate processes were 'tied' together. The owner of this particular project developed his own machinery for processes such as cutting and breaking glass, storing, packaging and laminating, as well as quality control. The VDMA also provided the manufacturing execution system (MES), a control unit, representing the central element of this entire plant and an essential element for module quality and material throughput. As Mr. Egbert Wenninger, a member of the board of Grenzebach puts it: "Our technology is behind one hundred per cent hands-off mass-manufacturing of thin-film modules."

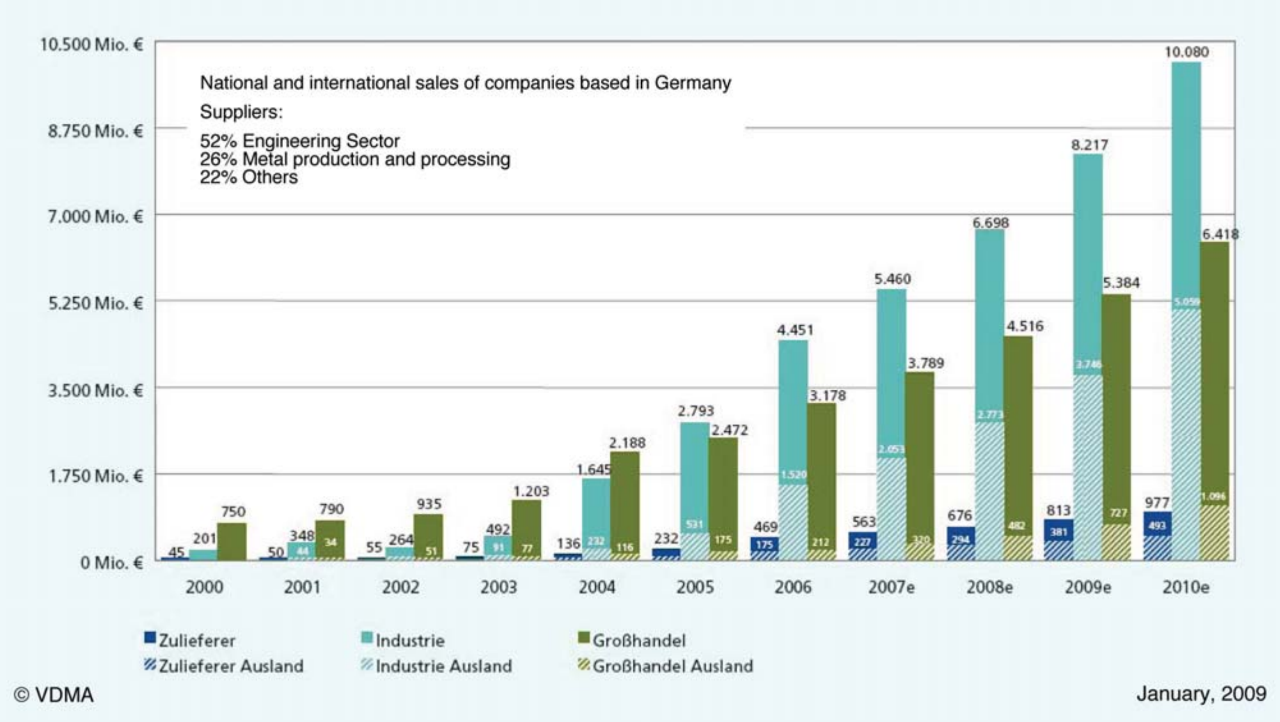
The decisive factor – cost per watt installed

Efficiency of thin-film modules currently ranks below that of silicon wafer-based modules. However, the deciding factor in this issue is not efficiency, but the cost per watt installed. At present, the price ranges between €5 and €8 for thin-film units. Mr. Wenninger of Grenzebach feels that by next year the market will see the first modules breaking through the magic €1 barrier. This would mean that electricity generated by thin-film cells would come at the same price as that generated by conventional power stations.

According to Wenninger, applications need not be confined to solar farms. "Why," he asks, "should people go to so much effort and plaster houses at great expense, if façades could also be covered with large solar modules, providing heat insulation at the same time?" If pre-fabricated solar modules were able to serve this purpose and generate energy, it would eliminate the sense in roofs being covered with tiles or other conventional materials. The plunge into solar energy, taken three years ago, is paying off for Grenzebach. By now, its share of business in this sector is already larger than for companies involved in traditional glass machinery making. The story reads the same for quite a few others, judging from data taken from approximately 80 glass machine manufacturers based in Germany. Following VDMA data, by now over half of them are involved in the photovoltaics and solar energy sectors. They established lines of cooperation and for many of these companies this new line of business has already grown into a major second line of business.

Development of the first non-laminated thin-film module

The Grenzebach company is not alone among German glass machinery makers in its recognition of a market holding tremendous potential for photovoltaic elements integrated into buildings. At present, its share of the entire photovoltaics market stands at less than 2%, but this figure is expected to rise with the blossoming of the thin-film sector. Significant growth rates are anticipated not only in Germany but also in the United States, Asia, France, Italy and Great Britain.



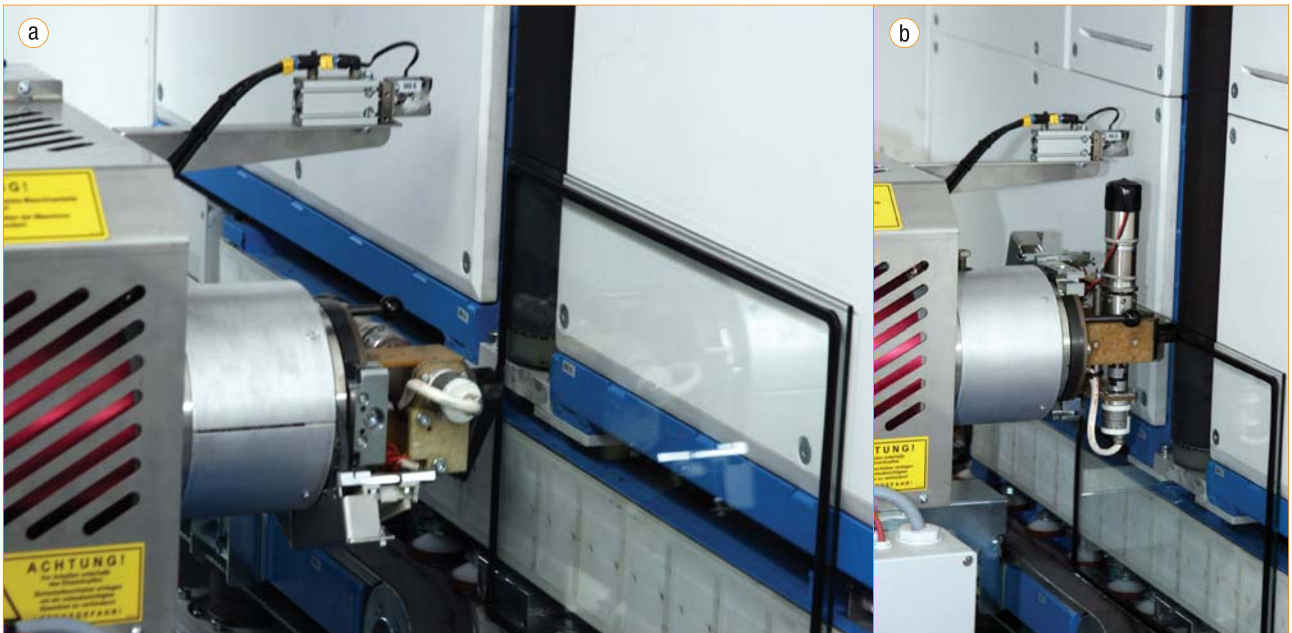
Source: EuPD Research, ifo.

Figure 5. National and international sales of Germany-based companies (2000 to 2010).

Mr. Siegfried Glaser, head of VDMA's photovoltaics/solar energy working group, is convinced "that it will not take very long and solar modules shall have become some totally normal features integrated into structures. This will come at a price acceptable to ordinary people building their own homes." Following Glaser, this idea of integrating modules into buildings brings out the specific advantages of the thin-film technology. Not only will modules generate energy, but they can also act as elements of multi-use glasses and glass systems for façades, roofs and facings for buildings. Additional design functions may be provided, such as safety and sound insulation, protection against the sun and heat, as well as controlled opacity and shading. Mr. Glaser adds: "The sky is the limit when it comes to sizes, shapes and colours."

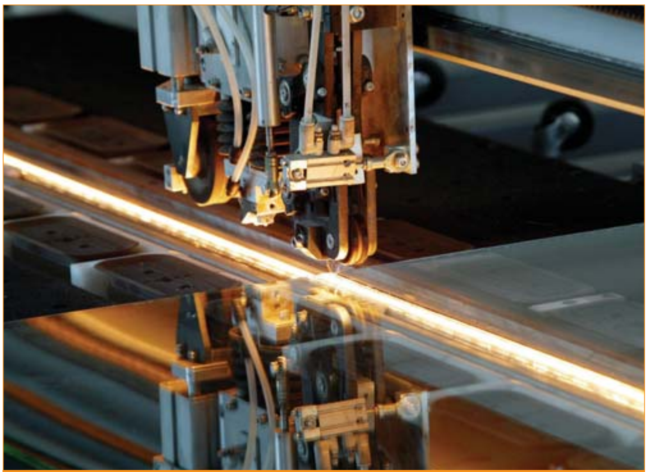
Representatives of Lenhardt, a German glass machinery manufacturer, also refer to the considerable potential offered by glass materials for thin-film technologies. This medium-sized company not only provided a completely new product when it offered the first laminate-free thin-film module, but it also put on the market ready-to-apply newly developed industrial manufacturing technologies that were much needed.

The production process is essentially the same as that for standard insulating glass, a product that is made all over the world in large quantities and in cycles spanning a few seconds. A glass pane, holding a thin-film cell of any possible type, is positioned on a conveyor to be moved towards a robotic device. This unit sprays a layer of thermoplastic starch (TPS) along the outer margins demarcating the solar cells. The two bus bars that will carry electricity from the cell later are then inserted, reaching the



Courtesy: Lenhardt.

Figures 6a & b. This robotic device developed by Lenhardt, the German glass machinery manufacturer, represents the central element of its unit to manufacture laminate-free thin-film modules. The device sprays a plastic material around the cells positioned on a glass substrate. The photo does not show solar cells.



Courtesy: Interpane.

Figure 7. Solar glass also needs high-quality edges. Robotic devices operate at speed, guaranteeing precision.

outside through a layer of TPS. In order to coat the bus bars on the plastic layer, the robotic device sprays another thin layer of plastic on the one already in place. Afterwards, a second panel is placed on top under high pressure. An inert gas such as argon fills any intermediate spaces. A socket is then inserted in this intermediate space. Alternatively, the bus bars can be shrunk into the plugs. Silicone then seals the module at its edges. Afterwards, the thin-film module is ready for use. "And," as Mr. Bernhard Schmidt, a manager of the Lenhardt company states, "it will be fully leak-proof".

Conclusion: modules manufactured in seconds

There is no longer any need for time-consuming and costly laminating procedures fusing solar cells embedded in very thin plastic coatings with a carrier material. This significantly reduces manufacturing cost. Mr. Schmidt adds: "Adapted glass making technology also guarantees the manufacture of king-size modules in a matter of seconds." Up until recently, several minutes were needed. Another positive feature is that machines operate vertically – the module-in-making is not lying on a conveyor, but it is held in an upright position inclined through six degrees. Schmidt sums up as follows: "Given that glass making technology allows for two-by-three metre modules, the factory may be significantly downsized."

About the Author

Joachim Schmid is Managing Director of the Construction Equipment and Building Material Machinery Association (Fachverband Bau- und Baustoffmaschinen) within the German Engineering Federation (Verband Deutscher Maschinen- und Anlagenbau - VDMA).

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Photovoltaic materials innovations continue to drive up efficiencies, drive down costs

Tom Cheyney, Senior Contributing Editor - USA, *Photovoltaics International*

ABSTRACT

Materials innovation in solar photovoltaic manufacturing has long played a key role in efforts to raise cell and module conversion efficiencies, improve overall device performance and reliability, and lower the overall cost per manufactured watt. Research and development in areas such as ultrathin-silicon wafering and replacement films for thin-film PV transparent conductive oxides often garner much of the industry's attention. But a wide range of emerging technologies could provide crystalline-silicon and thin-film cell and module manufacturers the kinds of materials solutions that will accelerate their attempts to reach competitive levelized cost of energy metrics and ultimately attain their goal of achieving grid parity with conventional energy sources – as well as open up lucrative market opportunities for the materials suppliers.

Safely moving beyond silane

Few materials in PV manufacturing are consumed as copiously as silane, both in c-Si cell production and, in ever-increasing amounts, amorphous-silicon TFPV fabrication. But the hazardous gas explodes on contact with oxygen, and so it must be transported, stored, and handled onsite with high standards of safety in mind, adding layers of cost and complexity. Throw in volatile pricing and less-than-secure supply-chain scenarios, and silane looks ripe for a replacement solution.

One company, SiXtron Advanced Materials, has come up with a possible alternative for one of solar manufacturing's workhorse substances: a nonpyrophoric, nonreactive silicon-carbon-nitride-based family of gases, available as a solid polymer source, which is showing efficiencies similar to those attained using the conventional silane approach to nitride deposition for antireflective coatings (ARCs). It can also be distributed and supplied to the existing PECVD tools without significant changes in the process flow or equipment configuration.

"We are not generating an unknown gas, we are generating a mix of different gases, but each specific gas in our mix is very well known in the semiconductor industry. People understand that it is not a blackbox," explains Zbignew Barwicz, President/CEO of the venture-backed Montreal-based company. "Because we are depositing a material which is pretty well known, people understand that if we can overcome the tradeoffs and keep only the advantages, this can be huge. We have demonstrated to some extent that we've overcome the different disadvantages of the carbon content, and we keep the advantages from a mechanical and chemical resistance perspective. What is lacking is our understanding of how it behaves on the

Figure 1. SixTron Advanced Materials' SunBox provides a gas generation system for the company's solid-source SiCN used for silane-free nitride deposition.

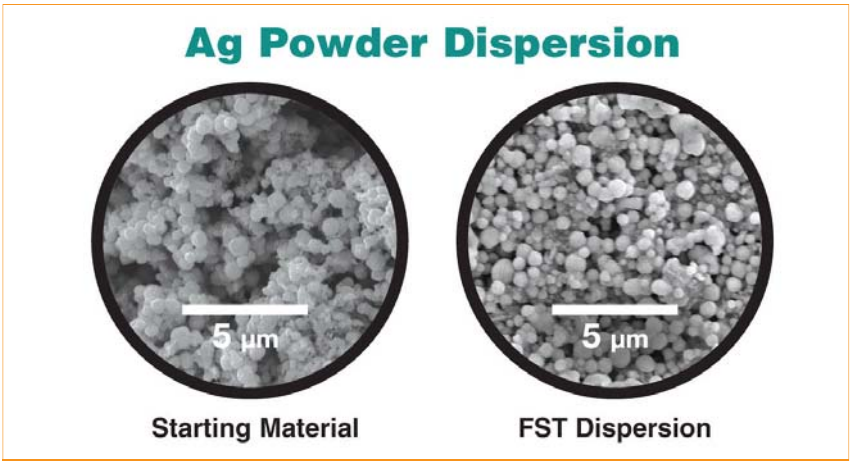

Figure 2. Five Star's silver powder material, before and after dispersion of the particles, shows excellent dispersion uniformity.

cell and how it behaves on the module, and what we are doing now is demonstrating it on the cell and on the module."

SiXtron has been working with Georgia Tech's University Center of Excellence for Photovoltaics (UCEP) to find out just how well the SiCN ARC cocktail behaves on high-performance monocrystalline solar cells, in terms of its optical and electrical properties and ultimately its conversion efficiencies compared to those achieved with conventional silane-based films.

"The beauty of the concept that SiXtron has, is that it generates gases that have carbon in it, instead of SiH_4," said Ajeet Rohatgi, Director of UCEP. "When you flow these gases which are bimetal or trimetal silanes into the same reactor and then flow your ammonia, which you do in the case of silane, the reaction takes place and you still form a silicon-nitride film, but these films have a little carbon in them. They are not 100% silicon nitride, but carbon can be changed by changing the deposition or the composition of the polymer. You can change the composition of the nitride film, and there is an advantage that you can grow films with the same composition using the SiXtron concept in addition to coming up with films that are nonpyrophoric.

"We've been looking at the cells or cell performance with these films and comparing them with the films grown with silane gas," Rohatgi continues. "We have been optimizing the performance and bringing it closer to the conditions of nitride films grown by silane. It took us almost a year of research but now we have produced cells with efficiencies in excess of 17% with the polymer source from SiXtron. These efficiencies are very comparable to the efficiencies we obtain with silane-type nitride films. The film properties look quite comparable to silane in terms of measured hydrogen content, transparency, refractive index, and the like."

SiXtron's SunBox gas-source system plays a critical role in the technology's ability to 'plug and play' to the existing PECVD production gear. The box, which contains a cartridge of solid-source polymer and performs as what Barwicz calls a "microplant of the gas" in close proximity to the deposition tools, replaces the conventional – and expensive – gas handling and safety systems used with silane.

> "We have produced cells with efficiencies in excess of 17% with the polymer source from SiXtron, efficiencies that are very comparable to those we obtain with silane-type films."
> **Rohatgi, UCEP**

"When we hooked it up to our machine, we removed the silane gas inlet and brought in the SunBox," explains UCEP Assistant Director Abasifreke Obeng, in describing the centre's experience with the system. "Same reactor, we just changed the inlet source, with no modification to the equipment. When we plugged in and used the old recipe, it didn't work, but we were able to work out the recipe and get the same performance (as silane) on the monocrystalline."

In search of ever-finer, sturdier contact lines

Another company benefitting from a relationship with UCEP is Cleveland-based Five Star Technologies, which uses a proprietary hydrodynamic cavitation process to produce silver front-side contact inks and aluminium back-surface field pastes for silicon solar cells. Because of the ElectroSperse S-series materials' tight particle-size distributions and excellent dispersion uniformity, cells can be screen-printed with very fine (well under 100µm) contact lines and achieve consistent electrical contact to the emitter layers (both conventional and high resistance), as well as increase line conductivity, thus improving overall device performance metrics, such as fill factor and conversion efficiency.

Tim Fahey, Five Star's VP of business development, said that the inks and pastes are in commercial qualification trials with 15 to 20 cell manufacturers and turnkey-line integrators in Asia, the United States and Europe, with more to come. The potential

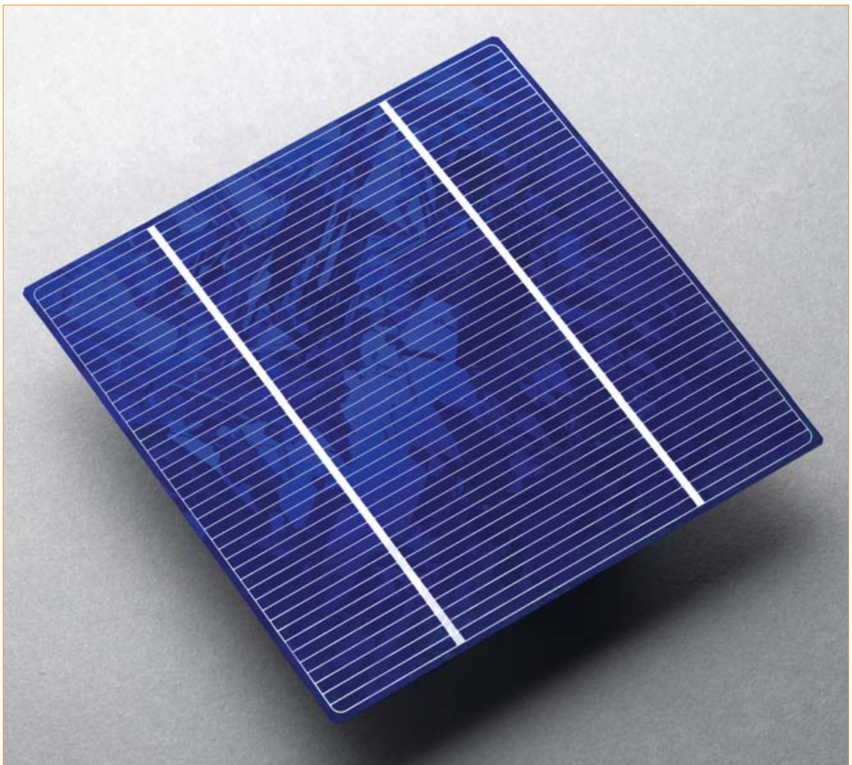

Figure 3. A high-quality printed/fired wafer fabricated using Five Star's ElectroSperse silver front-side contact solar ink.

customers are intrigued by the data from UCEP, which show that monocrystalline cells printed with the company's silver front-side inks can reach efficiencies in the 17.7-17.8% range, fill factors of 77-78%, and open-circuit voltage (V_{oc}) of >620mV, with very low series resistance (<1) and excellent shunt resistance results.

Unlike conventional pastes, ElectroSperse materials have an inherent adaptability to the wide range of different rapid thermal processor (RTP) firing profiles and process windows in use at solar-cell fabs. With the help of UCEP, Five Star has come up with "a very detailed document we provide to customers with processing guidelines for firing the S-series paste," said Fahey.

"For any front-side contact paste, there's a unique spike temperature that you need to reach," he continued, "in order to get the proper melding of the glass, so the glass can carry the silver down through the antireflective coating to make contact with the emitter layer. Everyone has their own proprietary formulation of what kind of glass they use, so for each paste you need to get to that proper temperature. It's critical to adjust the temperatures to hit the right spike for that particular paste."

UCEP's Obeng explained that researchers have "used the paste, optimized it, based on our understanding of RTP firing with a furnace that we have here. We were able to optimize and get the right firing temperature for them. This is very important because the emitter and the firing profile have to be right in order to obtain the right parameters. Their performance is on par with product pastes."

The next phase of the Five Star/UCEP collaboration focuses on the use of new ink formulations for aerosol, inkjet, and other noncontact methods for printing lines in the tens of microns on ultrathin wafers, what Fahey calls a "natural sweetspot for our technology" because of its particle size and rheology control properties.

Reflect fewer photons, get more energy

While technologies such as SiXtron's silane-free films and Five Star's advanced front-side inks provide enhancements of the solar cell's antireflective properties, another company's approach uses the outer surface of a PV module as the canvas for its innovative AR coating. Xerocoat's durable single-layer optical material, which can be deposited directly on cover glass or even plastic, can increase the transmission of light across the spectrum and at all angles to the cells inside. The ~100nm-thick porous silicon-oxide coating can elevate the watt-peak performance – and thus the energy output – of the module by at least 3% (equivalent to a 0.5-0.75% increase in cell efficiency) and produce about a 4% surge in power on a kilowatt-hour basis, potentially benefiting both module manufacturers and solar PV system owner/operators.

Figure 4. A rendering of Xerocoat's turnkey antireflective coating equipment for PV module production lines.

"From our point of view, we're basically agnostic as to how you convert the photons into electrons. What we do best is getting the most photons we can from the sun on the outside to whatever your technology is on the inside," quipped CTO Michael Harvey. The Xerocoat technology was developed a few years ago at the University of Queensland in Australia by cofounders Harvey and Paul Meredith, who is also VP of materials development of the company, now based in Redwood City, CA.

"We're agnostic as to how you convert the photons into electrons. What we do best is getting the most photons we can from the sun on the outside to whatever your technology is on the inside."

Harvey, Xerocoat

Xerocoat's initial market foray involves the 'drop-in' deployment of low-cost, high-volume turnkey coating-and-curing toolsets at crystalline-silicon module makers' production facilities, "which will take glass in from one side, from any manufacturer, apply the ARC to the glass and deliver it to the other side, to the module factory," said Harvey. The newly designed system (which will be made under license by a contract equipment manufacturer) consists of a high-speed, nonvacuum roll-coater, which initially deposits the liquid film on the glass, followed by a relatively simple, low-energy curing step – all done in atmosphere and at room temperature.

"The next big step for us is to complete our pilot line [in Redwood City], which will be using the technologies we have developed for a full-scale production line," said Harvey. "That will be the final step to confirm and demonstrate all the individual technologies we will put together to make a 100MW line. It will have the same throughput and speed of a production line, but we won't be feeding in a half-million pieces of glass per year. It will be completed early in the second quarter. From there, the next step is to ramp up engagement with customers who want to look at the technology in action, see real process tools, and work toward delivering our first coating line in the third or fourth quarter of this year."

Glass coated with Xerocoat's films and laminated onto modules has been undergoing rigorous indoor testing, according to Harvey. Flash testing has confirmed the ARC's merits, while other reliability and durability exams – methods he described as "well beyond the IEC tests" – have revealed no failures.

"As for outdoor testing in Australia, Florida, California, and Arizona," he continued, "what we see is that the coating performs under real-world conditions exactly as we expected under laboratory conditions. The benefits are maintained; in side-by-side comparisons with uncoated glass, the coated glass does not soil at an increased rate, there isn't any evidence that any moderate amount of rain or even dew, dust, and dirt settled on the glass, and it cleaned off more easily on the coated pieces compared to the uncoated pieces. The 3% benefit going out was maintained in the field compared to uncoated glass."

Capturing a slice of real money

Mark Thirsk, managing partner of Linx Consulting and veteran electronics materials market observer, believes Xerocoat's coating approach is a "really interesting piece of technology" that could tap into a growing solar PV antireflective material sector already worth hundreds of millions of dollars. While not citing SiXtron by name, he sees great potential for "deposition systems and materials that replace silane," believing that there is "money to be made" in such efforts. Among the companies innovating in the solar paste and ink realm, he thinks that "Five Star is the most exciting out there," noting how the company's technology "is eminently scalable and potentially brings key advantages." There are "about a half-billion dollars in pastes sold at the moment," he adds, so "if you capture a slice of that, that's real money."

Working principles of dye-sensitised solar cells and future applications

Mario Pagliaro, **Giovanni Palmisano** & **Rosaria Ciriminna**, Istituto per lo Studio dei Materiali Nanostrutturati (CNR), Palermo, Italy

ABSTRACT

Invented in their high efficiency version in the early 1990s, dye-sensitised solar cells (DSCs) entered the global market in 2007 with the first commercial modules based on this versatile, hybrid (organic-inorganic) technology. The 6-7% efficiency of the first modules is a result of their good performance in diffuse light conditions, allowing for the production of electricity both under cloudy conditions and indoors. These low-cost solar cells are manufactured by highly productive roll-to-roll printing methods over rigid or flexible substrates affording modules coloured in widely different tones. These attributes render DSC a photovoltaic technology particularly well suited for BIPV applications and for electrification in developing countries, as discussed in this paper.

Introduction

Attempts to create photoelectrochemical solar cells by mimicking nature's photosynthesis started in the 1970s with early efforts involving the covering of crystals of semiconductor titanium dioxide with a layer of chlorophyll. However, owing to the electrons' reluctance to move through the layer of pigment, the efficiency of the first solar cells sensitised in this way was about 0.01%. In the late 1980s, scientists discovered that nanotechnology could overcome the problem [1]. Instead of using a single large titania semiconductor crystal, they worked with a sponge of small particles, each about 20nm in diameter, coated with an extremely thin layer of pigment. This method increased the effective surface area available for absorbing the light by a factor of one thousand, hugely increasing the efficiency on conversion of the sunlight into an electric current. The first system used a 10µm-thick, optically transparent film of TiO_2 particles of tens of nm in size with a photosensitiser dye chemically linked (usually by -COOH, $-PO_3H_2$, or $-B(OH)_2$ functional groups) to the semiconductor surface, a solution containing a redox mediator and a metallic counter electrode.

"Beyond being highly effective, semiconductor TiO_2 is also abundant, low in cost, non-toxic and biocompatible."

Remarkably, even this first cell had 7.1% efficiency and photocurrent density up to $12mA/cm^2$.

Working principles

The working scheme of a typical cell is illustrated in Figure 1, showing a TiO_2 layer deposited in a conductive

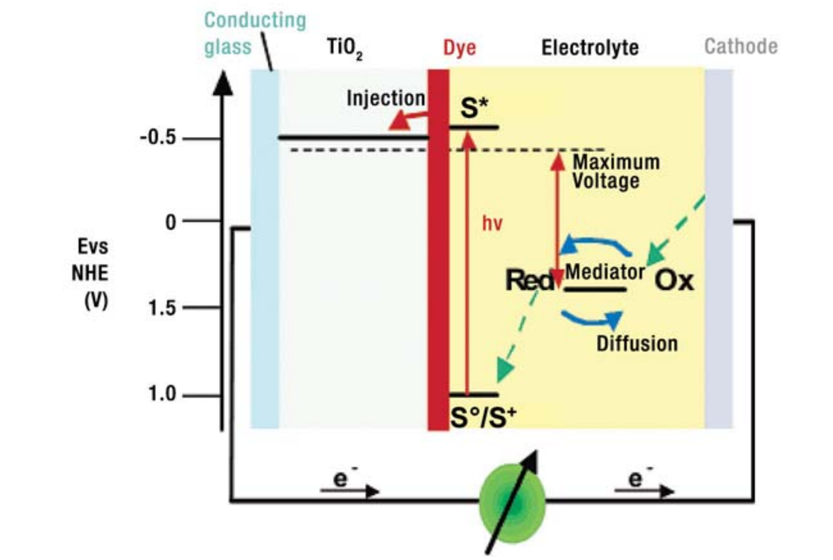

Figure 1. Working scheme of a typical dye-sensitised solar cell.

Image courtesy of [3].

ITO glass. The dye is placed over this semiconductor film, in contact with an electrolyte. The excitation of the dye upon irradiation is followed by injection of the resulting electrons into the CB of the semiconductor, from where they reach the cell anode (usually a conductive glass or plastic). Regeneration of dye electrons occurs through donation from a redox electrolyte in contact with the dye. This typically occurs through an organic solvent containing an iodide/triiodide couple. Triiodide is reduced in turn at the counter electrode, while electron migration from the anode to the counter electrode closes the circuit. The voltage generated is equal to the difference between the Fermi level of the electron in the solid TiO_2 and the redox potential of the electrolyte.

Beyond being highly effective, semiconductor TiO_2 is also abundant, low in cost, non-toxic and biocompatible. Typically, nanocrystals of mesostructured TiO_2 in the anatase phase are prepared by sol-gel hydrothermal processing of a suitable titania precursor in the presence of a template such as Pluronic P123. The xerogel is isolated as thin film supported over a glass, further covered by another conductive glass [2].

The redox couple in the electrolyte, most commonly iodide/triiodide, functions well because the electron transfer from nanocrystalline TiO_2 to I_3^- is much slower than that from a counter electrode [4]. The $I_2^{-\bullet}/I^-$ couple potential determines the thermodynamic driving force for the electron transfer from I^- to the oxidised dye. Indeed, the mechanism of electron transfer from TiO_2 to I_3^- is preceded by a weak dissociative chemisorption of iodine on TiO_2:

$$I_3^- \leftrightarrows I_2 + I^- \quad (1)$$

$$I_2 + e^-_{(TiO_2)} \rightarrow I_2^{-\bullet} \quad (2)$$

Equation 1 has a very low equilibrium constant (~10^{-7} in acetonitrile), whereas the iodine radical is further reduced in a second-electron-transfer step:

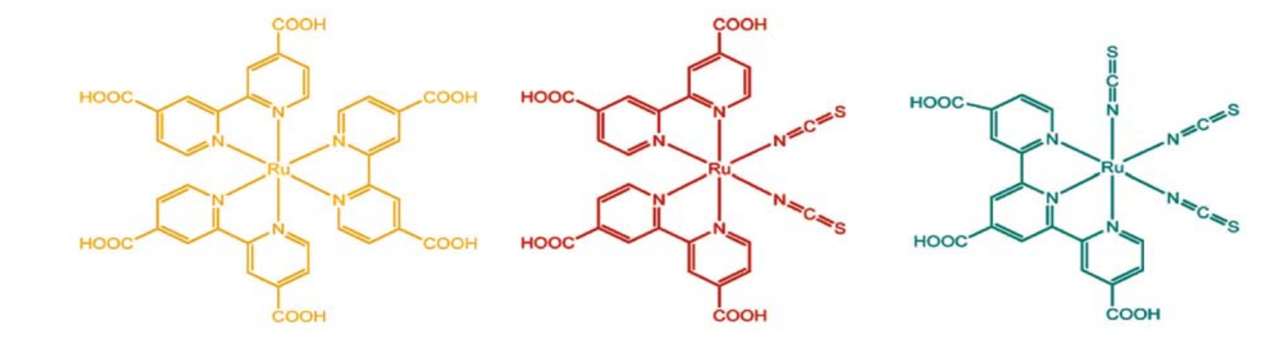

Image courtesy of [3].

Figure 2. Structure of the ruthenium sensitizers RuL_3 (left) cis-$RuL_2(NCS)_2$ (centre) and $RuL'(NCS)_3$ (right) where L = 2,2'-bipyridyl-4,4'-dicarboxylic acid and L' = 2,2',2"-terpyridyl-4,4',4"-tricarboxylic acid.

$$I_2^{-\bullet} + e^-_{(TiO_2)} \rightarrow 2I^- \quad (3)$$

Regeneration of the dye ground state involves reduction of the oxidised dye by iodide:

$$Ru(III) + 2I^- \quad Ru(II) + I_2^{-\bullet} \quad (4)$$

Sensitisers are generally based on polypyridyl complexes of Ru with an $RuL_2(X)_2$ structure (Figure 2). A monolayer is adsorbed over the deposited TiO_2 film; this is the device absorbing solar light at the beginning of the previously described cycle.

Current development – manufacturability

The Australian company Dyesol has pioneered the commercialization of DSC after obtaining a license from the inventors and has developed the technology in practically every aspect [5]. The company has recently introduced a flexible, foldable, lightweight and camouflaged solar panel for military applications which has been found to be superior to other PV technologies in maintaining voltage under a very wide range of light conditions, even in the dappled light under trees (Figure 3).

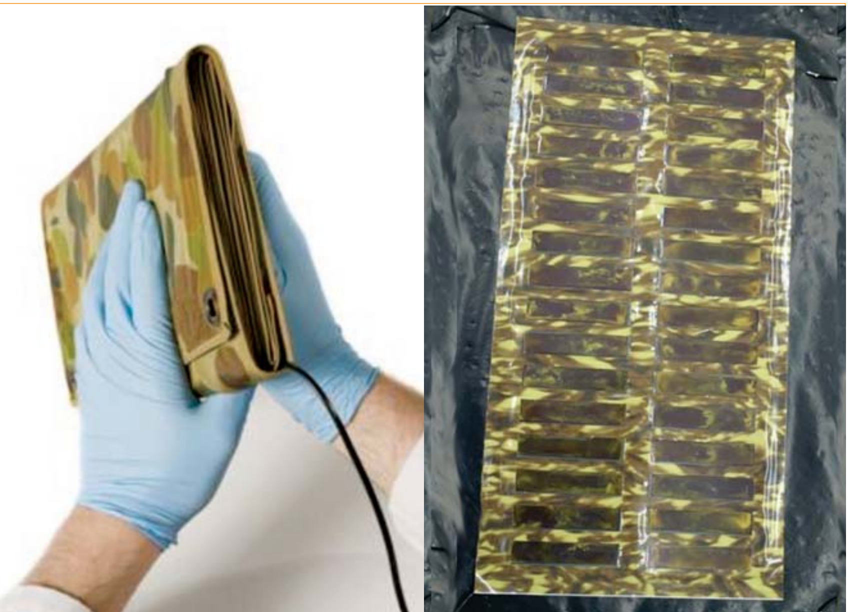

Photo courtesy of Dyesol.

Figure 3. The flexible DSC-based solar module developed by Dyesol for Australia's Army camouflages itself in trees from where it provides constant voltage under a wide range of illumination levels.

On one other hand, the roll-to-roll production developed by G24Innovation easily allows the transformation of a roll of metal foil into a 45kg half mile of dye-sensitised thin film in less than three hours (see Figure 4) [6].

Photo courtesy of G24Innovations.

Figure 4. Roll-to-roll production of the first PV modules results into a flexible, lightweight PV material that can suit largely different applications.

This material is rugged, flexible, lightweight and generates electricity even indoors and in low light conditions. In place of liquid electrolyte, solid or quasi solid-state hole conductors can be employed, but the reduction in efficiency currently precludes practical application.

The first and still the most efficient electrolytes were liquid, so cell and module designs that prevented electrolyte leakage had to be developed to prevent evaporation. Stability and lifetime of DSC modules have thus reached appreciable values, and rapid improvements are being made [7].

OrionSolar has developed inexpensive modules based on 15cm x 15cm dye cells, by using a low-cost method of depositing TiO_2 in a sponge-like array on top of flexible plastic sheets (Figure 5) [8]. This is only one of the many companies that are waiting for the best moment to start commercial activities to enter the market, as in the case of the Japanese Mitsubishi, Sony, Sharp and Aisin Seiki.

Photo courtesy of OrionSolar.

Figure 5. Orionsolar dye cells have an additional advantage in that they are particularly suited to warmer climates.

Applications

DSC technology is probably the most appropriate application for use in building integration. The wide range of available

Photo courtesy of CSIRO and Dyesol.

Figure 6. Dyesol manufactured the solar wall panels to supply and install in the CSIRO Energy Centre in Newcastle, Australia.

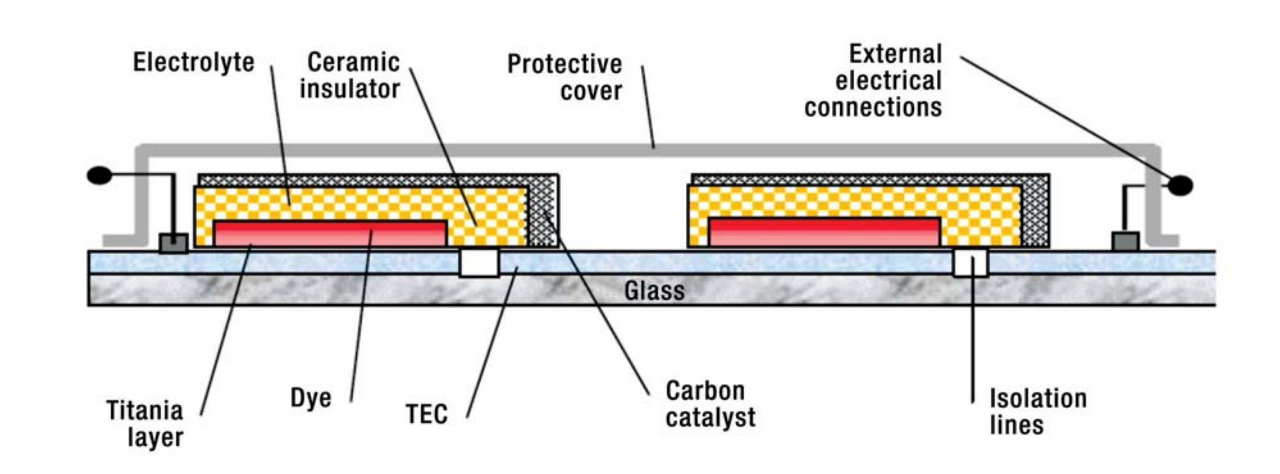

Image courtesy of Dyesol.

Figure 7. Integrated module design for a typical DSC module.

colours and transparency, along with the wide range of operation temperatures and the relative insensitivity to the angle of incident light make DSC modules very attractive. All these factors allow for building-integrated windows, walls and roofs of varying colour and transparency that will simultaneously generate electricity even in diffuse light or at relatively low light levels, in addition to whatever other function they serve.

A pioneering building integration took place in Australia in 2003 as the research body CSIRO commissioned a DSC BIPV system for the CSIRO Energy Centre in Newcastle, shown in Figure 6. The order was in April 2002, and Dyesol manufactured the solar wall panels to supply and install.

Solar wall panels are constructed in a laminated design, with the connected tiles sandwiched between two panes of glass, fully encapsulated in the UV-resistant transparent laminating polymer. Electrical interface can be typically via a short DC bus to a local area network for regulation and distribution or inversion to AC. The integrated module design comprises two sheets of conducting glass with the electrode deposited on one sheet and the counter-electrode deposited on the second sheet (see schematic in Figure 7).

Other applications, mainly developed by G24i, include efficient and lightweight solar power for extra talk time for mobile phones, solar stations consisting of an ecosystem of solar products to enable the use of mobile phones in areas not reached by the electric grid, and solar jackets with integrated battery supply for universal charging together with LED lights, as illustrated in Figure 8.

Roadmap

One of the major points of DSC technology is the technology's relative insensitivity to impurities. This, along with the intrinsically low cost of the constituents, allows for production costs much lower than those of conventional crystalline silicon.

Image courtesy of G24i.

Figure 8. Solar station (left) and jacket commercialized by G24i.

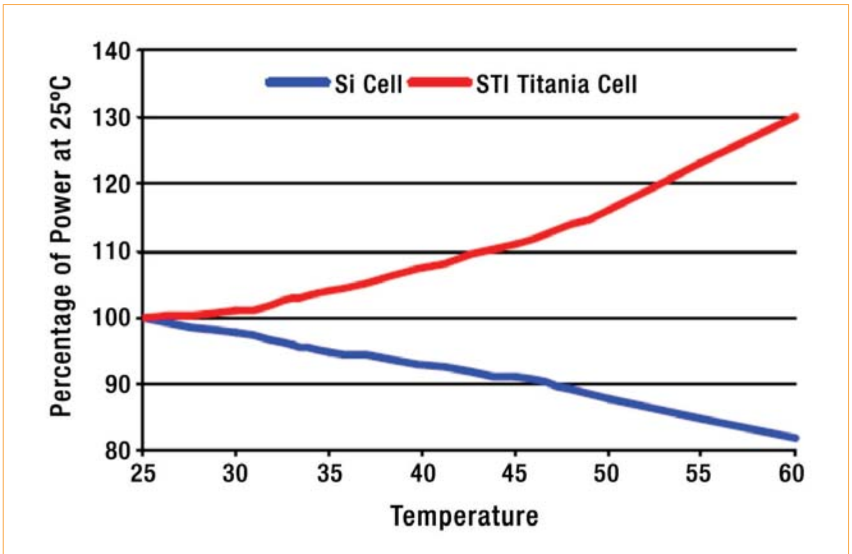

Image courtesy of [9].

Figure 9. The performance of dye PV modules increases with temperature, contrary to Si-based modules.

Advantages of the technology include its low cost - the materials are inexpensive, abundant and innocuous (titania is widely used in toothpastes, sunscreen, and white paint); ease of production; transparency; and compared to Si-based cells, DSCs boast easy bifacial configuration - advantageous for diffuse light - and colour, which can be varied by selection of the dye, including invisible PV cells based on near-IR sensitizers. Furthermore, contrary to Si-based modules, the performance of dye PV modules increases with temperature, as the graph in Figure 9 shows.

Hence, the global energy production of these modules is significantly higher than that of amorphous Si-based modules, despite their lower 5% efficiency. This was demonstrated during the 2005 Expo in Japan by analysis of the setup of the Toyota exhibition house, which was equipped with DSC modules consisting of wall-integrated 2.5m x 2.5m solar panels. Keeping a close eye on the energy produced, it was revealed that the

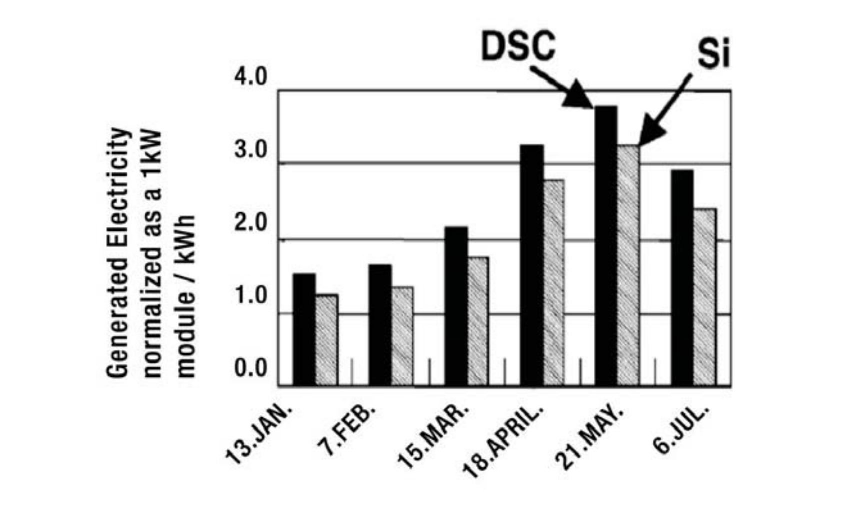

Image courtesy of [10].

Figure 10. Toyota's exhibition house at Aichi 2005 Expo was equipped with two large DSC modules whose output outperformed that of an a-Si panel.

DSC modules gave a faster output rise in the morning and a slower fall in the afternoon due to a different dependence on solar incident angle. The breakdown of the data collected is displayed in Figure 10 [10].

Stable and 10%-efficient cells are expected to become easily affordable in a very short time. These cells can surely give shorter pay-back times than other conventional and new PV technologies. As evidence of chemical and thermal robustness, recent accelerated aging tests showed that ≥8%-efficient laboratory DSCs retain 98% of their initial performance over 1000h when subjected to thermal stress (80°C) in the dark or when exposed to both thermal stress (60°C) and continuous light-soaking over 1000h. These results strengthen the technology's case for real investment, further proof of which is the evidence that suggests that and several companies are working toward commercializing [11].

As to the next few years' developments, it is expected that some companies will attain 10%-efficient modules that approach the criteria for solar module certification for thermal aging at 85°C for 1000h in the dark and for light-soaking in full sunlight for 1000h at 60°C. A realistic goal is that 20%-efficient laboratory-sensitised solar cells will be achieved by 2015.

Research on innovative dyes, for example, is expected to lead to considerable progress in the cell's efficiency. Mitsubishi, a manufacturer of traditional PV modules, has developed a whole new series of undisclosed, high-efficient new dyes. Progressively, the company makes its proprietary newly developed dyes available to Japan's scientific community engaged in PV research. Among such dyes, the early 2000s saw the first example of metal-free, entirely organic dye indoline, that (at the beginning of the 2000s) gave an 8% efficiency [12]. This is only one of the many developments made in the last few years that will surely bring DSC technology to the fore for many manufacturers as a viable processing method.

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Mario Pagliaro is a research chemist and management thinker based at Palermo's CNR where he also leads Sicily's Photovoltaics Research Pole and jointly directs the activities of the new Institute for Scientific Methodology. His research interests lie at the interface of materials science, chemistry and biology. Mario's laboratory currently collaborates with researchers from 10 countries. Their joint work has resulted in a number of achievements, including new commercial sol-gel catalysts and conversion processes for glycerol. Thus far, he has co-authored six books, some 80 research papers and has three patents.

Giovanni Palmisano is a chemical engineer working as a private consultant for the industrial development of photovoltaic products and as research fellow at the University of Rome "Tor Vergata", under the tutorage of Aldo Di Carlo. His research work mainly focuses on TiO_2-based new functional materials for DSC cells and photoelectrocatalytic applications. Giovanni works in close collaboration with his former Ph.D. tutors Vincenzo Augugliaro and Mario Pagliaro at Palermo University and CNR.

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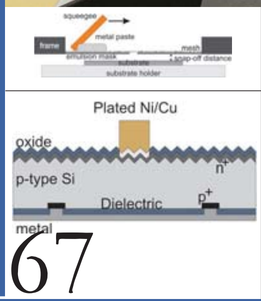
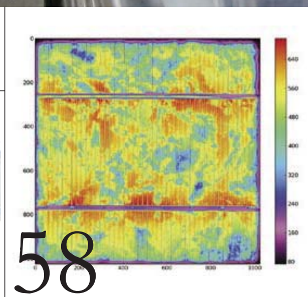
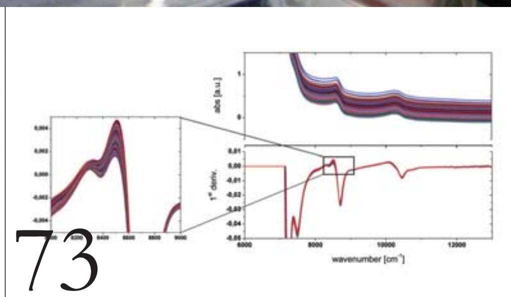
Cell Processing



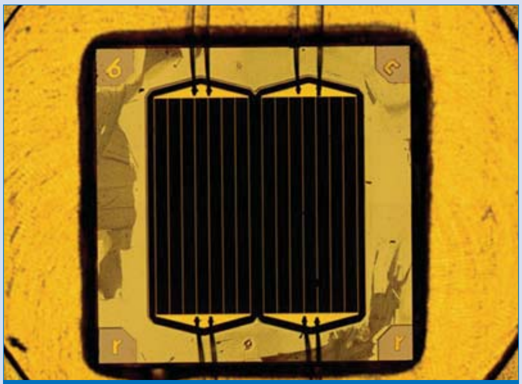




Fraunhofer ISE marks latest solar cell efficiency breakthrough

The Fraunhofer Institute for Solar Energy Systems (ISE) claimed another major breakthrough in solar cell efficiencies via its successful development of metamorphic crystal growth processes using triple junction cells. The cell is fabricated using GaInP/GaInAs/Ge (gallium indium phosphide, gallium indium arsenide on a germanium substrate) that has produced record conversion efficiencies of 41.1% with a 454 concentration factor.

"We are elated by this breakthrough," says Frank Dimroth, head of the 'III-V – Epitaxy and Solar Cells' group at Fraunhofer ISE. "At all times the entire team believed in our concept of the metamorphic triple-junction solar cells and our success today is made possible only through their committed work over the past years." Employing a metamorphic crystal growth process has proved elusive due to the lattice differences created in the cell creating dislocations and a range of defects, rendering poor results.



ISE's new GaIn/GaInAs/Ge solar cell.

The Fraunhofer researchers have worked on localizing the defects in a region of the solar cell that is not electrically active. The active regions retain only limited defects and therefore can produce electricity at good efficiency levels due to the favourable conversion rates when using the III-V materials selected.

"This is an especially good example of how the control of crystal defects in semiconductors can lead to a breakthrough in technology," noted Prof. Eicke R. Weber, Director of Fraunhofer ISE.

The success of the metamorphic crystal growth processes is expected to lead to a wider range of light absorbing III-V materials being selected for multi-junction solar cells, boosting cell efficiencies further. Efforts are expected to focus on matching efficiency levels within the three sub-cell areas as currently the lowest efficiency cell dictates current output.

R & D News Focus

1366 Technologies receives US DoE and NREL funding to develop self-aligned cell technology

MIT spin-off 1366 Technologies revealed that it was awarded an agreement worth up to US$3 million for further development of self-aligned cell technology. The cost-shared 18-month subcontract is between the National Renewable Energy Laboratory (NREL) and the U.S. Department of Energy (DoE) for the project dubbed "Self-Aligned Cell: Scaling up manufacture of a cost effective cell architecture for multi-crystalline silicon photovoltaics".

Funding for the project has been made available in part under the Solar America Initiative (SAI), whose SAI Incubator Program performed a technology review to determine whether 1366 was an eligible recipient of the funding. The company will use the funding to develop its Self-Aligned Cell technology, a method that allows for cost-effective, scalable manufacturing of multicrystalline solar cells.

1366 Technologies R&D facility.

Surfect Technologies claims cell efficiency gains with copper plating

Surfect Technologies released preliminary results of development work carried out with its Directed Energy Plating (DEP) process technology using copper plating techniques to boost solar cell conversion efficiencies over conventional silver paste metallization. According to Surfect, customer demonstrations have shown improvements of 0.5-0.6% higher efficiency or 4-5% increased energy capture from solar cells. Surfect believes that by using copper stack plating, both the emitter contact conductivity and bulk conductivity are boosted.

However, Surfect claims that evaluations undertaken with copper metal deposition, directly on bare silicon using the DEP technology, would result in 1.2% to 2.0% higher efficiency or 5% to 10% increased energy capture versus silver paste. Importantly, this would be achieved at lower cost than competing metal plating systems, the company claimed. Denser metal patterns with finer lines are achieved with its direct plating process, which enhances the capture area on top of the cell, the company said.

"The first phase of our strategy is to provide current solar manufacturers with an immediate solution to improve energy capture from existing manufacturing processes that utilize silver paste to capture and transport photons from the solar cell," commented Steve Anderson, Chief Executive Officer, Surfect Technologies. "We are encouraged by the successful deposition of copper on the current silver paste with good adhesion results and increased energy capture, demonstrating the effectiveness of our proprietary, computer-driven Direct Energy Plating technology."

Anderson noted that the company was currently continuing to accumulate data on bare metal plating efficiency levels.

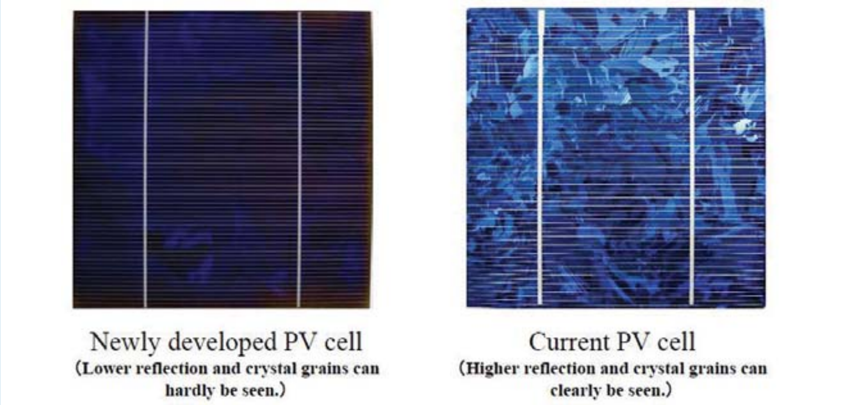
"For the final phase of our strategy, we look forward to introducing additional solar packaging solutions that will significantly enhance module integration and increase performance at the solar panel level," Anderson said.

Canadian Solar opens new cell research center

Canadian Solar Inc. opened its new 1500M2 PV Cell Research Center, which is located in the company's solar cell Fab II in Suzhou. It consolidates the company's R&D facilities to a single location and is meant to improve the efficiency and production yield of regular polysilicon cells and proprietary solar grade e-cells.

The center cost CSI US$10 million, and the majority has already been paid in 2008. It is the only provincially accredited PV cell research center in Jiangsu province.

CSI has been researching high efficiency solar cell structures, such as selective emitter, N-type and back-contact cells. Its research partnership contracts with DuPont, University of Toronto, and Shanghai Jiao Tong Unversity, will focus on improving their solar grade cells.



Mitsubishi's multicrystalline cell design.

Mitsubishi Electric boosts multicrystalline cell efficiency to 18.9%

Mitsubishi Electric Corporation has improved its highest conversion efficiency rate for a 150 x 150 millimeter practical-size multicrystalline silicon photovoltaic (PV) cell by 0.3 points from 18.6 percent to achieve a claimed new world record of 18.9%.

Mitsubishi Electric has succeeded in improving efficiency in utilizing infrared rays by 26% compared to the company's previous PV cells, whose development was announced on March 19, 2008. The newly developed PV cell has a rear-surface reflection structure, which reflects infrared rays that reaches its rear surface to allow the cell to absorb more light.

This newly developed PV cell adopts the same low-reflective honeycomb-textured structure as the one previously developed by Mitsubishi Electric that achieved an 18.6% conversion efficiency rate. The hexagon structure incorporates very small bowl-shaped concaves. Mitsubishi Electric also aims to increase output of PV systems by combining this technology with its PV inverters, which have a high energy-conversion efficiency rate.

Suntech focuses 2009 capital spending on 'Pluto' technology migration

Suntech Power Holdings has said that it would hold PV cell production capacity at 1GW in 2009, due to tight credit markets. The company reported full year 2008 shipments of 497.5MW, a 36% increase from 2007. Suntech now expects 2009 shipments to reach more than 800MW, indicating current capacity levels are sufficient to meet expected demand throughout the year. Suntech said that capital expenditures for the fourth quarter of 2008 reached US$109.1 million, allocated to expanding production capacity and new manufacturing facilities.

However, Suntech does expect to spend approximately US$100 million on equipment in 2009, despite the overcapacity. The company plans to further retrofit existing production lines to its next-generation, high efficiency Pluto cell technology as well as complete the building of its first thin-film facility.

At the end of 2008, Suntech said that it had a fully operational 34MW Pluto PV cell line. The Pluto technology is claimed to achive conversion efficiencies of close to 17% on multi-crystalline PV cells and close to 19% on mono-crystalline PV cells. The company plans to add a further 68MW of Pluto capacity in 2009.

Despatch installs thermal process equipment at U.S. solar PV manufacturer

Despatch Industries said that it has successfully installed and started up two pilot-scale solar manufacturing units at the facilities of an unnamed U.S.-based photovoltaics manufacturer. The installed equipment includes a pilot-scale integrated, in-line diffusion system and a 30-MW firing furnace.

Terms of the deal have not been disclosed. The company says its DCF1000, a pilot-scale integrated, in-line diffusion system, is specifically designed to be used to emulate full-scale production conditions and improve manufacturing performance results.

The newly installed equipment adds to the more than 8 GW of PV production capacity that Despatch says it has sold worldwide; the company also claims its metallization firing/drying furnace holds number-one global market share.

GP Solar scores first major order for photovoltaic measurement systems

The GP Solar unit of centrotherm photovolaics landed its first major order for its Inspect line of optical measurement systems designed for use in solar PV production. GP said the tools will be supplied to a gigawatt-scale factory being built in Southeast Asia by an unnamed major European solar-cell manufacturer.

The GP Solar Inspect family of camera-based vision systems are deployed in the manufacturing quality control of wafers, solar cells, and modules in more than 25 production lines worldwide. Special illumination units facilitate a significantly optimized degree of measurement acuity, the company says. Modular software architecture, fully automated calibration, and centralized production data collection are among the other features incorporated in the system.

Roth & Rau wins order for two turnkey production lines worth €26 million

Roth & Rau AG received a major order to supply two turnkey production lines worth €26 million to the Korean solar cell manufacturer Millinet Solar. The lines, which have production capacities of 60MWp each, will be supplied from June 2009 and November 2009.

This follows a substantial increase in new orders at Roth & Rau in the past 2008 financial year. Orders totalled €269.2 million, a 10.1% improvement compared with the previous year.

Despatch gets US$5 million order for PV equipment from European solar-cell manufacturer

Despatch Industries booked a $5 million order for photovoltaic manufacturing equipment with an unnamed European solar-cell manufacturer. The deal is for multiple units of the process tool company's newest generation of multilane firing infrared furnaces.

The Minneapolis-based firm said that the new furnace is an important addition to its in-line product portfolio and fits well with the industry's commitment to in-line processing results. The CDF-9024 drying-firing model has a wider belt to accommodate multiple lanes of cell processing and is capable of producing more than 2400 cells per hour.

Very fast ramp rates optimize contact formation on silicon wafers with shallow emitters and silicon nitride coating, according to the company. Rapid heating and cooling allows firing the contact through the silicon nitrate, while rapid cooling prevents damage to the junction.

In addition to increased throughput, the new model introduces a touchscreen graphical user interface, eye-level electronics access, and push-button chamber access. The company says that the new features focus on making the equipment user-friendly and easy to maintain. The exterior of the unit has been redesigned to include easy lift door access to the upper electronics panels.

Despatch says it has sold more than 8 GW of solar production capacity worldwide and claims that its firing furnaces are the global market-share leader.

AIXTRON to fulfill INER order for MOCVD tool for solar cell production

AIXTRON AG announced that, in the fourth quarter of 2008, the Institute of Nuclear Energy Research (INER), based in Taoyuan, Taiwan, ordered an AIX 2800 G4 Planetary Reactor system in order to produce Germanium/III-V based solar cells.

The MOCVD tool, to be shipped in the first quarter of 2009, will be delivered in 15x4 inch wafer configuration with options to utilize up to 8 inch wafers. INER's use of this reactor is part of its High Concentration Photovoltaic System Research and relevant advanced Development Project, which intend s to develop III-V based higher efficiency photovoltaic devices for its High Concentration Photovoltaic (HCPV) project. Through this project, INER has already developed a 100kW solar power system.

Manz Automation plan new turnkey cell production line with Roth & Rau

Roth and Rau plans to intensify their existing business relationship with Manz Automation and to work together in future in the form of a cooperation in key areas.

The company provided little information on the nature of this agreement beyond the intent to provide a new turnkey production line for the photovoltiac market using the relevant strengths of each company to cover all the process steps in the creation of c-Si solar cells.

Amtech's Tempress subsidiary receives US$5 million in orders

Amtech Systems, Inc. revealed that its subsidiary, Tempress Systems, Inc. received two new orders for its diffusion processing system, worth a total of $5 million. The orders consist of one in Asia, for multiple systems, and another from a solar research and development institute in Europe.

SOMONT's equipment assembly plant.

3S subsidiary Somont receives €14.5 million soldering system order from REC

Somont received an order for delivery of its "RAPID" automatic string soldering systems to the value of €14.5 million. The 3S Industries AG subsidiary will deliver the machines to REC's new solar factory in Tuas, Singapore, where they will be installed at the site and will be instrumental in REC's aim of reaching capacity of 740MW of wafers, 550MW of solar cells and 590MW of solar modules by 2012.

Somont and REC are furthering their existing professional relationship through this new order, which includes also includes the supply of various services and training. REC is currently using the previous generation of RAPID machine types for the production of solar cell strings and their assembly in 3-shift operation. The automatic string soldering systems are an integral part of the fully automatic lines for REC's production of solar modules, and will be delivered in phases until the end of November 2009.

Sales & Production News Focus

News

Plextronics opens new solar inks facility

Plextronics, Inc. officially opened its new development line, or D-Line, that will focus on technology developments for the company's printable solar inks. The new manufacturing facility will print solar demonstration modules to be used in research and progression of its solar inks using commercially viable manufacturing techniques.

Aussie government awards major project status to Spark Solar cell factory

Kevin Rudd's Labour government has chosen Spark Solar Australia's planned solar-cell manufacturing plant as the recipient of its first "Major Project Facilitation" award, recognizing what it calls the "strategic significance" of the factory to the country.

The company says it plans to invest AUS$60 million in a 40MW crystalline-silicon PV cell factory, with production capacity eventually expanding to 120MW. The initial line will lead to the creation of 115 permanent new jobs.

Silicon-ink production line installation completed by Roth & Rau AG and Innovalight

Roth & Rau AG and Innovalight together completed the world's first silicon-ink based solar cell production line, installed at Innovalight's Sunnyvale, California facility. The line has reached operational capability and its initial capacity of 10MW can be scaled to several hundred megawatts, according to the companies.

Installation of the majority of the solar cell manufacturing equipment was carried out by Roth & Rau, while Innovalight's custom proprietary inkjet printing platform and silicon-ink manufacturing systems formed essential elements of the new production line, which incorporates the cost benefits of crystal silicon wafer technology with the silicon-ink processing technology to produce low cost, high performance solar cells.

Japanese wafer cleaning equipment supplier files for bankruptcy

An early victim in the current downturn and credit crunch, wafer cleaning equipment supplier, S.E.S. Co Ltd filed for bankruptcy under the corporate rehabilitation law of Japan, with debts of 14.273 billion yen (US$158 million). S.E.S President, Masaya Shibagaki also resigned.

S.E.S. was known to be a major supplier of wet bench equipment to memory manufacturers such as Samsung and Hynix and had attempted to branch into the photovoltaics industry in 2006.

Plextronics ribbon cutting ceremony.

The rapid and wide spread reduction in capital spending, which virtually came to a halt in the fourth quarter of 2008, especially at memory manufacturers, could have been the key decision to apply for bankruptcy as further lines of credit evaporate in the tightening credit crisis.

The company had seen sales decline over 90% in its 2007/08 financial year and accrued losses of 3.2 billion yen in the six months to September 2008, according to regulatory filings.

E-Ton receives 50MWp solar cell order

The Taiwan-based crystalline silicon solar cell producer E-Ton Solar Tech received an order for 50MWp of solar cells from a previous client, with shipments to occur this year. Industry sources in Taiwan speculated that the client is BP Solar International, citing the fact that BP Solar's planned closure of its Australian factory by March 2009 would require an increase in its outsourced production. Sources stated that E-Ton would make solar cells from 6-inch poly-Si wafers, and Taiwan-based Motech industry would make solar cells from 5-inch poly-Si wafers.

Sources further reported that E-Ton has been certified by several clients for its 5-inch monocrystalline silicon wafer solar cells at an energy conversion rate of 18%. The sources also noted that E-Ton is prepared to produce 6-inch monocrystalline and poly-Si wafer solar cells.

ARISE gives glimpse of financial results; sees 24% shipments increase

ARISE Technologies Corporation has spoken out about its 2008 financial results, which will be officially released on March 9th, 2009. The company saw increases in shipments from its new German plant in the fourth quarter, reaching approximately 6.2MW, a 24% increase from the 5MW shipped in 3Q08, but overall shipments for the second half of the year were down to 11.2MW on the company's projection OF 12-13MW.

The company also announced following uncertainty regarding the completion date of its cell manufacturing line, dubbed Line 2, it can confirm that the plan is on track for completion early in the second quarter of 2009. The uncertainty had arisen from a lag in schedule in the manufacture of a key piece of equipment for the line.

ARISE's revenue will hit the US$18.5-19.5 million mark for the fourth quarter of 2008, below the US$21 million to US$24 million guide given by the company in November 2008. ARISE also managed to reduce the scrap rate by about 20% compared to the third quarter scrap rate, and saw even further reductions in January, according to the company.

An inventory valuation write-down in the fourth quarter of 2008 is necessary to counter the effects of purchase deferrals by customers as well as global price declines. The write-down will be approximately US$2.8 million. The company also plans to implement spending cuts for 2009, but was unable to give financial guidance for 2009.

"Our broad strategies remain the same. We are focusing on the silicon and PV cell businesses as the areas that should enable us to grow impressively and profitably in the future to create long-term, sustainable value for our shareholders," said Vern Heinrichs, interim President and CEO.

Solar Power, Inc. placed 60MW solar cell order with JA Solar

Accompanying the news of its appointment of a new CFO, JA Solar announced that it agreed to supply 60MW of polycrystalline PV cells to Solar Power, Inc. (SPI) in 2009, with the supply taking effect immediately. The one-year supply agreement will comply with Solar Power's monthly cell requirements and will see the cells used in the production of SPI's solar modules for distribution in Europe, Asia, and for turnkey systems in the United States.

China Sunergy initiates commercial production of four solar cell manufacturing lines

Nanjing-based China Sunergy Co., Ltd. brought four high-efficiency SE solar cell manufacturing lines into commercial production at a ceremony held to celebrate the commencement of China Sunergy's 3rd stage production. The door of the 3rd stage production lines was opened to visitors on the day, with attendees including China Sunergy executives Tingxiu Lu, Chairman, Dr. Allen Wang, CEO, and Dr. Jianhua Zhao, CTO.

These additional four lines bring the company's manufacturing line total to ten, five of which are for high-efficiency SE solar cells, four for HP solar cells, and one line that manufactures common P-type multicrystalline solar cells. The company now has an overall production capacity of close to 320MW.

Evergreen Solar mulls manufacturing outsourcing deal

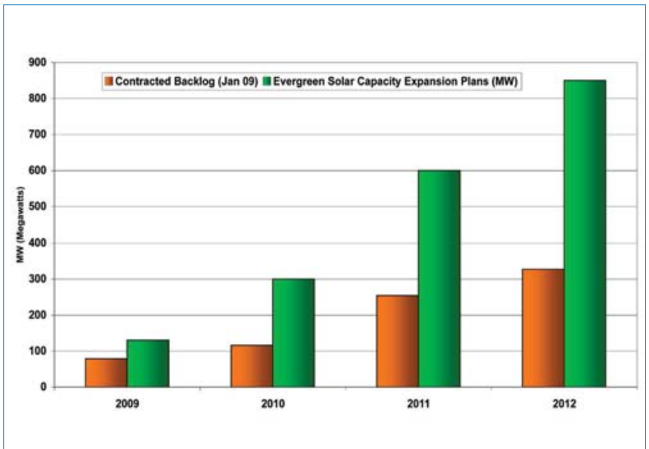
Evergreen Solar's President and CEO Rick Feldt surprised financial analysts during its fourth quarter earnings call by highlighting that the company was in various stages of talks with prospective subcontract manufacturers, mostly based in Asia. The executive noted that subcontracting production would significantly reduce the capital requirements the company would otherwise have to find, while meeting its contracted backlog that now stands at approximately 1GW over the next five years.

"Using a subcontractor would significantly reduce our need for expansion capital, while allowing us to meet our sales expansion goals," noted Feldt. "For example, we have stated that our next factory, built in Asia, would cost about US$1.50 per watt to build or about US$225 million for 150 megawatts facility. Under the subcontract manufacturing arrangement we could reduce our capital needs by about 75%, meaning we will be about US$56 million instead of US$225 million and still meet our sales goals in 2010."Evergreen Solar's President and CEO, Rick Feldt

Evergreen had plans to reach 130MW in 2009, 300MW in 2010, 600MW in 2011 and 850MW in 2012, as well as US$155 million in cash at the end of the fourth quarter 2008.

Evergreen's CFO Michael El-Hillow also noted that the company would need to spend approximately US$120 million over the next six months on capacity expansions. These include US$90 million for its Devens manufacturing plant, US$15 million for its String plant, and debt service of about US$15 million, leaving approximately US$35 million in cash and US$15 million of working capital.

Looking at Evergreen's current backlog of delivery schedules, approximately half of the projected capacity expansions through 2011 would serve existing contracts. Evergreenss current backlog is 79MW in 2009, 116MW in 2010, 254MW in 2011, 327MW in 2012, and 287MW in 2013.



Source: Photovoltaics International

Evergreen capacity expansion plans (MW) 2009-2012.

Product Briefings

SINGULUS TECHNOLOGIES

SINGULUS TECHNOLOGIES' new PECVD coating system offers high productivity on flexible platform

Product Briefing Outline: SINGULUS TECHNOLOGIES has developed a new solar coating machine named SINGULAR, which is used for coating of the anti-reflective and passivation layer on silicon photovoltaic cells. SINGULAR is a PECVD coating system designed as two versions for varying wafer throughput requirements.

Problem: The PV market requires fully-automated and cost-effective systems for coating of anti-reflective and passivation layer on photovoltaic silicon cells as lower production costs make a significant impact on the overall cost of photovoltaics.

Solution: The SINGULAR inline system employs an innovative inline concept for high output industrial production. Advanced layer characteristics are guaranteed by high quality coatings. The new tool is a fully-automated system for coating of the anti-reflective and passivation layer on silicon cells. The essential benefit of inline technology is the transport and processing of small substrate production lots, which guarantees stable process, continuous output, flexibility and a small footprint. Every SINGULAR is autarkic to maintain productivity during maintenance of the other module(s). Additionally, uptime is high due to automatic inline chamber cleaning that does not interrupt the throughput during production. The system has its own proprietary automated handling for loading and unloading the wafers gently to minimize wafer breakage.

Applications: Coating of the anti-reflective and passivation layer on silicon cells.

Platform: The SINGULAR is available in two basic versions. The guaranteed net capacity is 1200 wafers per hour or 1500 wafers per hour depending of the number of installed deposition sources. Up to three SINGULAR can be installed into a production to rise up the net output capacity to over 4500 wafers per hour.

Availability: Currently available.

STANGL Semiconductor Equipment

New inline wet process equipment for Si cells from STANGL

Product Briefing Outline: STANGL Semiconductor Equipment has launched its 'LINEA' horizontally-working inline wet process platform for cleaning and etching of crystalline solar wafers. The fully-automated 'dry-in/dry-out' STANGL wet process system offers a safe and reliable production capacity of up to 60MW per line.

Problem: The complex work flow of solar cell manufacturing lines has to be carefully designed to ensure a smooth production flow. Crucial elements of the wet process workflow are the transport system, the chemical flow system and handling of the wafers in order to ensure a low breakage rate and high uniformity even for solar wafers down to only 150µm.

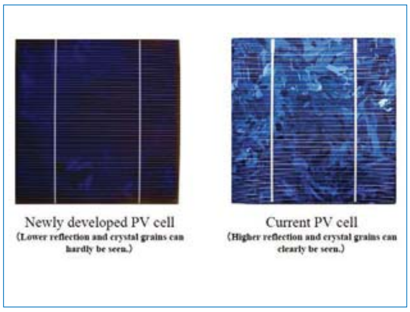
Solution: The LINEA system can be configured to 1,500 or 3,000 wafers per hour which equals a production capacity of 30 and 60MW. LINEA completes the company's portfolio of STANGL's integrated wet process solutions for solar cell manufacturing lines. The LINEA design is based on a newly developed transport system and a special chemical flow system to process the wafers horizontally with a very low breakage rate and a high etching uniformity. LINEA follows the trend towards handling solar wafers down to 150µm.

Applications: Cleaning and etching of Si Cells.

Platform: LINEA is characterized by its high flexibility concerning wafer type, size and thickness as well as its reduced chemical consumption.

Availability: Currently available.

Mitsubishi Electric Corporation



Mitsubishi Electric boosts multicrystalline cell efficiency to 18.9%

Product Briefing Outline: Mitsubishi Electric Corporation has improved its highest conversion efficiency rate for a 150x150mm practical-size multicrystalline silicon photovoltaic (PV) cell by 0.3 points from 18.6 percent to achieve a claimed new world record of 18.9%.

Problem: Production volumes of PV systems have been increasing as they have garnered attention as a good source of renewable energy, against the background of increased global environmental awareness. While silicon is an essential component in the wafers used to make PV cells, the supply of silicon has not been able to keep up with demand. This is driving research into the development of thinner wafers that not only use less silicon, but also have improved efficiency and increased electrical output.

Solution: To increase the photoelectric conversion efficiency rate in PV cells, it is important to absorb and generate electricity efficiently from a wide range of wavelengths in sunlight. Due to the characteristic of crystalline silicon, which has difficulty in absorbing infrared rays, only roughly half of the infrared rays in sunlight can be used to generate electricity, while the other half is usually lost as heat energy after reaching the rear surface of silicon cells. In particular, the thinner the silicon PV cell is, the more difficult it becomes to absorb infrared rays. Mitsubishi Electric has succeeded in improving efficiency in utilizing infrared rays by 26% compared to the company's previous PV cells.

Applications: Mitsubishi Electric photovoltaic modules are designed for both commercial and domestic applications suitable for grid-connected systems.

Platform: This newly developed PV cell adopts the same low-reflective honeycomb-textured structure as the one previously developed by Mitsubishi Electric that achieved an 18.6% conversion efficiency rate. Mitsubishi Electric also aims to increase output of PV systems by combining this technology with its PV inverters, which have a high energy-conversion efficiency rate.

Availability: April 2010 onwards.

BTU International

TRITAN furnace from BTU International provides faster wafer process speed

Product Briefing Outline: BTU International has introduced the 'TRITAN' firing furnace featuring triple-belt/dual-speed conveyor, dual-lane capability, wavelength optimization technology, and full chamber access.

Problem: Very fast ramp rates are required to optimize contact formation on Si wafers with shallow emitters. Rapid heating ensures proper fire-through to deliver excellent contact to n-Si layer and also to improve the aluminum BSF, while fast cooling is required to prevent the diffusion of Ag into the junction. Rapid ramp rates are constantly pushing for faster belt speed, which in turn drives the overall length of the firing furnace. Uptime, reliability, and CoO are also becoming increasingly important.

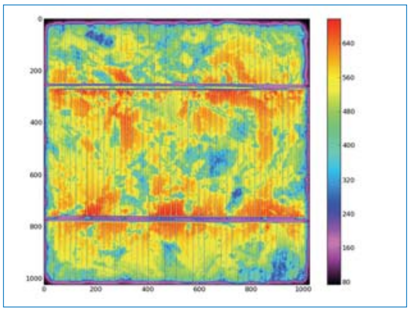
Solution: The TRITAN furnace is designed for faster process speed in combination with innovative heating and gas delivery technology. The enhanced rapid thermal processing capabilities allow more versatility to optimize the thermal profile for different silicon and paste materials. Wafers can be heated up with a very steep temperature gradient, while drying and binder burnout lengths have also been optimized for complete removal of organics. The higher belt speed driven by spike heating does not result in a longer furnace; the proprietary multi-drive system allows the drying and cooling sections to run at a reduced speed.

Applications: Paste drying, organics burn-out and contact firing for high-efficiency solar cells.

Platform: Single and dual lane processing of 125mm, 156mm and larger wafers to achieve 30 or 60MW output. As other BTU products TRITAN is controlled by BTU's windows-based, multi-lingual 'WINCON' software with touch screen GUI.

Availability: April 2009 onwards.

Andor Technology



Andor Technology offers low-cost cell defect inspection

Product Briefing Outline: Andor Technology has introduced two new high-performance cameras, the iKon-M 934 BR-DD and the Luca^{EM} R, that are designed to detect faults in solar cells and panels more easily than conventional methods. Both cameras have high quantum detection efficiency and sensitivity in the near-infrared (NIR) range, making them ideal for solar cell quality control during manufacturing.

Problem: Photovoltaic electroluminescence emissions are very weak and so require extremely sensitive cameras to carry out defect inspection.

Solution: The determination of luminescence in solar cells is an important characterization tool. Typical solar cells often have defects which limit the efficiency or lifetime of the cell. Electron Multiplying (EM) CCD technology, which combines single photon sensitivity and high QE, offers additional advantages when dealing with low-light EL signals, making it possible to record the faintest of signals. Including CCD/EMCCD technology in solar cell/photovoltaic research can significantly improve the quality of solar cells and panels.

Applications: Cell and module defect inspection.

Platform: Luca^{EM} R uses a monochrome megapixel frame-transfer EMCCD sensor, providing single photon detection sensitivity and high NIR quantum efficiency (27% @ 900nm) in a cooled, compact, USB 2.0 camera platform. The iKon-M 934 BRDD is designed to offer ultimate responsivity in the NIR region, delivering ~70% QE at 900nm. The megapixel CCD camera also benefits from deep TE cooling to -100°C, very low read noise and a convenient USB 2.0 interface.

Availability: Currently available.

Rudolph Technologies

Rudolph's 'Discover Solar' software pinpoints tool production issues impacting cell efficiencies

Product Briefing Outline: Rudolph Technologies' new 'Discover Solar' data management software tool helps photovoltaic cell manufacturers optimize tool parameters to achieve higher cell efficiency, increase process yield and reduce cost. It is designed for high-volume PV cell production, while providing comprehensive analysis of process performance.

Problem: With increased competitiveness and demand in the solar industry, PV manufacturers must focus on cell efficiency to maximize margins. To maximize ROI, a system must be capable of both line monitoring and process optimization.

Solution: Discover Solar data management software tool helps photovoltaic (PV) cell manufacturers optimize tool parameters to achieve higher cell efficiency, increase process yield and reduce cost. In manufacturing ramp mode, Discover Solar provides a methodology (Path Analysis) to analyze the interactions of recipes and their effects on cell test measurement. It also provides a correlation with inline measurements giving the answers needed to establish a set of baseline recipes.

Applications: PV cell manufacturing.

Platform: Discover Solar incorporates a completely re-engineered database structure and analysis engine optimized for the unique requirements of high-volume photovoltaic production. Discover Solar accepts all available data from each step in the solar manufacturing process.

Availability: Currently available.

Industrial diffusion of phosphorous n-type emitters for standard wafer-based silicon solar cells

Stefan Peters, Q-Cells SE, Bitterfeld-Wolfen, Germany

ABSTRACT

Formation of the pn-junction for charge carrier separation is one of the key processes of a modern high-volume solar cell production. In silicon wafer-based solar cell technology this is achieved by diffusion of phosphorus atoms in boron pre-doped wafers forming a sub-micron shallow n-type emitter in a 200μm-thick p-type base. In this contribution we discuss both the characteristics of emitter doping profiles and the diffusion process itself as required for optimal solar cell conversion efficiencies. In addition we give an overview on state-of-the-art industrial diffusion technologies and conclude with a brief outlook on their evolution.

Introduction

In modern production lines for standard silicon solar cells, average energy conversion efficiencies of up to 16% and 17% are achieved on multi- and monocrystalline wafers, respectively. The word 'standard' denotes solar cells featuring a diffused front junction and screen-printed contacts on both sides. Other concepts like back junction back-contacted solar cells can reach efficiencies exceeding 22%. This article focusses on diffusion for the standard solar cell. Though the process sequences and tools applied for the production of standard solar cells are very similar from case to case, there are small differences in the single process layout which can account for significant differences in the conversion efficiency produced. With respect to diffusion, a bad process could lower the mean efficiency easily by 0.5% compared to that of one's competitors, whereas in turn a good process can yield a major advantage regarding cost per Wp. To understand what it takes to have good emitter profile and corresponding process, let us have a look at a typical emitter profile and the manifold purposes it and the applied diffusion process serve.

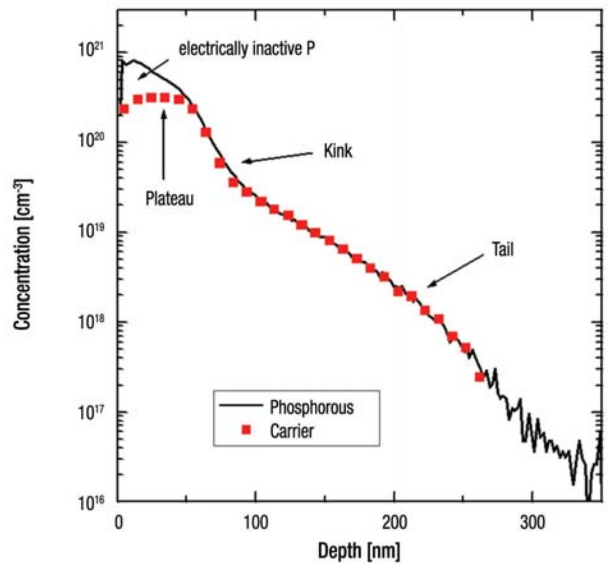


Figure 1. Charge carrier and chemical P profiles of an industrial-type 55Ω/sq emitter diffused by means of spin-on and in-line diffusion. The charge carrier concentration was measured by Stripping Hall Profiling; phosphorus concentration was determined by SIMS.

Preferred emitter profiles of solar cells

Figure 1 shows the chemical P and the resulting charge carrier profile of a 55Ω/sq emitter designed for standard silicon solar cells. The emitter was obtained by deposition of a highly concentrated P source on top of the silicon surface followed by a drive-in diffusion carried out in a lamp-heated in-line furnace [1]. Very similar profiles are obtained by classical quartz tube diffusion using phosphoroxychloride ($POCl_3$) [2]. The main characteristics of such an industrial emitter are as follows. The charge carrier concentration corresponds to the solid solubility of P in Si at the applied diffusion temperature – in this case, 3.3 x 10^{20}cm^3, which corresponds the 900°C applied [3]. The P profile exhibits surface near concentrations even above the solid solubility. The chemical nature of this electrically inactive P is likely to be SiP clusters. Comparatively high doping concentrations > 5 x 10^{19} cm^{-3} are maintained down to roughly 100nm. The junction depth x_j is roughly 300nm. The resulting emitter sheet resistances are in the range of 40 to 60Ω/sq.

> "With respect to diffusion, a bad process could lower the mean efficiency easily by 0.5% compared to that of one's competitors."

In order to understand why the presented profile is a well adjusted one and what it is that makes up a good emitter doping profile, let us have a look at the manifold purposes it serves:

(1) separation of charge carriers

(2) low carrier recombination within the emitter bulk at its surface

(3) provision of lateral conductivity

(4) provision of good Ohmic contacts to screen-printed Ag contacts.

(1) The main purpose of an emitter is, of course, separation of charge carriers by the strong built-in electric field within the space charge region formed in the transition region of n-type and p-type doping. This means that the hole of an electron hole pair generated by absorption of a photon in the emitter is transferred to the bulk once it encounters the space charge region (see Figure 2). Adversely, electrons are transferred from the wafer bulk to the emitter where

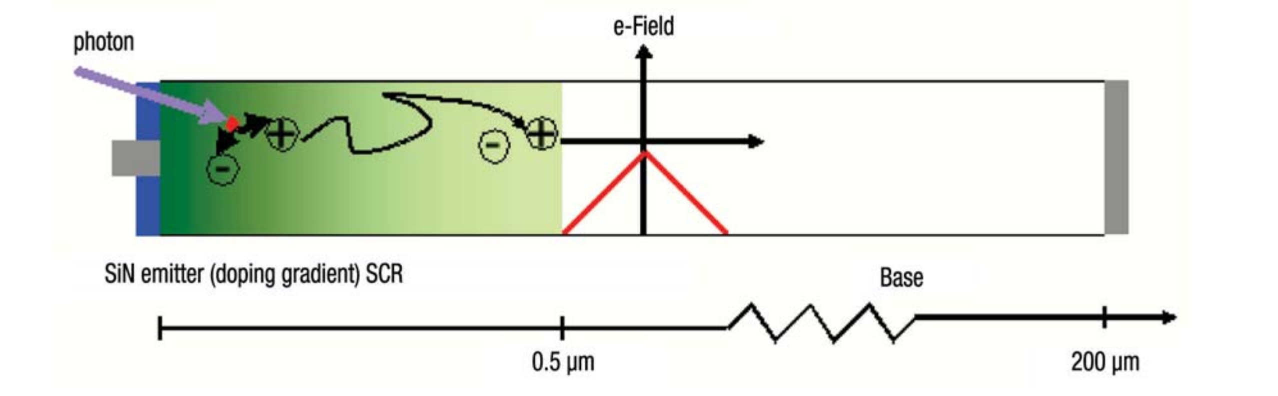


Figure 2. Solar cell cross-section showing the principle of charge carrier separation by the space charge region (SCR).

they become majority carriers. To serve the purpose of separation, the n-type doping only needs to overcompensate wafers' base doping, usually in the order of $10^{16}cm^{-3}$.

"For doping densities exceeding $10^{18}cm^{-3}$, Auger-induced recombination becomes the most dominating recombination channel."

(2) However, the physical surface of the emitter gives rise to strong recombination of charge carriers due to a high density of inner band gap energy states caused by dangling silicon bonds. This recombination channel can be closed by a strong increase in n-doping within the emitter towards its surface, usually by introducing an n^+ front surface field (FSF). Literally speaking, the FSF deflects the holes from the emitter surface. The FSF is the analogy to the p^+ back-surface-field on the solar cell's backside. However, the FSF is not free. The heavy doping needed for a good FSF gives rise to carrier recombination via the Auger mechanism. For doping densities exceeding $10^{18}cm^{-3}$, Auger-induced recombination becomes the most dominating recombination channel. For example, in n^{++} regions with doping concentration $>10^{20}cm^{-3}$, the carrier lifetime drops down to only 1 ns. Nevertheless, this lifetime corresponds to a diffusion length in the 300nm range giving the carriers a fair chance to reach the space charge region if the emitter is not too deep. The optimal doping of an emitter balances between a good FSF and little Auger recombination in the emitter bulk. It is important to note that the need for an FSF vanishes by provision of surface passivating layers like silicon nitride or thermally grown silicon oxide on top of the emitter. In this case, not only can the surface near doping be lowered, but the solar cells' performance even benefits from its lowering. Figure

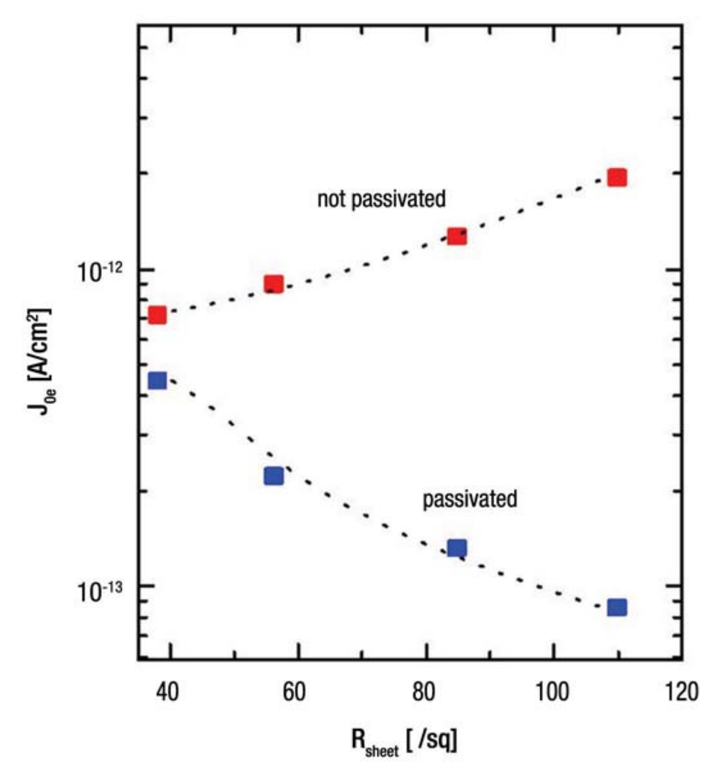


Figure 3. Emitter saturation current J_{oe} as a function of sheet resistance R_{sheet} for passivated and non-passivated emitter surfaces, respectively. Values have been determined experimentally. Surface passivation is provided by a 10-15nm rapid thermal oxide.

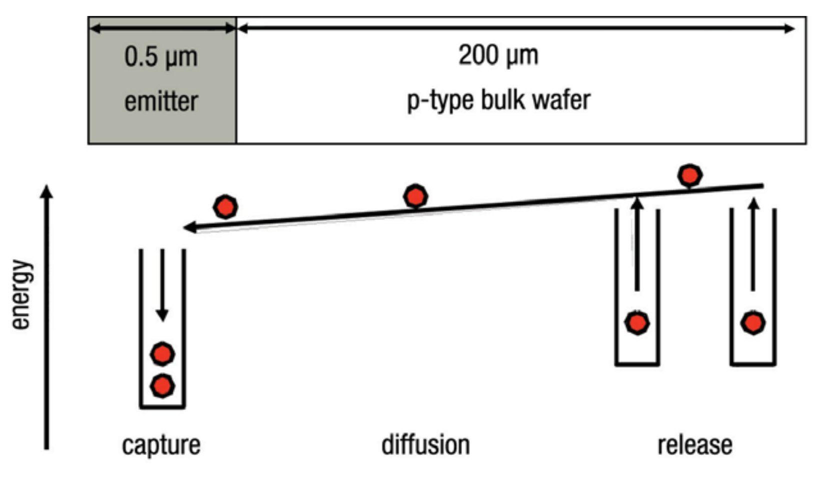


Figure 4. Sketch of the basic principle of diffusion-induced gettering of impurities.

3 shows the emitter saturation current J_{oe} as a function of sheet resistance. For the high doping case, i.e. low sheet resistances, the emitter J_{oe} is insensitive to surface passivation and hence it need not be applied. This explains why TiO_2 as a coating with almost no surface passivating characteristics can be used as AR coating as long as sheet resistances are in the 30Ω/sq range. However, for increasing sheet resistances, the emitter becomes sensitive to surface passivation allowing a significant gain in V_{oc}. Strictly speaking, it is the surface doping concentration C_s that drives V_{oc} in the passivated emitter case. The lower the C_s, the higher the V_{oc}. It is vital that solar cell manufacturers remain aware of their solar cells' front surface passivation quality if emitter doping is decreased.

(3) Being separated by the electric field in the space charge region, holes have to flow to the back contact through the silicon wafer, while electrons have to flow within the emitter layer to the nearest metal contact on the front. For standard solar cells featuring H-like contacts, the pattern metal fingers collect the current in the area while the busbars conduct the current. For low Ohmic resistive losses, a well conducting emitter layer is required, which purpose is served by using a rather high doping which in turn implies a low emitter sheet resistance. As a rule of thumb, we can say that the larger the finger spacing the lower the optimal sheet resistance. The roughly 2mm finger distance of standard solar cells usually yields 40 to 60Ω/sq.

(4) The biggest constraint on the emitter profile is placed by the screen-printed and fired-through silver pastes applied to the front. Due to the contact formation process, very high doping concentrations are required at the emitter surface. It has been proposed that chemical P concentrations in excess of the solid solubility are required by the pastes. In addition to this, high concentrations should be maintained down to approximately 100nm in depth. The reasons for these requirements are still under investigation. Initial studies on the underlying contact formation mechanisms haven been published recently [4,5,6]. Furthermore, the emitters need to be rather deep (>200nm), as metal contamination stemming from the paste can penetrate into the space charge region and poison its electrical characteristics. With respect to lateral homogeneity of the sheet resistance, the screen-printing process requires a uniformity = 100% x (Max-Min)/2 better than 5%. Missing this goal leads to poorly contacted wafer regions, thus reducing the overall cell performance.

From an engineering point of view it is important to know about these requirements as the resulting heavy and deep emitter doping massively downgrades the recombination properties. Relaxing these stringent requirements would yield significant gain in V_{oc} and J_{sc} (the latter due to improved blue response) and hence conversion efficiency. The good news is that all paste manufactures are currently working hard to resolve this issue. However, the diffusion people need to be prepared. If the paste manufacturers succeed, they have to have the right emitters available for full exploitation of the potential.

Obviously, requirements (1) through (4) contradict each other, making fine-tuning the emitter profile a complex task. Table 1 illustrates a summary of the requirements with respect to the desired surface doping, junction depth and sheet resistance. It is up to the engineers to experimentally optimize the profiles with respect to solar cell efficiency.

Condition		C_s	x_j	R_{sheet}
low Auger recombination		↓	↓	↑
surface passivated?	no	↑	↑	↓
	yes	↓	↓	↑
contact material	Ag paste	↑	↑	↓
finger distance	large			↓
	small			↑

Table 1. Overview of the various requirements regarding surface concentration C_S, junction depth x_j and sheet resistance R_{Sheet} of an emitter.

The selective emitter concept

Thus far we have discussed emitters with a laterally homogeneous doping. Why not provide different parts of the solar cell area with different doping and dissolve the contradicting requirements? This approach is commonly called the selective emitter concept. Selective means provide a highly doped, deep emitter below the metal contacts for good contact properties but a lowly doped, shallow one for improved recombination characteristics. Regarding the solar cells' characteristics, this concept promises high fill factors and high V_{oc}, as well as a good blue response (high J_{sc}). From a physical standpoint, this is the best possible emitter. In literature written on this topic, efficiency enhancements between 0.2% and 1% absolute have been demonstrated, simulated or calculated over the past decades. An estimated 20-plus different approaches and process sequences have been presented on how best to actually manufacture selective emitter solar cells. Some are feasible only in a laboratory environment; others are ready for production. However, so far the selective emitter concept has made it only in one or two solar cell production lines. Supposedly this is due to the higher cost and complexity brought to the table by additionally needed process steps and equipment. Obviously, these negative factors are not weighted off by a decent increase in conversion efficiency.

Interestingly, the old-fashioned idea of a selective emitter has seen a revival recently; many new technological approaches have been proposed of late. For example, local doping by a chemical liquid jet-guided laser [7], highly doped semiconductor fingers with perpendicularly crossing metal fingers [8] or local wet chemical etch back of originally highly-doped emitter [9] were presented at recent PV conferences. Solar cell manufacturers are continuously assessing whether any of the new concepts could actually bring a clear cost per Wp advantage.

Preferred diffusion processes of solar cells

Having discussed the correct emitter characteristics, let us now have a look at the diffusion process itself. In general, diffusion is a physical process transporting particles, e.g. atoms, from a region of higher concentration to one of lower concentration by random molecular motion. The latter relates to temperature and hence temperature is the biggest knob to manipulate the speed of a diffusion process. Eventually, diffusion will result in complete mixing or a state of equilibrium that for most practical applications is neither needed nor desired. Hence, temperature which was ramped up in the first place to make the diffusion process start is ramped down after a certain amount of time, practically ceasing diffusion. In fact, it would be desirable to freeze the concentration distribution as obtained at the diffusion temperatures.

In silicon, diffusion of many species can be well described phenomenologically, yet some of the underlying physics is not fully understood from a microscopic point of view. For example, the theory of P diffusion in Si is still under investigation. Kveder et al [10] propose a model where the main contribution to phosphorus diffusion at $[P] < 2 \times 10^{19} cm^{-3}$ comes from the kick-out mechanism, while at higher P concentrations the diffusion is dominated by phosphorus vacancy complexes. Their model nicely predicts the development of the well-known kink-and-tail profile for P diffusion as shown in Figure 1. It does, however, not predict the surface near supersaturation with electrically inactive P.

It is worth noting that their model enables the prediction of phosphorus diffusion-induced gettering (PDG) of (substitutional) metal impurities. For block crystallized multicrystalline silicon wafers, proper gettering is important for achieving high efficiencies since it effectively removes reminiscent contaminations like Fe, Cr and Cu from the wafer bulk [11]. Gettering helps to increase the carrier lifetime, thus enhancing the solar cell efficiency. As sketched in Figure 4, a gettering process consists of three steps: impurity release from its energetic binding, travel through the wafer by diffusion, and finally capture of the impurity where the emitter acts as a sink. From a solar cell's perspective, two things should be kept in mind. First, though the impurities gather inside the phosphorus emitter they are less harmful there than in the p-type bulk since its carrier lifetime is limited by Auger recombination anyway. Secondly, a proper gettering process asks for comparatively moderate temperatures. This is because the emitter capabilities of acting as a sink strengthen with decreasing temperature. On the other hand, the impurities make their way to the sink by diffusion which takes quite some time if temperatures are low. As a rule of thumb, proper gettering of multicrystalline silicon wafers should be performed below 900°C for several minutes to hours. In support of this statement, Figure 5 shows the mean bulk carrier lifetime of neighbouring block-cast multicrystalline wafers after phosphorous diffusion gettering at different temperature and time conditions. Following a 15-minute gettering process at 870°C, the carrier lifetime can be tripled compared to the as-grown wafer. However, for RTP-diffused samples where very short gettering times down to a few seconds were applied, little or no lifetime improvement is observed. Remarkably, for temperatures exceeding 900 to 950°C, a thermally-induced degradation of the carrier lifetime occurs. We suspect this to be caused by the dissolution of metal precipitates at elevated temperatures and their subsequent decorating of intrinsic defects like dislocations [1]. The temperature and time combination of an optimal gettering process depends on the specific defect spectrum of the multicrystalline silicon material to be improved and has to be found experimentally.

It should be noted here that for wafers made of monocrystalline silicon, gettering is far less important as it features significantly fewer harmful metal impurities. This eases the restrictions on diffusion temperature and time. In general, monocrystalline can be diffused at any temperature and time, giving you the chance to speed up the diffusion process and thus increase the throughput of a diffusion system [1].

Manufacturer's choice: diffusion equipment

Making use of solid-state diffusion of impurities for doping purposes has been one of the old-fashioned processes applied in semiconductor device fabrication for many decades. While in memory and logic chip fabrication diffusion has been replaced by ion implantation plus activation step (where no diffusion must occur), it is still the state-of-the-art doping technique used in silicon solar cell production lines. According to the author's view, this is likely to remain so for the next few years. With modern equipment, the cost of ownership is well below 10 €cent per wafer. In general, two technological solutions are available for emitter diffusion.

The traditional solution is the resistance heated quartz furnace utilising $POCl_3$ as a source of phosphorus. This approach was borrowed from the semi industry many years ago and has been elaborated ever since according to the PV industry's requirements. The throughput of modern five-stack furnaces has been increased up to 1500 wafers (6-inch) per hour sorting the wafers in a back-to-back mode into boats made of quartz or SiC. Currently, the boats' slot spacing is 4.76mm in order to obtain the desired <5% lateral doping homogeneity. However, by the application of diffusion at reduced process pressure, the slot spacing can be halved without sacrificing lateral homogeneity [12,13]. Theoretically this enables twice the throughput. Special wafer handling equipment has been developed for boat loading that minimises handling-induced wafer breakage.

In contrast to the batch-type quartz tube furnaces, dedicated in-line equipment was developed in recent years to meet the industries' demands of highest throughput, low breakage rates and improved lateral doping homogeneity. Any in-line diffusion system consists of two units. One unit is meant for deposition of the phosphorous source on the silicon wafers' surface, e.g. spray-on of P-containing liquids. The second unit serves for the actual diffusion of P from

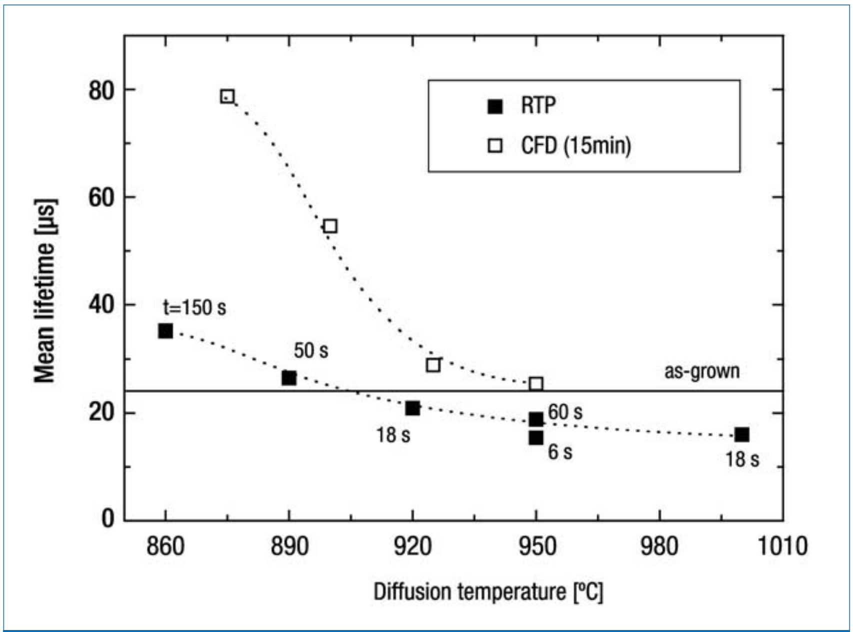


Figure 5. Mean bulk carrier lifetime of neighbouring block-cast multicrystalline wafers before and after phosphorous diffusion gettering at different temperature and time conditions. RTP was carried out applying a P spin-on source. The diffusion times are given next to the measurement points. Conventional diffusion was performed in a quartz tube furnace using $POCl_3$ for 15 minutes. Prior to lifetime measurement, the diffused layers were etched off and the wafer surfaces were passivated by SiN.

the source into the wafer. It consists of a more or less thermally isolated channel heated either by means of tungsten IR lamps or resistively. The majority of the transportation of the flat lying wafers through the furnace is achieved by a metal belt. As alternatives, metal-free and low-mass techniques featuring ceramic rollers or strings working according to the walking beam principle have been developed [14]. These novel transport systems minimise metal contamination and allow the realization of high heating and cooling rates, which help to reduce the length of such systems. It is up to the customer to decide on the appropriate combination of P source, heating method and transportation system. The throughput of current in-line diffusion systems is in the range of 1500 wafers per hour depending on furnace length and the number of tracks [15]. It has to be noted that for in-line systems, throughput is driven mainly by the required diffusion time. Increasing the diffusion time of a given system, for example for gettering reasons, will inevitably lower throughput.

This is a close competition between batch and in-line systems. Taking the pros and cons into account does not present any clear favourite for this process. It seems that deciding for either of them depends on a company's history and philosophy regarding automation.

Summary

Formation of the pn-junction by phosphorus diffusion is one of the key processes of modern solar cell production. The phosphorus emitter serves many purposes: separation of charge carriers, provision of lateral conductivity and provision of good contacts to screen-printed Ag contacts. All of this has to be achieved with an emitter profile exhibiting low carrier recombination characteristics within the emitter bulk and at its surface. For multicrystalline silicon solar cells, the applied diffusion process also needs to provide efficient gettering of impurities. Elaborated diffusion equipment and optimized processes are available to fulfil these requirements.

Nevertheless, current diffusion equipment needs to be improved continuously in order to meet the 10% cost of ownership reduction per year target as imposed by the German feed-in tariff. Therefore, scaling-up of such systems to the limits is the right way to go. However, in doing so, the electrical quality of the diffused emitter must not suffer and has to be monitored carefully. Additionally, future diffusion equipment must be suited for the formation of high Ohmic emitters exhibiting low surface near doping concentration while maintaining excellent cross wafer and wafer-to-wafer uniformity.

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Current and future metallization challenges and solutions for crystalline cell manufacturing

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ABSTRACT

In any solar cell process, the metallization step is critical as it often sets conditions and limitations for the other process steps. The main metallization technique used today in Si solar cell production is screen-printing of metallic pastes; namely, Ag pastes for the front side, Al pastes for most of the rear side, and Ag or Ag-Al pastes for the solder pads at the rear. While these techniques are clearly robust and convenient, they have limitations. Therefore, alternatives are being investigated. A technique that is presently finding its way into production is two-step metallization with Ag plating. Another more radical approach is to avoid printing altogether, instead using some kind of ablation followed by plating. For the rear, the full Al-BSF is being replaced by dielectric passivation and local Al-alloyed contacts. Back-contacted cells are increasingly being introduced in production, and they pose very specific challenges to metallization. For the sustainability of Si photovoltaics, it is crucial that the future metallization solutions only make use of abundantly available and non-toxic materials.

Introduction

Thick-film metallization by means of screen-printing is the contacting technique employed by more than 85% of photovoltaic solar cell manufacturers. The majority of solar cells produced worldwide are fabricated using silver thick-film contacts on the front and aluminum thick-film contacts on the rear side. In addition, solder pads on the rear are formed using Ag and Ag-Al pastes. A process simplification in the front and rear contact formation was enabled by the development of the silicon nitride firing-through process of the front side Ag paste and the formation of the back surface field (BSF) by an Al paste during the same firing step. This has elevated screen-printing to be classed as one of the key process steps in silicon solar cell manufacturing.

> "Back-contacted cells are increasingly being introduced in production, and they pose very specific challenges to metallization."

The demand towards high-efficiency and low-cost solar cells has increased the research effort on thick-film contact formation processes and pastes in the past decade. Nevertheless, further reduction of the price/Wp requires processes on larger and thinner wafers with higher throughputs. In this framework, novel cell concepts, such as metal wrap-through (MWT), emitter wrap-through (EWT), back contact (BC) and silicon heterojunction (SHJ) have been developed. Finally, material availability for future gigawatt production drives the contact development towards alternative metallization techniques adapted from microelectronics and modified for the needs of the solar cell industry.

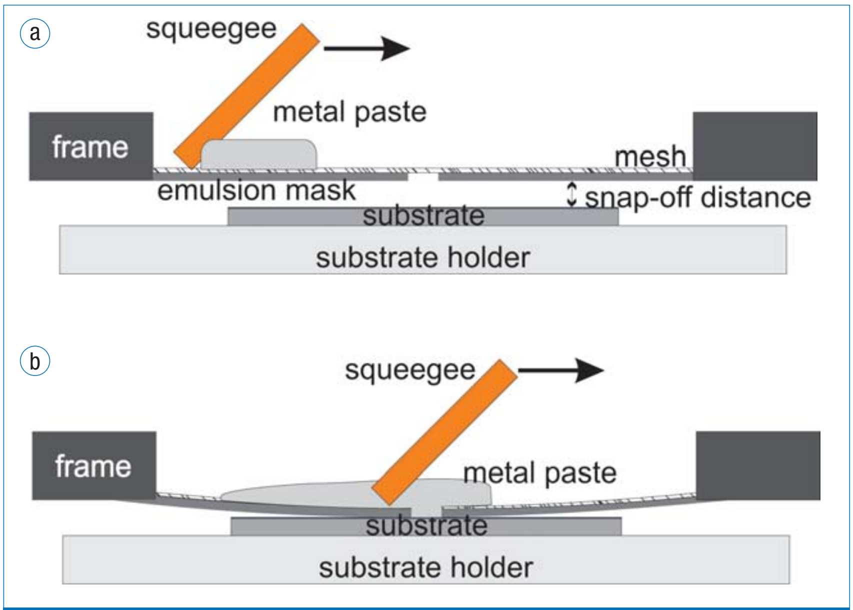

Figure 1. Schematic illustration showing (a) non-contact screen-printing, and (b) in-contact screen-printing of a metal paste.

State-of-the-art

Screen-printing (see Figure 1) is established in high throughput solar cell manufacturing as a reliable metallization technology. The front side grid is printed in one step while the rear side is contacted by a full area-covering Al paste and a following Ag/Al contact pad, both of which are applied by screen-printing. The applied screen-printing pastes are soft-baked in a conveyor belt furnace. The contact formation is performed in a high temperature process using a firing furnace. In industrial applications, screen-printing lines can reach throughputs of 1500-2000 wafers/hour, with a typical line width of 100 to 150µm.

The printing process consists of three single steps, illustrated in Figure 1. In the first step, the screen is covered with paste by moving a squeegee over the surface of the screen-printing mask in the filling phase. Secondly, the squeegee moves over the screen, again applying an additional vertical force that presses the screen on the wafer and the paste through the meshes of the mask. In the last step the mask is lifted, creating distance to the solar cell's surface, which is known as the snap-off distance. The printing process is determined by the following parameters: printing speed (squeegee speed), squeegee pressure and snap-off distance. The screen-printing quality is determined by the printing parameters, the screen-printing paste and the screen quality.

Silver paste is the most commonly used material for front side metallization of silicon solar cells. Although a large variety of silver pastes is commercially available, the composition is rather similar. The pastes consist of silver particles, solvents, glass frit and binding agents.

Ultimately, the goal of the contact formation is a good adhesion, a high aspect ratio, a high line conductivity and a low Ohmic resistance between the contact and the highly-doped emitter layer. The shape of the silver particles can vary between flakes and spheres and are in the order of 1-10µm in size. The trade-off in the choice of the particles' shape and size is either the density being too high or the formation of agglomeration. The latter leads to clogging of the screen and could be avoided by providing sufficient large screen openings (where the opening is approximately five times larger than the particle size). Other compromises are decided upon by defining the viscosity and the relaxation time, which is the paste's or another system's need to return from low viscosity back to high viscosity.

The lead-oxide silicate glass frit is responsible for adhesion, contact formation and line conductivity. It provides the penetration through the SiN_x layer, assists silver crystallization and reduces the melting point of silver.

Contact formation is performed using an inline firing belt furnace with different heat zones. In first heat zone the solvents are evaporated at maximum temperatures of 300°C. The temperature is ramped up to 500°C in the second heat zone, at which point the organic binders in the paste are burned. In the next heat zone, the contact is formed by applying fast temperature ramping between 800 and 900°C. The high temperature is applied for up to five seconds and subsequently cooled down to room temperature.

Aluminum-containing pastes are most often used for the rear side contact. By firing the paste into the silicon at high temperatures – a step that is performed simultaneously with the front side contact – a BSF is formed. A thickness of approximately 20µm of aluminum is required for the BSF formation to take place correctly.

Two-step metal process

As an alternative to the state-of-the art metallization technologies, an interesting concept is the two-step metal process. This process is based on the idea of first applying a thin metal seed layer to create a good Ohmic contact between the metal and the semiconductor and subsequently applying a thick highly conductive metal layer. In this way, the amount of freedom of optimization of both the properties of the solar cell contacts and the underlying emitter is enlarged. The thin seed layer is optimized to contact a lowly-doped emitter, with a surface dopant concentration of $1x10^{19}cm^{-3}$. This seed layer can be, for example, a silicide that has good electrical and mechanical properties. Decreasing the doping level of the emitter, compared to a profile suited to be contacted by screen-printing, will most importantly result in enhanced surface passivation and will lead to higher energy conversion efficiencies.

> "The shape of the silver particles can vary between flakes and spheres and are in the order of 1-10µm in size."

The second metal layer needs to be optimized to be highly conductive, so the natural choice for this material is silver or copper. For front contacted solar cells it is important that a narrow seed layer is deposited and that the subsequently applied thick metal layer will not cause too much widening of the contacts compared to the width of the seed layer, such that a low degree of shadowing underneath the contacts can be achieved.

Metallization based on silver

A first implementation of the two-layer concept for front side metallization is based on fine line printing in combination with (light-induced) silver plating. Using this kind of process most resembles the traditional screen-printing of silver. There are several techniques under investigation for application of the thin seed layer by printing means. Advanced screen-printing, inkjet printing, pad printing, aerosol jetting and sintering of metal powder will be discussed later.

Advanced fine-line screen-printing

Advanced fine-line screen-printing is the metallization method most related to traditional screen-printing. Using hot melt ink instead of traditional paste is one way to reduce the line width of the applied fingers [1]. This type of ink is solid at room temperature and is printed at temperatures in the range of 50 to 80°C by heating the screen and the squeegee, a process that has resulted in demonstration of metal lines as narrow as 60µm. Application on the solar cell level results in increased efficiencies compared to standard screen-printing with fill factors up to 80.6% [2].

Inkjet printing

An emerging method of printing a metal seed-layer for solar cells is inkjet printing. This method has the capability to print very narrow lines and is a non-contact technology, thus ideally suited to printing on thin substrates. Most of the research carried out so far has been focused on direct printing of the complete metallization pattern; in this case, however, multiple printing is needed to obtain a sufficient thick and conductive metal layer [3,4]. A key element of this process is the development of a suitable ink as the viscosity of the ink should be sufficiently low in order to be printable.

Pad printing

Pad printing is a metallization technique based on gravure offset printing. The metallic ink is spread out on the cliché, the template with the imprinted image, after which the patterned ink is transferred to the substrate by using a silicone pad. This method allows for fine-line printing of well below 50µm, has the potential for high throughput, and is compatible with current solar cell technology since similar metal pastes can be used to apply the contact [5,6,7]. Depending on the type of pad, the method can be suited to thin and uneven wafers. A disadvantage is that the paste transfer from the template to the wafer is rather limited, giving rise to a relatively thin metal layer. Using the pad-printed line as a seed layer subsequently thickened by metal plating is a promising solution and has so far resulted in efficiencies of 17.9% on $10x10cm^2$ CZ c-Si substrates [8].

Aerosol jet printing

Another interesting method for seed layer deposition is aerosol jet printing [9]. In this case, the metal-containing ink is converted into an aerosol, a colloid with small sized metal particles suspended in a gas. In order to be able to print thin lines of metal, the aerosol is focused onto the substrate by an additional gas flow. This method allows for printing of very narrow line features down to a width of 14µm. Furthermore, it is shown that the line width is constant on uneven surfaces and is well-suited for very thin and fragile samples. Even so, the printed metal line can still be fired through a layer of silicon nitride when using slightly modified standard metal pastes. Using aerosol jet printing of a silver seed layer in combination with light-induced silver plating to thicken the layer, a solar cell efficiency of 20.3% has been reached on float zone silicon wafers [9]. Aerosol jet printing can also be combined with hot melt ink to further enhance the properties of the deposited metal lines [10]. An aerosol printer has recently been developed that can print a solar cell every 2.5 to 3 seconds [11].

Laser micro-sintering

Laser micro-sintering is a technique whereby a metal powder is distributed over the wafer area. Subsequently, the powder is locally heated by a laser [12], such that the metal powder will melt locally. As a result, a thin metal seed layer is obtained, which can have a line width of less than 30µm. During the laser sintering process, the metal also penetrates through the dielectric passivation layer. Care should be taken to avoid shunting of the solar cell, as in some cases the metal might move too deep into the silicon. Advantages of this metallization method are the reduction in thermal budget of the complete process, the applicability on thin and fragile samples, easy recycling of remaining metal powder and a reduction in contact resistance compared to printing techniques where a metal paste is used. In the case of first realized solar cell structures, a best cell efficiency of more than 14% has been reached using tungsten as the seed layer metal, where the chosen high-doping level of the emitter is the main reason for the limited performance [12].

On top of the applied seed-layer, a thick highly conductive layer can be deposited by silver plating [13,14]. This can be electroless plating, electro-plating or light-induced plating. The main advantage of light-induced plating, where the current generated by the illuminated solar cell itself is used to plate the metal, as opposed to classical electro-plating, is that the front contact grid does not have to be contacted, thus simplifying the wafer handling. In the first instance, silver is a well-suited metal to the process as no barrier layers

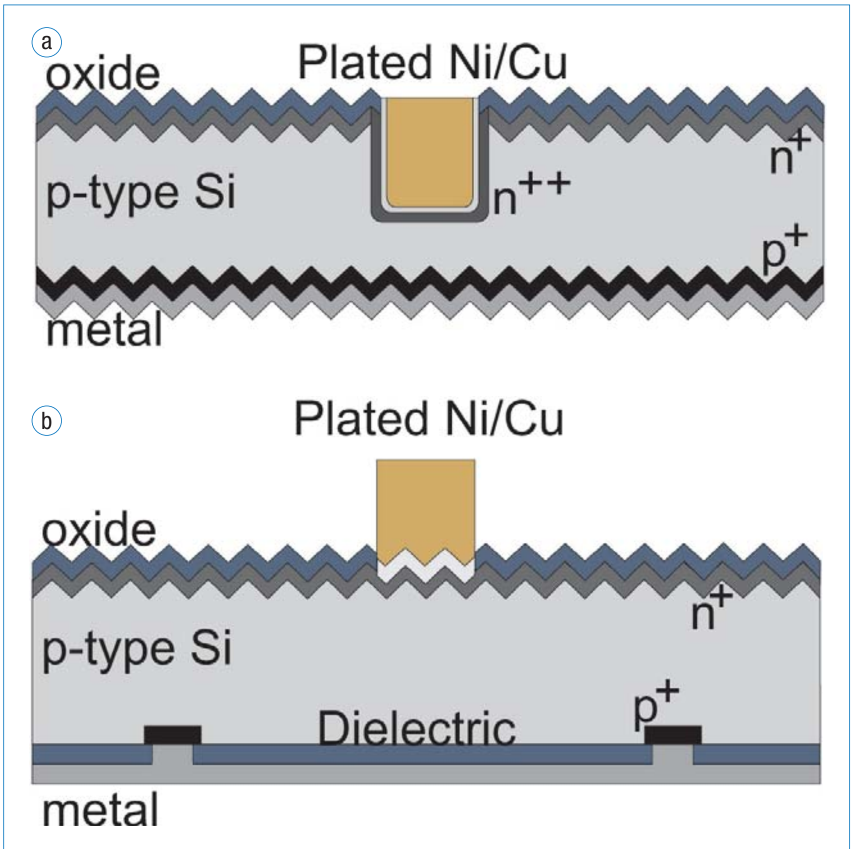

Figure 2. Illustration of different cell concepts using the two-metal-layer concept, showing (a) a buried contact solar cell, and (b) a cell with laser ablated openings in the dielectric layers in combination with a self-aligning metal plating process.

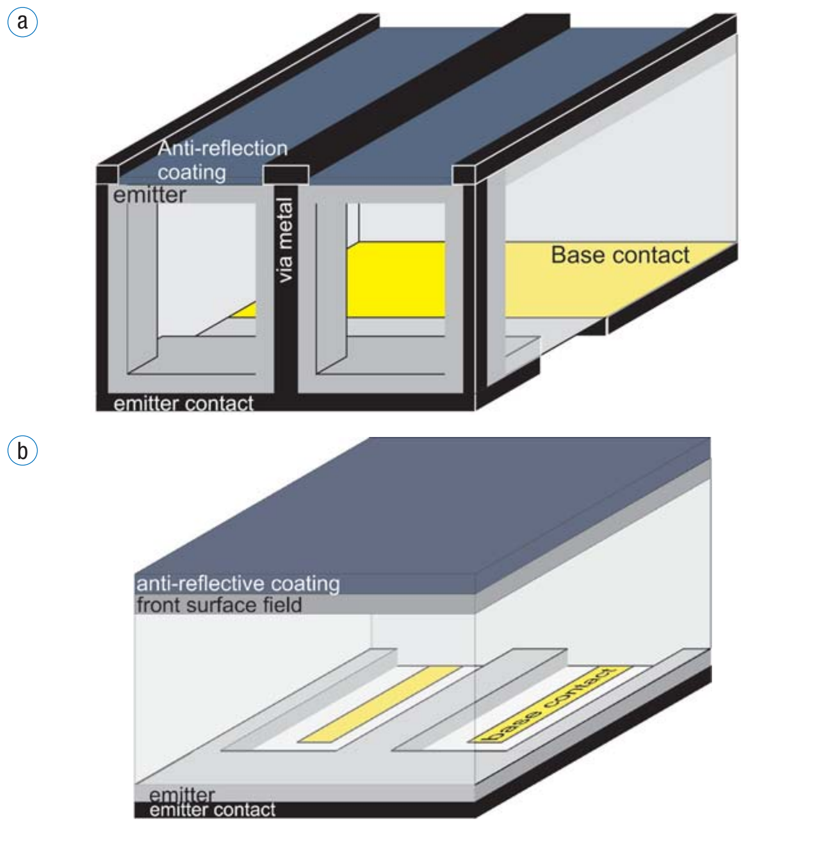

Figure 3. Schematic illustration of back-contact solar cell concepts, showing (a) a metallization wrap-through cell (MWT), and (b) a cell with interdigitated back contacts (IBC).

are needed in this case to prevent silver diffusion into the silicon. Of late, special chemical solutions, both cyanide-based and cyanide-free, are being optimized for solar cells, especially for light-induced plating where clear solutions are needed to allow for the illumination of the solar cell.

Metallization based on copper

A second more radical implementation of the two-layer concept is the application of the seed layer by electroless plating and subsequent combination with copper or silver (electro)plating (see Figure 2). It is expected that, in the near future, copper will be used more and more for silicon solar cells due to its lower cost relative to silver [15]. The metal seed layer can be converted into a silicide, which will be beneficial in terms of adhesion and can also serve as a barrier layer against copper diffusion.

A well-known concept using a layer of plated nickel and copper is the buried contact cell process [16,17,18], shown in Figure 2a. In this case, for example, 40μm-deep contact grooves are realized at the front of the cell by mechanical abrasion, which can be done by using a 15μm-thin dicing blade [19]. The contact grooves can also be made by application of a laser [16]. In this way narrow contact lines are created, which results in decreased shadow losses compared to screen-printed contacts. Since the grooves are made after surface texturing, emitter diffusion and deposition of the dielectric, a selective emitter can be made relatively easily by performing a heavy second diffusion, where the dielectric serves to protect the area outside the grooves. Nickel is electroless-plated in the grooves and on the rear of the cell. Subsequently it is sintered to create the silicide that prevents copper diffusion into the silicon and to improve the adhesion properties. Finally, a thick layer of copper is plated on top of this seed layer. Due to the narrow buried contacts, this high efficiency process allows for an industrial implementation on both mono- and multi-crystalline substrates, and has so far resulted in a large area efficiency of 17.5% [19] and 18.1% [18] on multi-crystalline 156.25cm^2 and 137cm^2 substrates, respectively. Even lower optical losses are expected for angled buried contact cells, where the groove is made under an angle in order to maximize the optical properties of this cell design [18].

A more recent application of plated nickel and copper (or silver) contacts has been triggered by the development of new laser technologies (see Figure 2b). Instead of making a deep groove, a dedicated laser process, using a picosecond laser, is used to ablate the dielectric front surface layer without creating relevant damage to the emitter [20]. After locally removing this anti-reflection coating, the nickel seed layer can be grown selectively on the bare silicon areas, while no deposition will take place on the dielectric. The nickel seed layer can then be converted into a silicide by thermal treatment. The metal contact will be finalized by electro- or light-induced plating of copper. As an alternative to laser ablation, photolithography [21] and inkjet masking [22,23] are used in combination with wet-chemical etching to locally remove the dielectric. Using a lab-scale process to show the feasibility of the electroless nickel plating and copper plating has resulted in best cell efficiencies of 21.4% on FZ-Si with a cell area of 45.75cm^2 [21].

Metallization for back-contact cells

Contact formation for back-contacted solar cells imposes specific demands on the metallization concept.

In the case of the well-known metallization wrap-through structure (MWT) (see Figure 3a), the metallization is very specific as it is the only back contact cell structure that has metal grids of the same polarity both on the front and rear surface of the cell. The interconnection of the grids through small holes in the cell is easily done by technologies like screen-printing or plating; it is expected that the new developments would be able to perform equally as well.

For all back-contact structures, such as that shown in Figure 3b, large-scale implementation ultimately relies on a low-cost way of contacting regions of different polarities with tight tolerances on the rear surface of the cells. Particularly for back junction concepts, this is very challenging as the concept imposes that the base-contact regions are sufficiently small to maintain a high collection probability, whereas the need for majority carriers to flow through the base towards these contact regions imposes a high density of these regions. The lateral current of majority carriers through the base of the cell also occurs at the location of the connection pads of the emitter area. These pads must have a sufficiently large area to connect electrical leads to it, but it pays to reduce their width as much as possible.

The use of photolithography throughout the processing permits for the definition and alignment of contact windows and regions without excessive shunting. It also relatively easily allows for separating the actual contact area and the real metallization coverage of the rear of the cells, keeping a large part of the metal-covered area at the rear of the cell separated from the semiconductor by use of a dielectric. However, processes with multiple aligned lithographic steps can hardly be applied in a high-throughput production line. For traditional screen-printing on the other hand, the act of forming several metal grids on a single surface with very tight tolerances of line width and spacing is extremely challenging. This is even more stressed for successive metallizations on the same surface, as the height of the deposited pattern during the first print tends to make the second print less accurate. The latter can be resolved by contactless methods that are being introduced to replace screen-printing, such as metal jetting. The conductivity of both the base and emitter metallization has to be sufficiently high to limit an increase of series resistance invoked by replacing the full coverage of the former metallization with a gridded structure. This leads to the use of highly conductive materials for both contact grids.

Whereas silver could be used for both contacts, the cost related to the abundant use of Ag would be prohibitive of its use. Plating of Cu as a relatively low cost and highly conductive material onto a layer that acts as an electrical contact and diffusion barrier for the metal into the semiconductor could resolve this problem. Plating technologies such as light-induced plating that are being investigated for conventional cells, however, will hardly be applicable when the metal is expected to be built up on both polarities at the same time. The latter will rely much more on the background knowledge that has been built up in the back-end technology of semiconductor processes on the use of formation of seed layers and subsequent electroplating.

Sustainability issues

In order to be consistent with mass production with low environmental impact, the sustainability of the selected metallization solutions has to be considered carefully. Firstly, the materials used should be available in the huge amounts required, an aspect that is closely linked with the materials' cost. A shortage of a substance on the world markets immediately results in a sharp cost increase. Al is abundantly available and therefore poses no problem. The long-term availability of Ag, on the other hand, is a subject of debate. Some studies indicate that the consumption of Ag by the photovoltaic industry will be such that the need will exceed the available resources by 2040 [24]. Others point out that the large volumes of Ag previously used in the photographic industry are now available for the photovoltaic industry. In any case, it is clear that recycling of this precious metal will become mandatory for a Terawatt industry.

The main components of the metallic screen-printing pastes, Ag and Al, are non-toxic. However, the pastes do contain non-negligible amounts of toxic substances. Cadmium was a common ingredient in the past, but has now disappeared from most commercial pastes. Lead, however, is difficult to replace. The PbO in the glass frit gives the pastes the property of firing through silicon nitride, and for replication of this property, no straightforward substitute has been found. Bi is used in some pastes, but it is more expensive and not yet considered quite as effective as Pb. It should be noted that photovoltaic panels are presently exempted from the European RoHS Legislation (Reduction of Hazardous Substance) that would otherwise exclude the use of Pb in solar cell production [25]. This is not conducive to a quick phase-out of Pb in metallization pastes.

The introduction of plating in solar cell production poses an additional environmental challenge. To be environmentally acceptable, plating solutions need to receive appropriate treatment after use, which adds to costs. Plating solutions that generate small volumes of waste per volume of deposited metal (e.g. galvanic plating) therefore have an advantage over other plating techniques.

Summary

Crystalline Si solar cells are likely to continue to dominate the photovoltaic industry over the next two decades. At the moment, screen-printing of Ag and Al pastes is the most widespread technique, albeit a technology that is reaching its limits in terms of performance and throughput. Plating is starting to find its way into the industry, initially as a means to improve the conductance of screen-printed contacts, but in the longer term as part of alternative metallization techniques that will involve totally new process sequences. For the sustainability of Si photovoltaics, it is crucial that the future solutions only make use of abundantly available and non-toxic materials.

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Spectroscopical analysis of wet chemical processes

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ABSTRACT

Crystalline silicon solar cell fabrication involves many wet chemical process steps. Like most processes in solar cell manufacturing, many of these wet chemical processes were transferred from the semiconductor industry. In contrast to microchip fabrication with maximum throughputs of 100 wafers/hour, state-of-the-art solar cell equipment relies on several 1,000 wafers/hour. Furthermore, specific processes have been developed for the texturisation of the wafer surface. Therefore, there is a need for dedicated methods of characterization of these wet chemical processes. Fraunhofer ISE has developed several analytical methods such as titration, ion chromatography and near infrared (NIR) spectroscopy for the complete analysis of the chemical composition of wet chemical processes baths. These methods were compared considering the inline/online capability, measurement cycle and running costs, with the result that NIR spectroscopy was identified as a complex but very powerful tool for process characterization, as outlined in this paper.

Introduction

Quality control methods gain more and more importance throughout the production chain of crystalline silicon solar cells. For most of the relevant process steps, control measurements of changing wafer or process conditions have to be taken at least in a batch-wise mode, as the process conditions can typically be kept quite stable, with the only changing parameter being the wafer material itself. Control of emitter diffusion processes may serve as an ideal example, where the resulting emitter sheet resistivity typically does not change instantaneously.

For wet chemical processes, this picture is becoming more complex. In typical etching processes, e.g. for texturisation, it is not only anticipated that the process conditions will change during the course of the process, but that the bath constituents themselves might also change as more and more silicon is dissolved into the bath.

As an example, the dissolution of silicon and formation of hexafluorosilicic acid

(H_2SiF_6) in an acidic etching mixture is shown in the following equation:

$$3Si + 18HF + 4HNO_3 \rightarrow 3H_2SiF_6 + 4NO + 8H_2O$$

While the silicon removal per wafer, e.g. the etching rate, can be also adjusted in certain process latitudes by variation of the bath temperature, the etching properties depend mainly on the concentrations of HF, HNO_3 and H_2SiF_6 [1].

Additionally, bath constituents such as alcohol are present in alkaline texturing processes, and are in turn lost due to evaporation into the exhaust system as a result of their low vapour pressure. Exact online control and knowledge of the bath constituents are in this case mandatory to stabilize the etch quality.

Another important motivation for exact etching bath control is the determination of the end-of-bath-lifetime, e.g. the determination of the critical bath lifetime after which it is impossible to maintain the etching properties only by redosing with fresh chemicals. Therefore, the exact knowledge of the bath constituents allows the maximum usage of the involved chemistry.

Constant process monitoring in silicon solar cell production features several wet chemical processes of note. For the fabrication of standard screen-printed industrial solar cells, there are a number of relevant wet chemical processes, mainly for texturisation and cleaning purposes. While one-component systems like pure HF for oxide removal are easy to monitor, – i.e. by conductivity measurement, typical texturisation processes are, due to the number of constituents, much more complex.

For acidic texturisation of multi-crystalline silicon wafers, typical mixtures involve amounts of hydrofluoric acid (HF), nitric acid (HNO_3) and water [2]. There have been cases where mixtures featuring additional additives such as phosphoric acid (H_3PO_4) [3], acetic acid (HOAc) [3] and sulphuric acid (H_2SO_4) [4] have been used.

In alkaline random pyramid texturisation for monocrystalline wafers, a base like potassium hydroxide (KOH) or sodium hydroxide (NaOH) and an organic additive like isopropanole (IPA) are used [5].

In addition to these processes, recently developed high efficiency cell concepts require several additional wet chemical process steps like advanced cleaning processes, chemical edge isolation or single-side oxide removal processes. In order to obtain continuously stable and reproducible process results, a reliable monitoring of the bath concentrations is essential.

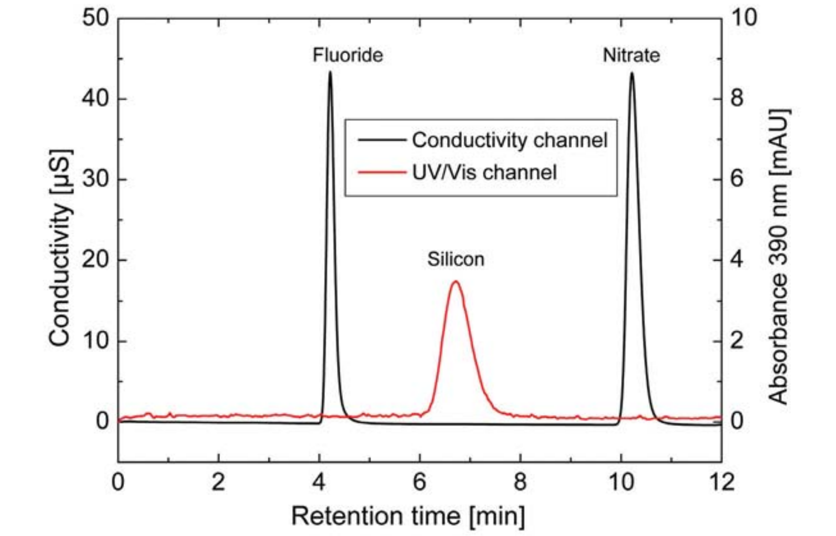

Figure 1. Chromatogram of a mixture of HF, HNO_3 and H_2SiF_6.

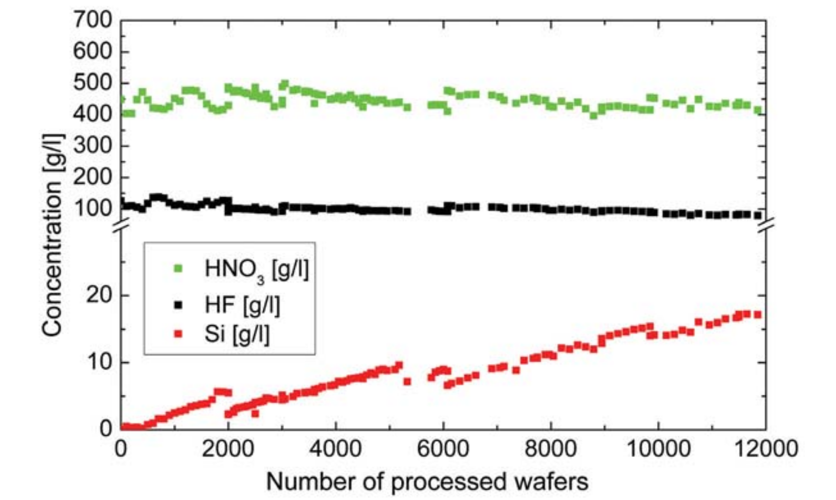

Figure 2. Development of the concentrations of HF, HNO_3 and H_2SiF_6 during the texturisation of 12,000 mc-si wafers.

	J_{sc} [mA/cm^2]	V_{oc} [mV]	FF [%]	η [%]
Average	31.6	604	76.9	14.7
Relative Standard Deviation	0.3%	0.9%	0.6%	1.5%

Table 1. Solar cell results for 100 neighbouring mc-Si solar cells.

State-of-the-art analysis techniques

Titration

A very well known and robust method for the determination of ionic species is titration, a versatile method that is suitable for the determination of the main components in almost all wet chemical process baths. For the alkaline texturisation bath, the concentrations of alkaline hydroxide, alkaline silicate and alkaline carbonate can be measured in one single titration.

The concentrations of ammonium hydroxide (NH_4OH) and hydrochloric acid (HCl) in cleaning processes can be detected by pH-titration; the content of hydrogen peroxide (H_2O_2) is measurable by a potentiometric titration with potassium permanganate ($KMnO_4$).

In acidic texturisation baths hydrofluoric acid (HF), nitric acid (HNO_3) and the reaction product hexafluorosilicic acid (H_2SiF_6) are accessible via titration [6,7]. Due to the similarity of the pKa-values of the four acids – H_2SiF_6 is a divalent acid – the determination of the three concentrations has to take place in two steps. In the first pH titration, the total acid amount and the concentration of hexafluorosilicic acid are measured. The second step is a potentiometric titration, where lanthane nitrate ($La(NO_3)_3$) is used to precipitate the fluoride ions. The decreasing fluoride concentration is monitored with a fluoride ion sensitive electrode (F-ISE), while the total consumption of the present fluoride ions appears as an inflection point in a graph, where the potential of the F-ISE is plotted against the volume of $La(NO_3)_3$. The concentrations of HF, HNO_3 and H_2SiF_6 can be calculated from the total acid amount, the concentration of dissolved silicon and the total fluoride concentration from the second titration.

Ion chromatography

Another method for the determination of main components is liquid chromatography. In this process, the sample is injected in a liquid mobile phase, which is pumped through the chromatographic column, where the species are separated. A detector on the column outlet detects the arriving particles; the signal intensity is proportional to the component's concentration.

Organic additives like isopropanol can be separated in a high performance liquid chromatography (HPLC)-System and measured in a refractive index detector. The anions and cations of acids and bases are separated in ion exchange columns and quantified via electrical conductivity measurement.

The measurement of the silicate concentration is more difficult, particularly with regard to acidic texturisation baths, since silicic acid is a very weak acid and shows nearly no intrinsic conductivity. One possibility is the precipitation of H_2SiF_6 with potassium chloride in cold ethanol [8]. The precipitate is then dissolved and hydrolyzed in a sodium hydroxide solution. The hexafluorosilicate concentration is then measured indirectly via the fluoride amount. The precipitation is a very time-consuming and labour-intensive procedure and as a result is not a suitable technique for use in routine analysis.

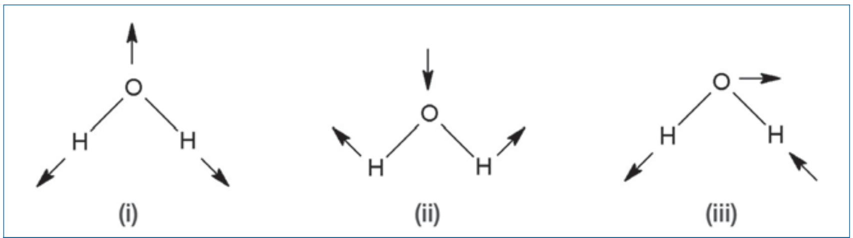

Figure 3. Normal vibration modes of the H_2O-molecule.

A more practicable approach is the postcolumn derivatisation of silicon [9]. After passing the electrical conductivity measurement cell, a derivatisation reagent is added to the eluent flow. The silicic acid reacts with sodium molybdate; the resulting molybdosilicic acid is a yellow complex, which can be detected in a UV/Vis-detector at 390nm.

Figure 1 shows a chromatogram of an acidic texturisation solution, recorded with postcolumn derivatisation. The black graph shows the conductivity channel while the red graph shows the absorption at 390nm after the derivatisation reaction. Fluoride ions from the hydrofluoric acid and nitrate ions from the nitric acid appear as peaks in the conductivity channel at retention times of 4.1 minutes and 10.1 minutes, respectively. The silicon peak arises at 6.6 minutes in the UV/Vis channel.

The capability of this system was tested in the photovoltaic technology evaluation center (PV-TEC) at Fraunhofer ISE during the texturisation of 10,000 multicrystalline silicon wafers. This texturisation process took place in an inline saw damage etching tool with a bath volume of 170 litres. During the texturisation process, labelled and neighbouring mc-Si wafers (format: 156 x 156mm²; thickness: 240µm; resistivity ρ = 0.5 – 2.0 Ωcm) were etched after each 120

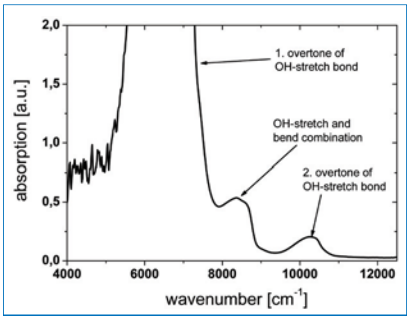

Figure 4. Near-infrared spectrum of pure water.

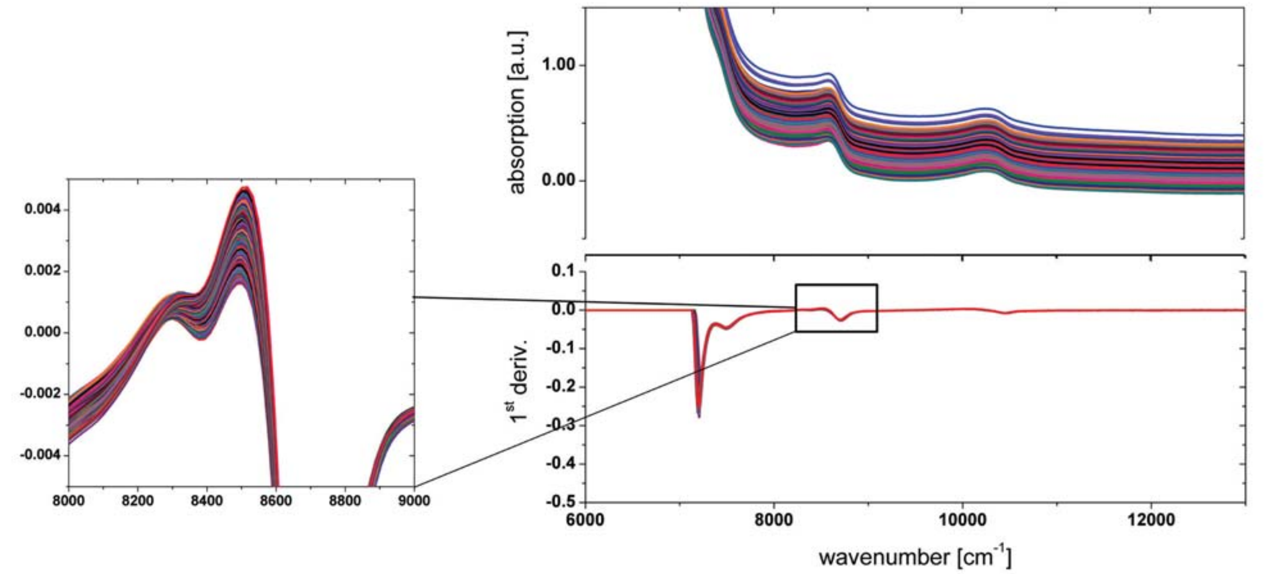

Figure 5. Calibration dataset of 661 near infrared spectra with different concentrations of HF, HNO_3 and H_2SiF_6. The baseline shift in the original spectra is eliminated by calculating the first deviation. The chemical information remains in slight differences in the peak regions of the spectra.

wafers. A sample of the etching solution was taken for each labelled wafer. Figure 2 shows the concentration plot for the main components in the etching bath. The HF- and HNO_3-concentration were kept constant, while the silicon concentration increased. The labelled wafers were processed as solar cells (the main parameters of the illuminated current-voltage measurement are shown in Table 1). The low relative standard deviation of the cell parameters is an indicator of a stable texturisation process.

NIR spectroscopy: a real inline measurement technique

Principles of NIR spectroscopy

A widely used method for the process control in pharmaceutical and chemical industries is NIR spectroscopy [10]. This measurement principle is based on the observation of vibrational-spectral transitions between energy levels that differ by two or more vibrational quantum number units. According to the quantum mechanical model of the harmonic oscillator, these transitions are not allowed, but, due to the anharmonicity of real molecular oscillator systems, overtone and combination bands are observed in the wave number range between 4,000 and 12,500cm^{-1}.

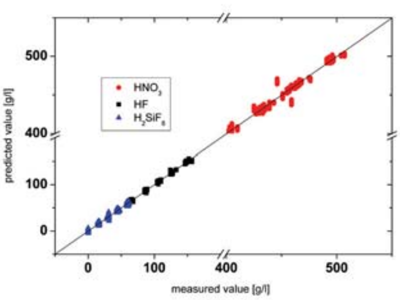

Figure 6. Calibration curve for H_2SiF_6, HF and HNO_3.

One such oscillation system is the water molecule, which contains two OH bindings so that three different vibration modes are possible. The first mode is a symmetric stretch vibration (Figure 3(i)), the second is the bending mode (Figure 3(ii)), and the third is the asymmetric stretch mode (Figure 3(iii)) [11].

Figure 4 shows an NIR spectrum of pure water at 20°C with a path length of 0.375 inches. Three bands are visible: the first overtone of the OH stretch bond at 6,500cm^{-1} (which cannot be completely resolved at the given conditions); the OH stretch and bend combination at 8.300cm^{-1} and the second overtone of the OH-stretch bond at 11,000cm^{-1}.

It is known that many inorganic components like hydrofluoric acid (HF) or potassium hydroxide (KOH) do not show any infrared active vibrations. As these components are completely dissociated in aqueous solutions, the resulting (respective) fluoride ion and potassium ion are monoatomic ions where vibrations are not possible. Others like the nitrite ion have vibrations with very low excitation energies, thus the bands do not occur in the observed NIR-region.

However, even if there are no directly observable absorption bands in the NIR-spectra, the presence of inorganic ionic components affect the appearance of the spectra of water. This is due to the perturbation of the well-regulated molecular water structure. This perturbation leads to small shifts in vibration anharmonicity and energy levels and therefore to shifts in the peaks' height and location.

This leads to the insight that simple calibration methods like the use of 'Beer's law,' where the absorption at a certain wavelength is proportional to the chemical concentration, must fail when used in these circumstances. Even multivariate calibration approaches like the 'classical least squares' algorithm is not usable, since the mathematical precondition for the usage of this calibration is an exact knowledge and quantification of all parameters that influence the spectra. This can be avoided by using such nonlinear calibration algorithms as the principal component regression (PCR) or the partial least squares (PLS) algorithm [12].

NIR spectroscopy in acidic texturisation

The calibration model for acidic texturisation contains a model for hydrofluoric acid, nitric acid and hexafluorosilicic acid. None of these three species show separate vibration bands in the near infrared region, and so require a nonlinear algorithm. In contrast to titration, where only the titer of the stock solutions has to be determined, or ion chromatography, where each component can be calibrated separately, the interaction between the components must not be neglected. Therefore, the calibration samples for one component have not only to cover the calibration range of the examined component, but also the estimated range of all matrix components. This is given by a fractional factorial design, where five concentrations are realized for each of the three components. The resulting experimental design contains 62 calibration samples, which were prepared from pure acids. Hydrofluoric acid was calibrated in the 70 – 120g/l range; nitric acid was calibrated between 380 – 520g/l and dissolved silicon in the range from 0 to 60g/l H_2SiF_6.

Adjacent to the presence of inorganic species, the temperature has a high influence on the appearance of the NIR-spectra. To compensate for the temperature's effect, each calibration sample was measured at temperatures between 5°C and 15°C. All spectra were measured with a FTPA 2000 FT-NIR spectrometer (ABB, Québec, Canada).

After the elimination of outliers, the calibration dataset consisted of 661 spectra with exact knowledge of the HF-, HNO_3- and H_2SiF_6-concentrations (see Figure 5). In the peak-free region near 12,000cm^{-1}, where no chemical information is expected, a baseline shift is observed. This shift can be eliminated by calculating the first derivation of the absorbance spectra. The chemical information remains in slight differences in the peaks of the first derivation.

The calculated models for HF, HNO_3 and H_2SiF_6 are validated via cross validation. For each sample, a model is calculated, leaving out the actual sample. The predicted concentration is then compared with the given concentration of the sample. The Standard Error of Validation (SEV) can then be calculated from the square sum of these residuals. It gives a first impression of the quality of the calibration model. A more detailed overview of the methodical approach is given in [12]. In Figure 6, the predicted concentrations from the cross validation are plotted against the given concentrations. A good compliance is observed for all three components.

The cross validation is only a first order quality parameter. During real texturisation processes, other parameters like gas bubbles or nitrogen oxides can influence the prediction quality of the NIR model. Therefore, a validation experiment was executed where the evidence of the PLS-models was tested. In this experiment, a solution of HF and HNO_3 was prepared from pure acids. Nine carriers with five small wafer pieces (30x30mm^2) were etched in 250ml of the etching solution. The concentrations in the solution were measured continuously by NIR spectroscopy, and validation measurements were carried out with ion chromatography and titration.

Titration	Ion Chromatography	NIR spectroscopy
✓ Easy and robust	✓ Very flexible	✓ Very fast method
✓ Low cost method	✓ No preparation Stepps	✓ Real inline-method
	✓ Easy calibration	✓ No maintenance
× Not extensible	× High maintenance	× Very time-consuming calibration
× Slow method	× Indirect determination of HF	
× Sample preparation		
× Indirect determination of HF and HNO_3		

Table 2. Comparison of the different analysis techiques.

Figure 7 shows the concentration plots for HF, HNO_3 and H_2SiF_6 during the texturisation process. In the first period the solution was cooled down from 22°C to 9°C. During this cooling-down phase, no concentration shifts are visible, suggesting that the NIR models are not temperature dependent. The etching process shows an increasing silicon concentration and decreasing HF- and HNO_3- concentrations due to the consumption of HF and HNO_3 in the reaction with silicon. Under the given etching conditions, nitrogen oxide bubbles occur, which are responsible for the higher noise and the observed spikes in the concentration graphs.

To investigate the precision of the developed NIR model, samples were taken during the etching process and then measured with titration and ion chromatography. To compare the offline-measured results with these from the inline NIR measurement, the concentrations are plotted as dots in Figure 7. In the limits of the reached accuracy of the used methods, no differences are found between titration, ion chromatography and NIR spectroscopy.

Conclusion

To date, three different methods are available for the chemical analysis of wet chemical process baths in solar cell fabrication. These methods differ in many aspects, regarding inline capability, running cost, flexibility and calibration workload. An overview is given in Table 2.

Titration is a very robust and widely used method for the determination not only of acids and bases, but also the concentrations

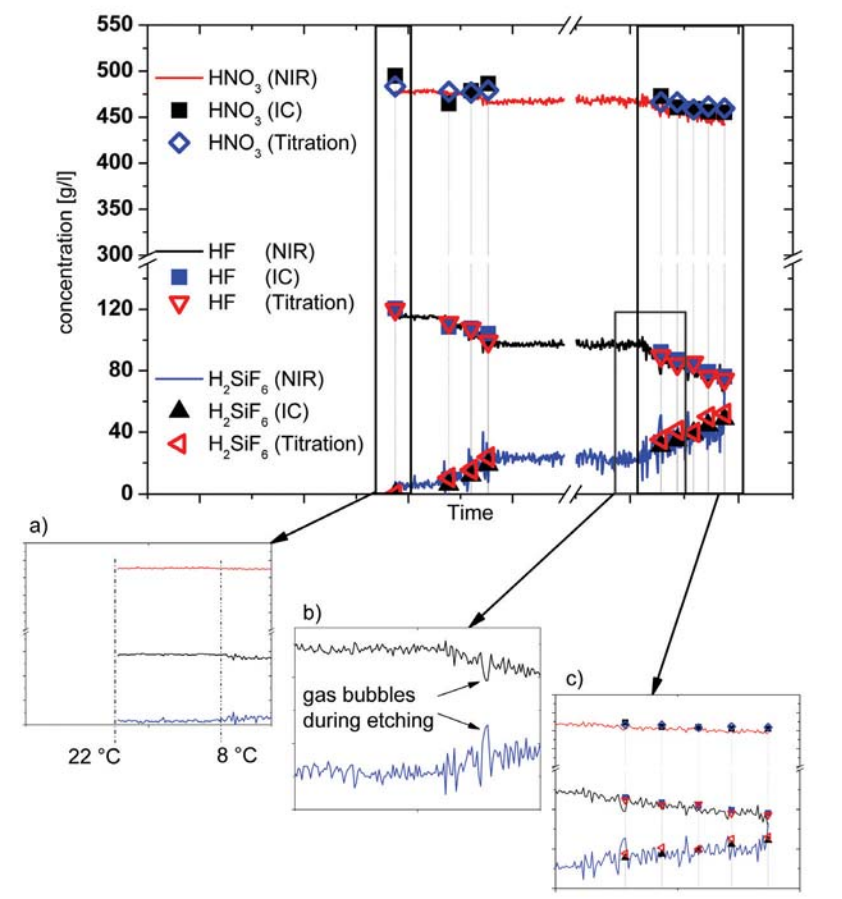

Figure 7. Concentrations of HF, HNO_3 and H_2SiF_6 during the validation experiment. The temperature independency is shown in (a) where the calculated concentrations remain constant during the cooling-down phase. (b) shows the influence of gas bubbles in terms of spikes in the concentration course. Good compliance of concentration between measurements taken with titration and ion chromatography are shown in (c).

of oxidizing agents like hydrogen peroxide. Maintenance and calibration costs are quite low, since most of the used stock solutions are commercially available. The measurement cycle is in the range of 10 to 15 minutes. A constraint for the usage of the titration is the limited number of components that can be detected simultaneously. Acidic texturisation is an example where additional titration steps become necessary for the analysis of all components. The determination of organic components like isopropanol is not possible.

A faster and more flexible method is chromatography, which process allows measurement of inorganic acids and bases and organic additives in cycles that are usuallly shorter than 10 minutes. Commercially available high-end equipment has a high automation level that can reduce the running costs to a minimum. Despite the high automation level, a sample preparation step and hence a contact with corrosive media is necessary for both titration and chromatography. A real inline system can be realised with NIR spectroscopy.

Since NIR spectroscopy is a nonselective method, interactions between the measured components as well as the influence of varying temperatures have to be included in the calibration dataset. This can lead to a high workload, which can be offset by the fact that calibration models for most purposes in photovoltaic industries are commercially available. After setting up a calibration model, further maintenance requirements are minimal. Modern FT-NIR instruments reach a measurement cycle of 30 seconds so that NIR spectroscopy enables a real-time process control.

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Ralf Preu is Head of the Department for PV Production Technology and Quality Assurance at Fraunhofer ISE. He received a diploma degree in physics in 1996 from the University of Freiburg, Germany, a Ph.D. degree in electrical engineering in 2000 and a diploma degree in economics in 2003 from the University of Hagen.

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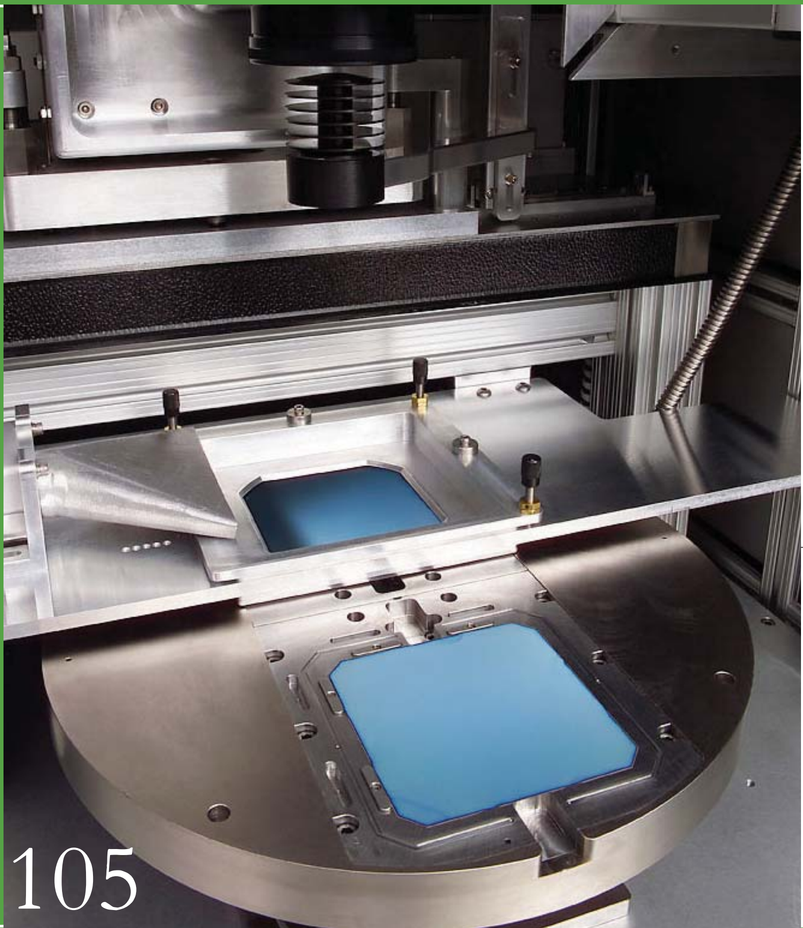
Thin Film



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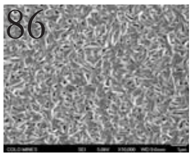

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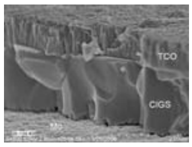
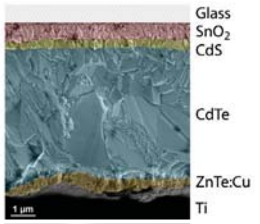
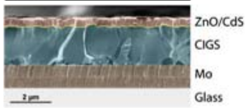


TCO
CIGS



Glass
SnO_2
CdS
CdTe
ZnTe:Cu
Ti
1 µm



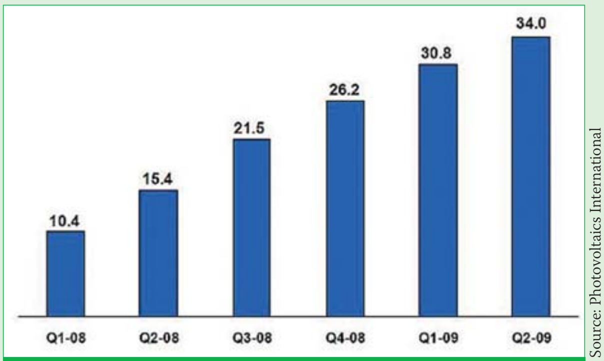
ZnO/CdS
CIGS
Mo
Glass
2 µm

95

ECD maintains 1GW capacity target in 2012

Energy Conversion Devices, Inc. reiterated plans to reach 1GW of nominal production capacity of its flexible a-Si thin-film photovoltaics in 2010. Company executives also said in a conference call with financial analysts that they had added 60MW of nominal capacity in the last six months, bringing total capacity to 178MW. A new site had also been chosen to bring capacity up to 420MW in 2010.

ECD posted revenues for its 2Q09 of US$103.1 million, compared to US$95.8 million from the first quarter and US$56.4 million in the 2Q08. Solar product sales were US$97.3 million, compared to US$89.5 million in the 1Q09.



ECD thin film capacity ramp.

Despite acknowledgements that the company was not immune from the global economic downturn and tight credit markets that had seen order push-outs in recent months, executives guided full fiscal year revenues to reach between US$395-440 million, with solar product sales reaching between US$375-410 million.

ECD noted that its order backlog had increased by approximately US$400 million to reach US$2.4 billion. However, it was not clear whether the increase was based on take-or-pay contracts, due to an overall decline of approximately US$100 in such order backlogs on its balance sheets.

Executives remained bullish on demand for the second-half of the year as demand for BIPV and commercial rooftop installations in France and Italy are expected to grow, due to the favourable feed-in tariffs for such installations over land-based projects in these countries.

In the U.S. ECD executives noted that the stimulus packages as well as a range of new legislation at the state level would boost demand for solar in the country by a substantial amount and that ECD expected to benefit from these positive actions.

ECD has approximately US$468 million in cash and short- and long-term investments and plans to meet capacity goals using these reserves and cash from future operations.

SANYO and Nippon Oil confirm thin-film solar JV

SANYO Electric and Nippon Oil finalized plans to form a 50/50 joint venture thin-film solar manufacturing company, which will be called SANYO ENEOS Solar Co., Ltd. The JV will develop a cell technology based on SANYO's, Heterojunction with Intrinsic Thin layer (HIT) solar cells, currently used in its crystalline solar cells. The companies did not disclose any details regarding equipment and material suppliers or the planned manufacturing location.

SANYO ENEOS Solar has been given ambitious production targets based on an initial capital injection of approximately US$225 million. The JV is projected to start volume production in fiscal year 2010 with a nominal capacity of 80MW and reached 1GW in production sales by FY2015 and approximately 2GW by FY2020.

Roth & Rau plans turnkey CdTe production solution with acquisition of CTF Solar

CTF Solar GmbH, a cadmium telluride (CdTe) PV manufacturing start-up, which can trace its roots back to 1993, is to be acquired by equipment specialist Roth & Rau to launch turnkey production lines for interested parties by end of 2009. CdTe is currently the most mature thin film technology currently in volume production, best associated with First Solar and its success with the technology. According to Roth & Rau, there are currently no equipment suppliers providing CdTe coating facilities or complete turnkey solutions that are not PV manufacturer specific.

Roth & Rau said that it had purchased all of the outstanding shares in the privately held firm in the 'single-digit million euro range.' The shares were held by the current management as well as by an investment company, Murphy & Spitz Green Capital AG.

Roth & Rau plans to offer CdTe turnkey production lines as a general contractor as well as produce the coating facilities required for the deposition of the cadmium telluride, which is a core competency required for volume production capability.

Currently, First Solar has been attributed with the lowest cost per watt of any PV technology and has experienced rapid growth in the last two years, since entering volume production.

Roth & Rau said that it had received strong interest from potential customers and expected the acquisition to significantly grow its business.

XsunX signs sales deal to supply 4MW of thin-film PV modules

XsunX signed a two-year supply deal for the sale of 4MW of its amorphous-silicon thin-film photovoltaic modules to an unnamed Oregon-based commercial project development firm. The contract raises the value of the company's total sales agreements to US$47 million on the basis of commitments to provide 19MW of ASI-120 TFPV modules.

"This agreement represents approximately US$10 million dollars in total contract value, with an initial 2MW slated for delivery in calendar 2009, and the remaining 2MW balance for delivery in calendar 2010," stated Tom Djokovich, CEO of XsunX. "This sales contract underscores XsunX's efforts to develop business and distribution relationships for its solar products in Oregon and extends to the creation of new jobs in Oregon's renewable energy sector."

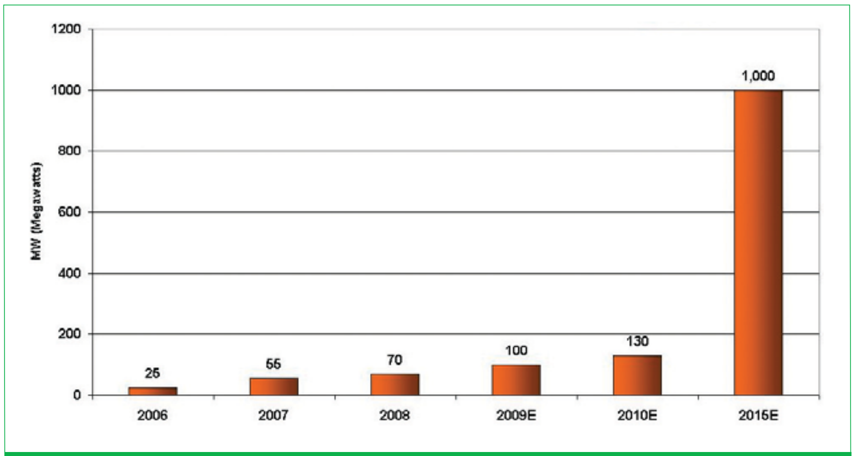
Total taps into Konarka with US$45 million investment & R&D pact

Energy conglomerate Total, via its U.S. subsidiary, Total Gas & Power USA (SAS) made a US$45 million investment in organic thin-film specialist Konarka Technologies, Inc. The investment will result in Total becoming the largest shareholder in the start-up with a stake close to 20%. Previously, Total had made investments in crystalline silicon technology firms such as Photovoltech and Tenesol. The investment in Konarka is Total's first foray into the fast emerging thin-film market.

Konarka said it would also be collaborating on developing new products with Total's chemical subsidiaries – Atotech, Bostik, Hutchinson, Sartomer and Total Petrochemicals USA. 'Power Plastic,' Konarka's flexible organic photovoltaic (OPV) product, has been touted for use in a wide range of applications that span commercial, industrial, government and the consumer.

Philippe Boisseau, the President of Total Gas & Power, stated: "This investment positions Total strategically to secure the future of solar energy while expanding its technological portfolio."

In October 2007, Konarka received a US$45 million investment from Mackenzie Financial Corporation, Good Energies, Draper Fisher Jurvetson (DFJ), Asenqua Ventures, New Enterprise Associates (NEA) and 3i. Other investors include Vanguard Ventures, Chevron Ventures, Massachusetts Green Energy Fund, NGEN Partners and Angeleno Group.



Source: Photovoltaics International

Kaneka Corporation planned thin film capacity ramp by 2015.

Kaneka plans 1GW a-Si thin film production ramp by 2015

Japan's Kaneka Corporation is investing approximately US$1.1 billion in expanding its a-Si thin film production through 2015 to reach capacity of approximately 1GW. As part of the production ramp, a new plant could be built in Belgium by 2011 at a cost of approximately US$224 million, though an exact location had not been finalized according to the report.

Kaneka Solartech, the thin-film division of Kaneka Corporation had a thin-film capacity of 23MW in 2005 and claimed expansions in 2007, reached capacity of 55MW. Plans were also announced for capacity to reach 70MW in 2008, at its Toyooka, Hyogo Prefecture, plant in Japan. At its c-Si module facility in the Czech Republic, Kaneka had plans to expand production from 20MW to 30MW in 2008.

Auria Solar begins pilot production using Oerlikon's micromorph technology

Taiwan-based Auria Solar is the first company in Asia to commence production of thin-film silicon solar modules using Oerlikon Solar's Micromorph technology. Auria has already produced its first thin-film module using the technology, less than four months after having the equipment delivered. Oerlikon's Micromorph technology will aid in the company's reaching its target of annual production of 500MWp by 2012.

In early 2009, Auria expects to enter full-volume production, reaching an annual capacity in excess of 60MWp. The news follows the announcement that Berlin-based Inventux Technologies is also adopting the technology, which is claimed to increase efficiencies by up to 50%. Currently, first generation a-Si module efficiencies are in the region of 6.5% and Oerlikon Solar's second-generation technology a-Si/μc-Si tandem structure has claimed to reach the 8.7% module efficiency range.

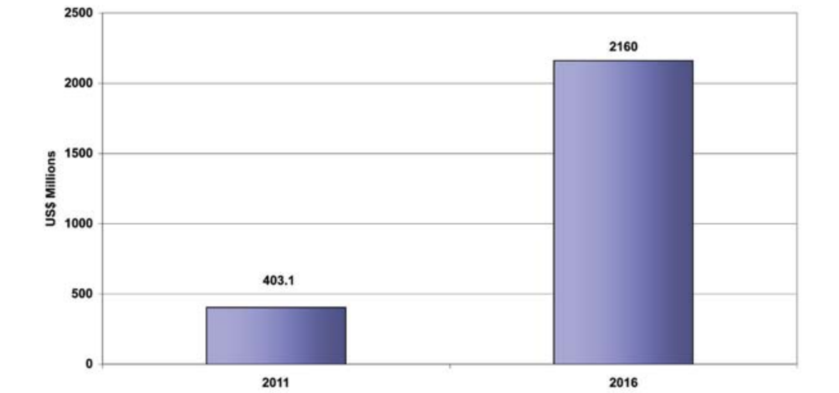
NanoMarkets: CIGS thin-film sales to top US$2.1 billion by 2016

NanoMarkets forecasts strong growth for CIGS-based thin-film photovoltaics, despite current economic difficulties. NanoMarkets projects CIGS sales to reach US$2.1 billion in 2016, up from US$402.1 million expected in 2011.

However, the landscape of the technologies used for both substrates and deposition techniques is set to change, as lower cost panels are required to drive global markets. Key changes include the growth of flexible roll-to-roll substrates compared with the current dominance of glass substrates. The development of non-vacuum-based deposition tools is also expected to rise such as electrodeposition and printing techniques to further reduce the cost of cells.

NanoMarkets believes that recent cell efficiency records for CIGS set by NREL 20% and the development of new substrate materials such as glass-polymer composites and polyimide materials will spur future growth.

New entrants in the form of IBM and co-developer TOK are also noted for their focus on CIGS based cells and the impact this could potentially have on the growth of CIGS-based photovoltaics.



Nanomarkets: copper-indium-gallium-selenium (CIGS) sales growth forecast.

Sontor in micromorph silicon thin-film module ramp with 8% efficiencies

Q-Cells SE's start-up subsidiary Sontor GmbH produced and sold a total of 3.6MW in 2008. The production ramp has already started at its Thalheim, Germany plant, which has a nominal capacity of 24MW. Module efficiency of its a-Si/μc-Si thin film 'micromorph' modules (1.8m^2) are said to be stable at up to 8% conversion efficiency.

At cell level, Sontor claims stable values of up to 9.3% efficiency on the active surface, while the ramp has continued.

Thin-film solar PV company Solyndra opens European headquarters

Solyndra opened its European headquarters in Holzkirchen, Germany, near Munich and tapped Clemens Jargon as its regional managing director and VP to head the thin-film PV company's sales and service operations in the region as well as in the Middle East and Africa.

The Fremont, California-based company, which has booked more than US$1.5 billion in orders and shipped commercial products for almost a year, already works with international solar power project integrators such as Phoenix Solar and Gecko Logic of Germany and leading international roofing systems manufacturer Carlisle Energy Services.

Solyndra says its copper-indium-gallium-(di)selenide (CIGS) thin-film PV panels (which feature a unique cylinidrical-module design) are fully certified for European solar installations and have received independently validated product verification and performance testing from multiple sources, including IEC, GSE, and Fraunhofer ISE.

Moser Baer celebrates IEC certification for its 40MW thin-film module line

Moser Baer's 40MW thin-film module production line was granted certification by the International Electrotechnical Commission. The IEC certification guarantees that the thin-film modules being produced at the company's Greater Noida plant have passed all requirements for functional and mechanical capabilities for long-term operation, as well as maintaining safety specifications under challenging environmental conditions.

CTDC unit secured US$36 million credit line to expand solar PV manufacturing

A subsidiary of China Technology Development Group Corp. lined up US$36 million credit from a leading Chinese commercial bank to expand the solar PV company's manufacturing plant. The company said that China Merchants Zhangzhou Development Zone Trenda Solar Energy Ltd. (known as Trenda Solar) received a commitment of credit line worth RMB 250 million from the Fujian branch of China Construction Bank.

The credit, subject to certain terms and conditions, was extended for the purpose of expanding CTDC's existing amorphous-silicon thin-film photovoltaic manufacturing facility in Xiamen Bay Solar City.

TÜV Rheinland Japan to offer thin-film testing services

The TÜV Rheinland Asian Group, located in Yokohama, Japan, will begin new testing services for the IEC 61646 Thin Film terrestrial photovoltaic modules, as well as design qualification and type approval. This will serve as a complement to their pre-existing PV outdoor testing facilities and Crystalline PV Module competence center.

HelioVolt shuffles executive management team anticipating full scale commercialisation

HelioVolt has made changes to its executive management team and is searching for a permanent CEO. Board member Ron Bernal has been appointed as interim CEO and Sanjeev Kumar, the former chief financial officer of Energy Conversion Devices, has joined the Austin-based thin-film PV company as CFO. Founder B.J. "Billy" Stanbery will continue to play a key role as chief strategy officer and chairman of the board. The company says its board will conduct an international search for a permanent CEO to lead the company in its next phase of growth as a manufacturer of copper-indium-gallium-(di)selenide (CIGS) TFPV products.

MKS Instruments posts record sales to solar industry in 2008

Process control and sub-systems specialist MKS Instruments reported record sales in the solar manufacturing industry in 2008. MKS almost tripled sales from the same period a year ago, reaching US$49 million. The increase in sales was the result of doubling its customer base in the solar sector to over 120 customers, leveraging a broad product portfolio that included penetration of its RF and DC power systems, reactive gas generators as well as pressure flow instrumentation for vacuum processes and its Residual Gas Analysis equipment for process control.

CIGS thin-film PV company HelioVolt lays off small number of workers, report says

HelioVolt, a copper-indium-gallium-(di)selenide thin-film PV company, reduced its workforce by 15 positions due to the weak economy as well as the company's shift away from pure research, toward becoming a manufacturer of solar power products.

HelioVolt founder B.J. "Billy" Stanbery stated that the cuts were "a natural consequence of the transition of the company from being development-oriented to ramping up for manufacturing operations. We have had to rebalance our workforce in a tough economic environment where we need to be careful with our cash." Stanbery went on to state that "the company will have its factory qualified to begin production this year" at its 122,400 sq-ft, 20MW capacity plant in Austin, which officially opened in October, 2008.

At the time of the ribbon cutting, the company said it would hire 160 employees to work at the facility once it was fully ramped, and the number would grow to as much as 300 by the end of 2009.

ECD signs multi-year laminates order with Carlisle Energy Services

Energy Conversion Devices, Inc. (ECD) received a multi-year order from Carlisle Energy Services, a new division of Carlisle Construction Materials, for its thin-film UNI-SOLAR laminates. The volume of the order was not revealed, but it was stated that the laminates are scheduled for use in commercial rooftop installations.

Taiwan's AU Optronics to enter thin-film solar market

One of the world's largest manufacturers of thin-film transistor liquid crystal display panels (TFT-LCD), Taiwan-based AU Optronics Corp plans to start an a-Si thin-film pilot line using what it describes as a 'third generation' technology with conversion efficiencies in the 10% range, starting in 2009. The thin-film pilot line will be based at its R&D facility in Taichung, Taiwan and will be operated within a new 'Energy Project Office,' the company said in a statement. AU Optronics Corp is a multi-billion US dollar company employing over 40,000 people.

CVD Equipment Corporation doubles 2007 orders to US$29M

Having seen US$14.4 million in order levels in 2007, CVD's orders for 2008 reached US$29.0 million, representing an increase of 101% on the previous year.

It seems that a large part of the order growth came from the fact that close to half of the 2008 orders were related to the solar market, most of which incorporated thin-film or CVD proprietary solutions. The company's CVD/FN and SDC divisions increased by 146% and 58% respectively in 2008's sales, while the Conceptronic division decreased slightly by 3% compared to 2007 order levels, showing an effect of the electronics industry's downturn.

Smit Ovens to supply Jenn Feng with thermal processes for CIGS thin-film PV production

Smit Ovens has signed a deal to supply Taiwan-based Jenn Feng Industrial with thermal process solutions for the mass production of thin-film PV cells. Smit Ovens will provide Jenn Feng Industrial with equipment and non-vacuum processes in order to manufacture CIGS PV cells, implementing nanoparticle precursors in the selenization process. This will help Jenn Feng Industrial reach its goal of beginning mass production of thin-film CIGS cells and modules this year, with an annual capacity of 35MWp.

Min-Fu Jong (left), CEO of Jenn Feng Group, and Wiro Zijlmans, CEO of Smit Ovens

News

Product Briefings

Product Briefings

3D-Micromac

3D-Micromac's microSPIN laser system handles flexible thin-film roll-to-roll production

Product Briefing Outline: 3D-Micromac has launched microSPIN, a laser micromachining system for ablation of thin-film solar cells on flexible substrates, handled with an integrated roll-to-roll transportation system. The microSPIN system is designed to minimise edge effects and lower processing costs significantly through a much higher throughput, without damaging cells.

Problem: Lightweight, flexible thin-film substrates are expected to produce a lower cost per watt than conventional crystalline solar cells. However, to reach grid parity goals, such substrates must provide the same essential functionality as higher throughput or larger machining areas. Roll-to-roll manufacturing methods can reduce production cost and are well suited to the use of lasers, which are claimed to guarantee high efficiency and throughput at best attainable precision with minimal damage to the cells.

Solution: A special feature of the roll-to-roll technology is the laser processing of substrates 'on-the-fly' a continuous winding process with speeds of around 17 to 170 metres per minute for reaching a very high throughput. Particular advantages of laser machining of the very fragile thin-film solar cells include contactless energy insertion, the capability of flexible beam guidance, and the exact control over supply of energy. The method also avoids damage to the material, consequently reducing failure rates.

Applications: Thin-film solar cells on flexible substrates that include edge isolation, laser surface structuring in process steps P1, P2 and P3 and laser marking.

Platform: The system is available as a standalone product as well as an integrated solution for existing, fully automated production lines for laser machining of thin-film solar cells. Numerous process monitoring methods including tracking and tracing of process parameters, while online energy monitoring ensures additional process reliability.

Availability: Currently available.

Komax AG

Komax's new thin-film bussing system enables precise contacting of thin-film modules

Product Briefing Outline: Komax AG has introduced its new thin-film bussing system which enables precise dispensing of one- and two-component glue. The existing ribbon handling technology was further improved to eliminate the chambering of the ribbon which allows supply of the ribbon from bigger spools. In order to cover and fix the ribbon, a black cover tape can be applied (particularly for CIGS modules); if no tapes are needed, the glue can be cured directly in an additional cell. As an option, an automatic cross contacting is available.

Problem: Thin copper ribbons are used together with conductive glue to contact the first and the last cell of a thin-film module. Those ribbons are delivered on coils or on large spools (with up to 2000m on a single spool). However, the chambering of the ribbons makes it very difficult to contact a single, small cell, especially in the case of thin-film modules where the cells are often longer than one metre. In addition, the viscosity of the silver-filled epoxy glue strongly depends on the ambient temperature.

Solution: In order to eliminate the chambering for long thin-film cells, Komax adapted its existing ribbon handling technology from the Xcell stringers. In addition, a technology to apply a cover tape was developed as well. To keep the viscosity of the glue constant and independent from the ambient temperature, Komax has introduced a heating/cooling element in its dispensing head. This allows precise dispensing of the glue, together with a mechanism which keeps the distance between the nozzle and the glass surface constant.

Applications: Thin-film photovoltaic modules (substrates as well as superstrates).

Platform: Komax supplies equipment for the crystalline module production and for thin-film back-end module production. The thin-film bussing system is part of the Komax thin-film pre-lamination line.

Availability: Currently available.

VAT

'SolVAT' transfer valve specifically designed for thin-film vacuum chambers

Product Briefing Outline: Vacuum valve specialist VAT has introduced a new transfer valve, 'SolVAT', which is tailored to the growing thin-film solar cell manufacturing sector. The new transfer valve targets the widest range substrate sizes currently in production and is available in slit sizes between 45-150mm in height and 1000-3000mm in length.

Problem: A large number of thin-film PV technologies use various coating methods under vacuum conditions. Due to the low-cost, high-throughput requirements of thin-film PV manufacturing, transfer valves need to be highly reliable over long cycle times even in harsh, corrosive environments.

Solution: The SolVAT transfer valve is available as an aluminium or stainless steel body with shaft-sealed or bellows-sealed actuators to take into account variations in chamber environments. Rigorous testing and decades of experience in similar processing environments has resulted in an endurable valve technology to withstand the aggressive gases, contamination and high temperatures associated with thin-film PV production. The modular design allows for a best fit for the customer application and allows aluminium or stainless steel as well as cooled body and gate, shaft-sealed or bellows-sealed actuators, various valve body coatings, O-Ring free gate and many more features. In addition, the valve is resistant to differential pressure in both directions and allows independent maintenance or cleaning of the process chambers. State-of-the-art production methods allow VAT to provide a high performance and cost-efficient transfer valve.

Applications: Vacuum based thin-film equipment. The valve is applied in all common PV processes e.g. PVD, CVD thermal evaporation, etch and PV thin-film technologies such as a-Si, CdTe and CIGS.

Platform: The SolVAT transfer valve is available in different slit sizes (height 45-150mm, length 1000-3000mm).

Availability: Currently available.

LPKF SolarQuipment

LPKF SQ's 'Allegro' thin-film laser scriber combines precision and throughput

Production Briefing Outline: LPKF SolarQuipment has developed the 'Allegro' laser scribing system for thin-film module production that is intended to combine both high precision and high throughput. The LPKF Allegro laser system is designed for all processes (P1 through P3) of laser structuring on thin-film solar cells.

Problem: Production of thin-film solar modules requires a precise laser scribing method to achieve the monolithic series interconnection in a cost efficient way. The efficiency of the solar panels directly depends on the accuracy of the scribing process. Scribing insulating channels on thin film solar panels has to be very exact as the smaller the dead area, the higher the output of the module. If there are any thermal or plastic distortions in the glass substrate, the resulting solar panel becomes less efficient.

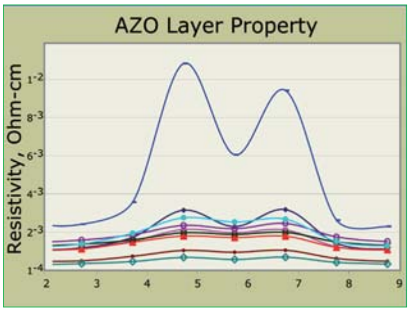
Solution: To achieve precise results, the LPKF Allegro laser systems employs air bearings for low maintenance, long-term stability and high-axis precision. The 'Dynamic Design' technology always moves the dynamically most reasonable component, which is the compact laser working head and not the sensitive glass substrate. Automatic alignment of scribing against existing structures and an integrated compensation of glass waviness ensures the required accuracy, according to the company. A variety of laser sources is available to machine different thin-film technologies.

Applications: Laser scribing of thin-film solar panels based on CdTe, aSi, aSi/µSi, CIGS technology.

Platform: LPKF Allegro series is modular in construction and can be tailored to customer requirements. A variety of laser wavelengths is available for different thin-film technologies, allowing for compensation for variations in glass thickness and waviness and continuous setting of cell width (distance of structuring paths) of 5-15mm.

Availability: Currently available with 6-8 month lead-times from purchase order.

Gencoa Ltd.



Gencoa improves TCO layer deposition for thin-film production

Product Briefing Outline: Gencoa Ltd. has combined process and material testing with advanced 3D plasma simulation tools to determine the critical factors that influence the sputtered TCO (Transparent Conducting Oxides) properties. Improvements to the TCO properties have been made using advanced magnetic designs that are fitted to its range of planar and rotatable magnetron cathodes.

Problem: In thin-film PV module production, transparent conducting oxides are commonly used as the front contact material. The desired properties combine high electrical conductivity, high optical transmission and good light scattering. There are a range of TCOs commonly used, such as ITO, AZO, ZnO and SnO. The choice of material will partly determine the film properties, but the source design and deposition process will also have a profound effect on the layer performance. It is therefore important to maximise the product quality by focusing on the deposition factors that affect the TCO layer.

Solution: The enhancement of the properties of TCOs can be achieved by optimising the plasma interaction with the substrate during the coating process. It has been found that although layer types differ, the factors that influence the layer quality of sputtered ITO and AZO are similar. A very wide range of properties can be achieved depending upon the magnetic design, anodic interactions and processing parameters.

Applications: Thin-film TCO layers for photovoltaics where the deposition method is sputtering.

Platform: Supplied as complete planar and rotatable magnetron sputter cathodes in single and double magnetron formats.

Availability: Currently available.

SOPRALAB

SOPRALAB's SE5 PV metrology station handles large-substrate thin-film modules

Product Briefing Outline: SOPRALAB, now part of SEMILAB, has launched the SE 5 PV metrology station, which integrates their Spectroscopic Ellipsometry unit into a large modular platform for large-substrate thin-film PV panels. The non-invasive technology is used to rapidly and accurately characterise the properties of thin-film modules.

Problem: With large-scale production of PV panels well underway, the challenge still remains in mimicking the same efficiency and lifetime for these materials as that achieved in the R&D laboratories. The key lies within the integration of non-invasive characterisation techniques to reduce defects and control material morphology, thereby increasing the performance.

Solution: Spectroscopic Ellipsometry (SE) is used to detect the change of the polarization state of light after reflection from a plane surface. Parameters accessible from SE include: thickness (from nm to several µms), optical properties (refractive indices, extinction coefficient, band gap, absorption and transmission) and material properties (roughness, composition, crystallinity). Single layer and multilayer structures on various substrates (glass, metal, silicon, and plastic foil) can be measured and analysed using a very small probe area. The SE 5 PV is a pilot line and production control system orientated towards mapping the deposition uniformity over large surface areas.

Applications: Silicon thin-films (a-Si, PolySi, µSi), TCO, OPV, CIGS, CdTe, DSSC, NanoPV.

Platform: Other metrology tools can be mounted on the same SE 5 PV and driven by the same software (e.g. Spectroscopic Reflectometer, 4PP, Lifetime & Eddy Current Scanners, Contact Angle, Infra Red Ellipsometer), thereby allowing one platform to provide a complete characterisation of each material under investigation. The metrology station is compatible for integration with large panel robotic handling and factory automation using WinSE software for SECS GEM protocols.

Availability: Currently available.

Using a field-assisted simultaneous synthesis and transfer technique to print CIGS thin-film photovoltaic devices

Louay Eldada, HelioVolt Corp., Austin, TX, USA

ABSTRACT

In recent years, a new generation of solar electric products has emerged from the lab into the global market: thin-film technologies that employ approximately 1% of the active, expensive photovoltaic material used by standard crystalline-silicon cells. Through a combination of cost advantages and new product applications, cadmium telluride (CdTe), amorphous silicon, and copper-indium-gallium-selenide (CIGS) thin-film PV have the potential to foster a paradigm shift toward distributed electricity generation at cost parity with other forms of energy.

CIGS has long been seen as one of the most promising thin-film PV materials. But until recently, the photoactive compound has not had a reliable, rapid manufacturing process that could scale effectively to multi-megawatt-scale volume production and provide significant amounts of electricity at the point of use. This article describes a novel process, known as field-assisted simultaneous synthesis and transfer (FASST) printing, a manufacturing approach that enables the rapid printing of microscale CIGS films with p- and n-type nanodomains that are critical for achieving the highest efficiencies possible.

The promise of CIGS

More efficient than CdTe, amorphous silicon, and other thin-film materials, CIGS has achieved 20% conversion efficiency in laboratory settings for small-area cells [1] and 13.5% for large-area modules [2]. This performance level pushes CIGS to near parity with traditional crystalline silicon panels, which usually boast panel efficiencies in the 12-18% range.

CIGS thin films have other competitive advantages. The relatively low material usage means that $1 worth of silicon can be replaced with just $0.03 of CIGS materials. The silicon market has been constrained by an imbalance between supply and demand, resulting in manufacturers being tied to a volatile, unpredictable commodity market characterised by wide price fluctuations. CIGS production benefits not only from material advantages, but also from the potential for improving costs throughout the value chain, leveraging manufacturing maturity in related thin-film technologies, such as the electronics and display industries.

Because of its inherent aesthetic versatility, CIGS also offers expanded product innovation choices. While the current solar market has recently been

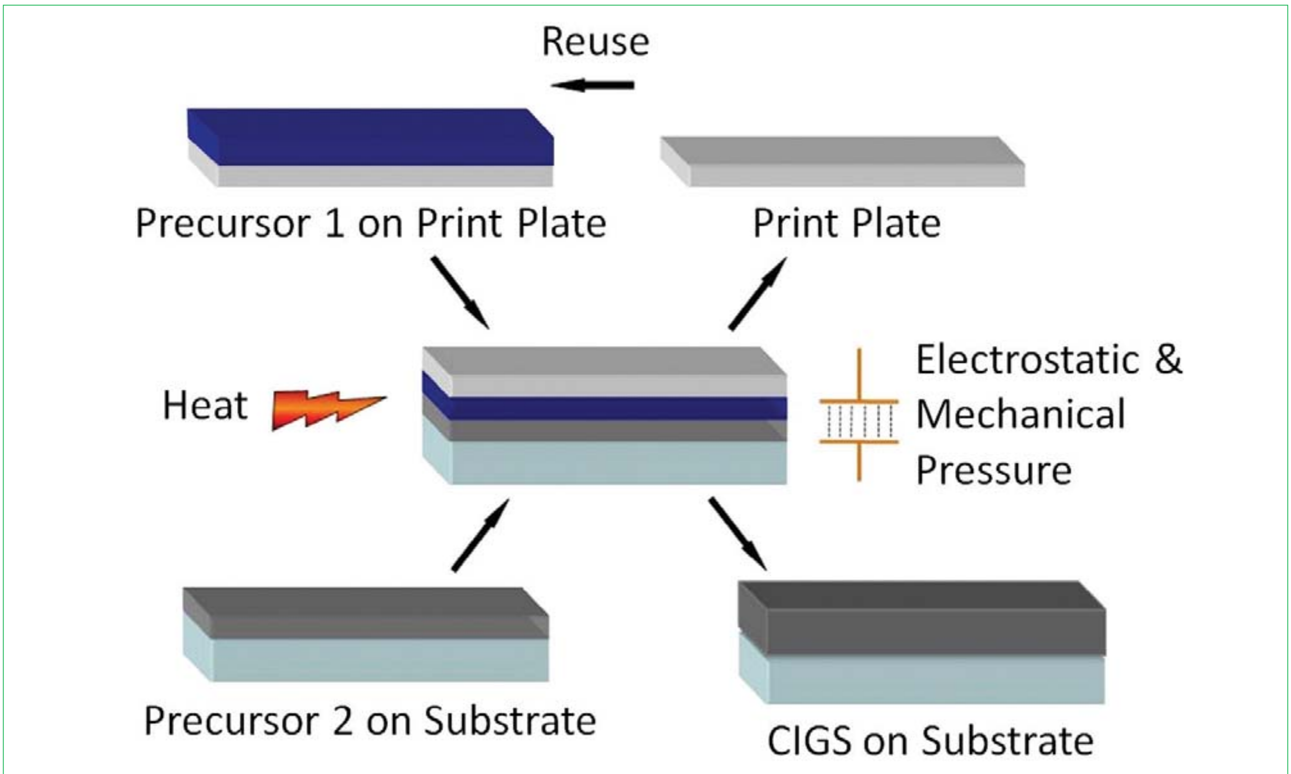


Figure 1. Schematic of the field-assisted simultaneous synthesis and transfer (FASST) process.

underserved with demand outpacing supply, differentiators such as appearance and the ability to adapt products to various market segments will play an increasingly important role as the sector approaches equilibrium. Silicon PV companies such as SunPower have already proven that high-end products with a strong aesthetic advantage can attract significant investment and secure market share at a premium.

CIGS thin-film builds on this idea. The material can be integrated into a wide variety of building and construction materials. For instance, CIGS can offer the appearance of tinted glass on sides of buildings, or of slate on rooftop applications. Semitransmissive modules could serve the dual function of vision glass and electricity generation.

> "The relatively low material usage means that US$1 worth of silicon can be replaced with just US$0.03 of CIGS materials."

Among the TFPV materials, CIGS may be the most promising for cost-effective power generation. With its high conversion efficiency, it has the potential to provide the maximum power per unit area available, and with it, an attractive energy payback time of about 1.5 years, with expected advances leading to a payback time of about a half-year in the near future.

A novel way to produce CIGS

Depending on the manufacturing technique, CIGS can be processed as monolithically interconnected modules (MIMs). Instead of discrete, individual cells that are strung together, PV modules can take the form of photovoltaic integrated circuits (PVICs), which can simplify the manufacturing process and reduce costs. MIMs consist of a packaged PVIC, in which the thin films are deposited on a substrate and undergo a series of scribe patterning steps that create an integrated circuit of cells already in series. The integration method circumvents the significant cost associated with cell cutting/testing/sorting/assembly used in many other thin-film PV technologies. First Solar has taken a similar approach, which has proven very effective for scalable, high-throughput manufacturing of CdTe thin-film modules. While not all CIGS manufacturing processes can use PVICs, FASST's reactive transfer process capitalises on the advantages of this approach as well as offering rapid deposition over large areas.

> "Among the TFPV materials, CIGS may be the most promising for cost-effective power generation."

High-performance CIGS is characterised by relatively large grain sizes, an overall copper deficiency compared to the structure of the conventional α-phase copper indium diselenide ($CuInSe_2$), and a composition lying in the equilibrium α+β 2-phase domain [3]. This latter characteristic is behind the intra-absorber junction (IAJ) model that describes the formation within individual grains of α domains that are copper-rich with p-type conductivity and β domains that are copper-poor with n-type conductivity, forming nanoscale p-n junction networks [4]. The n-type networks act as preferential electron pathways, while the p type networks act as preferential hole pathways, allowing positive and negative charges to travel to the contacts in physically separated paths, reducing recombination and improving efficiency.

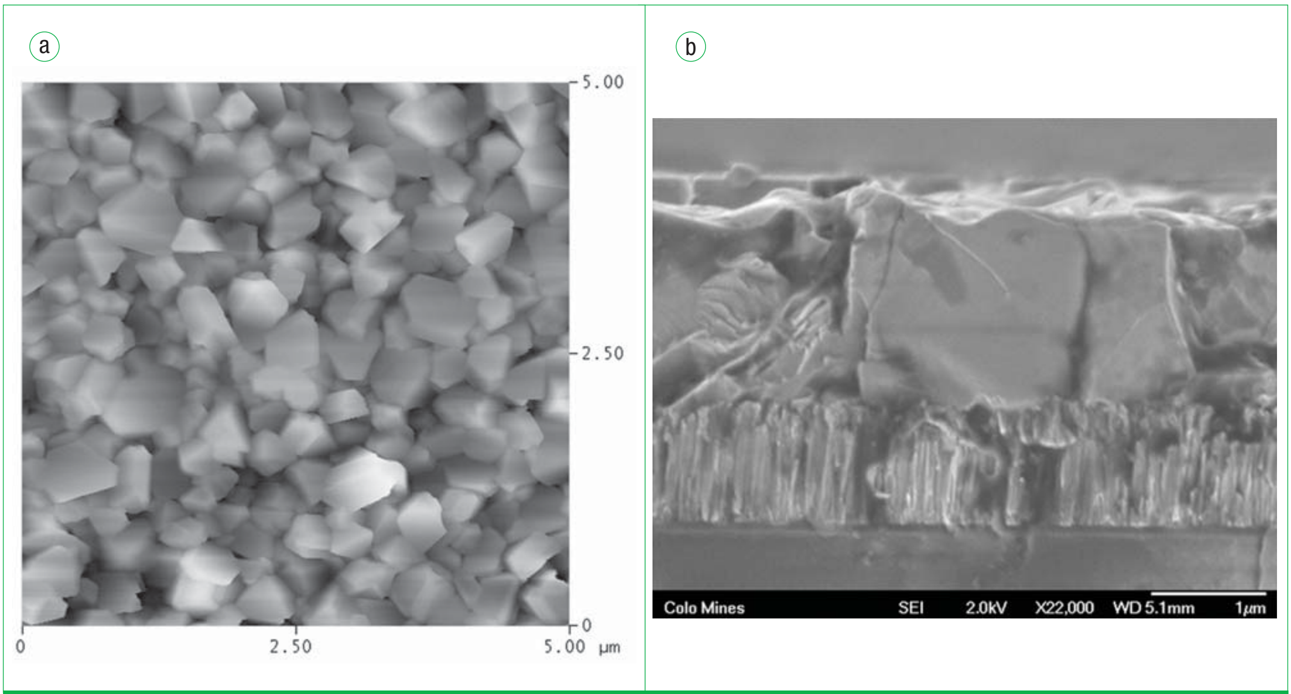


Figure 2. (a) Precursor film and (b) FASST CIGS cross-section.

The most common conventional method used to synthesise high-performance thin-film CIGS devices is a high-temperature, coevaporation method. The multistep deposition sequences developed to achieve this performance involve the topotactic transformation of a fairly large grain precursor into very large grain CIGS, rather than the direct synthesis of CIGS from condensation of elemental vapours as in molecular beam deposition. The FASST process uses this same topotactic transformation.

The process utilises a two-stage reactive transfer printing method relying on chemical reaction between two separate precursor films to form CIGS (see Figure 1). In the first stage, two Cu-In-Ga-Se-based precursor layers, forming the chemical basis of the films, are deposited onto a substrate and print plate, respectively. The two separate precursors provide independently optimized composition, structure, deposition method, and processing conditions for each precursor. Separating the precursors eliminates prereaction prior to the second-stage of the process and facilitates optimized CIGS formation in the second stage. Precursors can also be deposited at a low substrate temperature, which can help lower cost and increase throughput.

In the second stage, these precursors are brought into close contact and rapidly reacted under pressure in the presence of an applied electrostatic field. The method utilises physical mechanisms characteristic of rapid thermal processing (RTP) and anodic wafer bonding (AWB), effectively creating a sealed microreactor that ensures high material utilisation, direct control of reaction pressure, and low thermal budget. The rapid thermal transient provides the similarity between FASST and RTP. By pulse heating the film through the print plate, the overall thermal budget is significantly reduced, allowing the use of low-cost, less thermally stable substrates.

Sufficient mechanical pressure can substantially prevent the loss of selenium vapour from the reaction zone, thereby achieving highly efficient incorporation of the vapour into the composition layer. The use of an electrical bias between the print plate and substrate creates an attractive force that serves to ensure intimate contact between the precursor films on an atomic scale, and can thus be used in conjunction with mechanical pressure to control the total pressure in the reaction zone. This is the area where FASST resembles AWB, a method developed historically to reduce the temperature required to bond two dissimilar materials together.

Using precursors to synthesise high-quality CIGS films

Large-grain, high-quality CIGS is synthesised from two precursors in

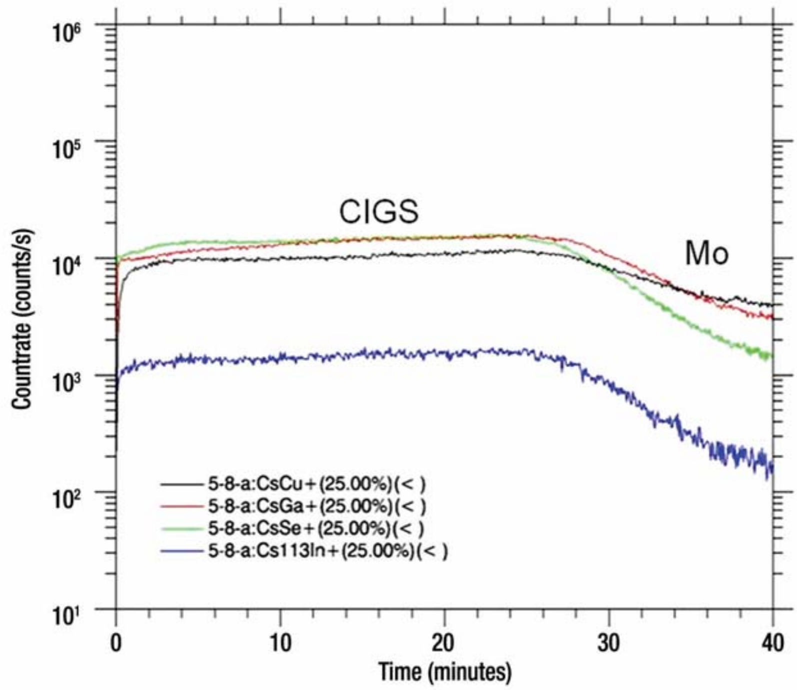


Figure 3. SIMS depth profile of a CIGS film. This film was formed in six minutes by the novel transfer process.

six minutes using the process. Figure 2 depicts a precursor film with grains on the order of a quarter-micron in size and the cross-section of a printed CIGS film with micron-scale grains.

Figure 3 shows a secondary ion mass spectrometry (SIMS) depth profile of a CIGS thin film processed by the synthesis and transfer technique. The precursors are produced by physical vapour deposition (PVD). The uniform elemental distribution indicates a complete reaction of the precursors, and the x-ray diffraction (XRD) analysis shown in Figure 4 confirms the absence of deleterious phases other than CIGS. The XRD peaks are indexed based on a chalcopyrite-type CIGS and molybdenum structure. The processed film has a (220/204) preferred orientation. Evidence indicates that the (220/204) oriented films help junction formation and improve solar cell performance [5].

The rapid processing of the CIGS formation significantly increases the manufacturing throughput. As noted above, this approach results in a much lower thermal budget as compared to the more commonly used coevaporation and two-step selenization processing techniques. The reduced thermal budget, virtual elimination of selenization, and high throughput all contribute to the potential to lower the process cost and improve manufacturability.

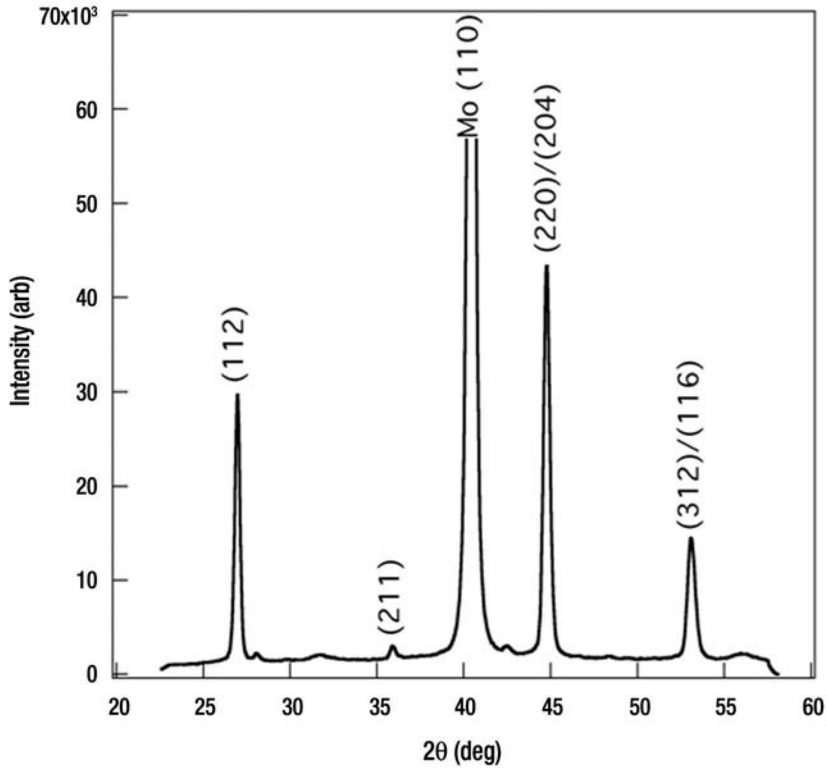


Figure 4. XRD pattern of a CIGS film fabricated by the process.

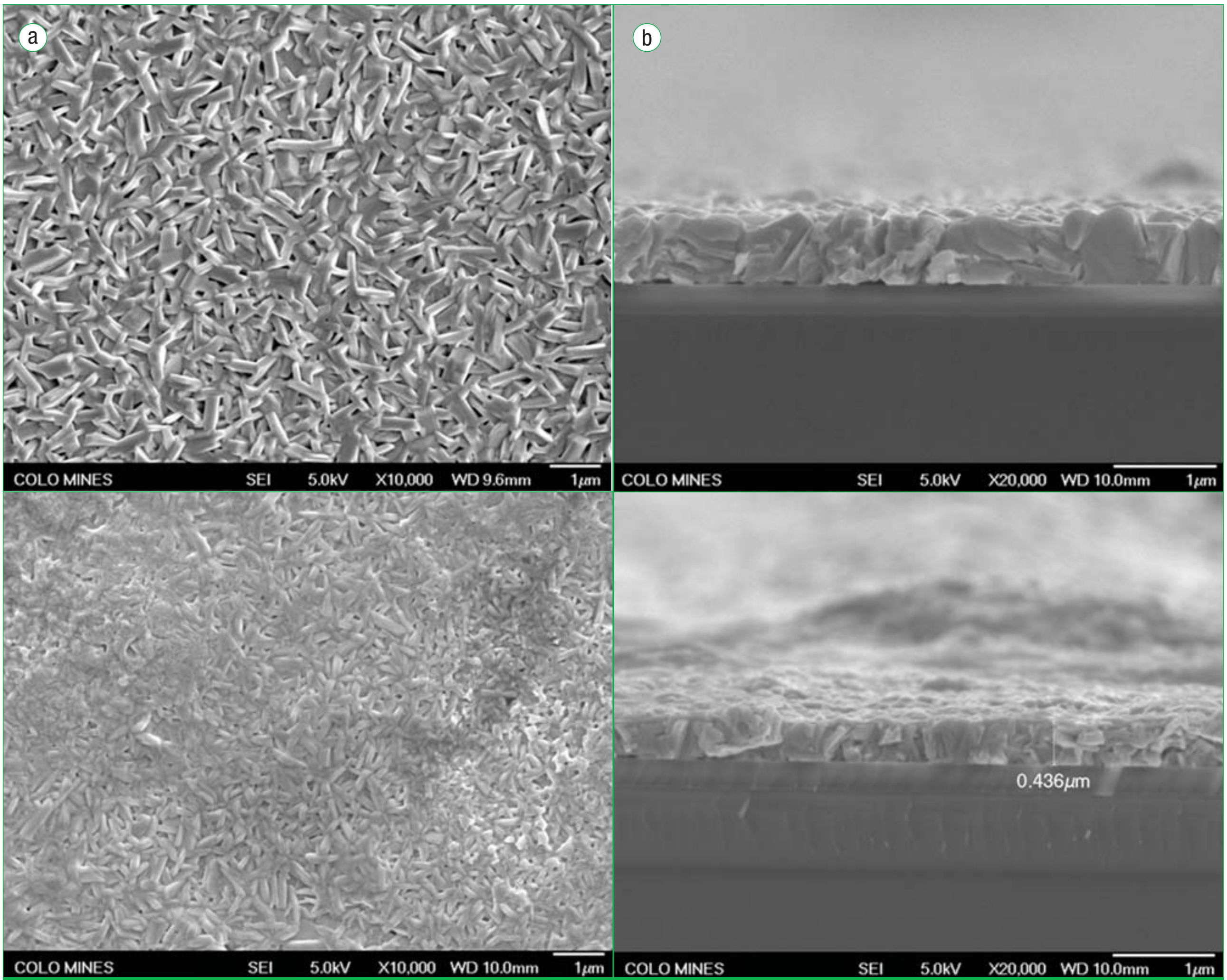


Figure 5. Top views and cross-sectional SEM views of (a) a PVD-deposited CuSe film, and (b) an atmospherically spray-deposited CuSe film from a solution-based process.

The opportunity to tailor the two precursors independently permits the use of unconventional, nonvacuum deposition techniques, such as die extrusion coating, ultrasonic atomization spraying, pneumatic atomization spraying, inkjet printing, direct writing, and screen printing. These atmospheric-pressure-based deposition tools can offer enhanced flexibility and open up new avenues for materials processing. They also provide a viable means of introducing nanoparticle technology, metallorganic chemistry, and novel reaction paths to produce CIGS. The low capital equipment cost and high-throughput capabilities associated with atmospheric-pressure processing can reduce manufacturing costs. Since these materials can be deposited at temperatures below 200°C, there is potential for a lower thermal budget [6].

Proprietary inks containing a variety of soluble copper, indium, and gallium multinary selenide materials were developed by HelioVolt and the U.S. National Renewable Energy Laboratory. These inks – so-called metal-organic

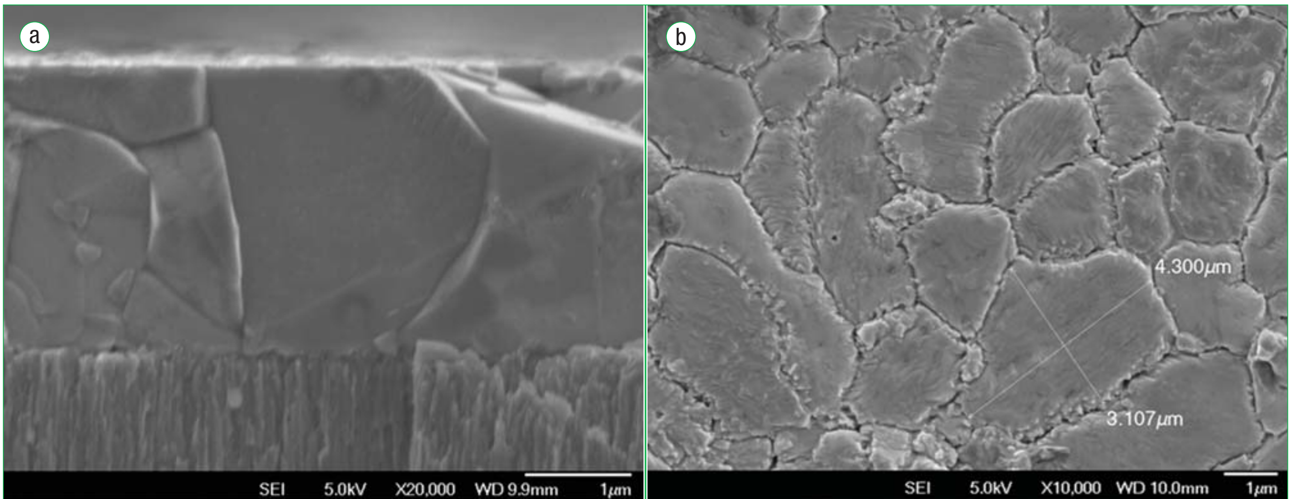


Figure 6. SEM micrographs of (a) the cross-section and (b) the top view of a CIGS film synthesized using a nonvacuum-deposited precursor.

decomposition (MOD) precursors – are designed to blend into the desired precursors, which are then used in step one of the FASST process.

For the work described here, the inks were deposited using an ultrasonic spray head fed by a variable-speed liquid pump. A substrate heater mounted on a computer-controlled X-Y motion system allowed for the movement of heated substrates under the sprayed stream. The thickness of the sprayed film was controlled by varying the ink concentration, the flow rate through the sprayer, and the number of coats deposited. Conditions were optimized such that smooth, uniform precursor films were obtained for all of the sprayed inks.

The precursor films were converted to the desired materials through RTP in a controlled atmosphere. The thermal processing conditions were varied systematically to ascertain the effect of conditions on the film compositions and morphologies obtained. The film compositions were characterised by X-ray fluorescence (XRF), crystalline phases were identified using XRD, and film morphology was examined using scanning electron microscopy (SEM).

"Various Cu-Se MOD precursor recipes were also formulated, resulting in tunable phase and stoichiometry in as-deposited films, ranging from phase-pure $CuSe_2$ to Cu_2Se."

Binary Cu-Se, In-Se, and Ga-Se materials were developed and then used to produce precursors. Various Cu-Se MOD precursor recipes were also formulated, resulting in tunable phase and stoichiometry in as-deposited films, ranging from phase-pure $CuSe_2$ to Cu_2Se. Figure 5 compares the cross-sectional morphology of vapour-deposited CuSe films to that of atmospheric MOD CuSe films. The remarkable similarity between grain size, morphology and density shows the promise of using solution-based precursors as alternatives for vacuum deposition-produced process materials.

A hybrid CIGS can be produced when one precursor is deposited via PVD and the other precursor in ink form via atmospheric-pressure deposition. Figure 6 features cross-sectional and top-view micrographs of such a film, revealing high-quality, large columnar grains up to 4μm in size. The XRD pattern for the sample in Figure 7 shows that the chalcopyrite CIGS phase is clearly identified.

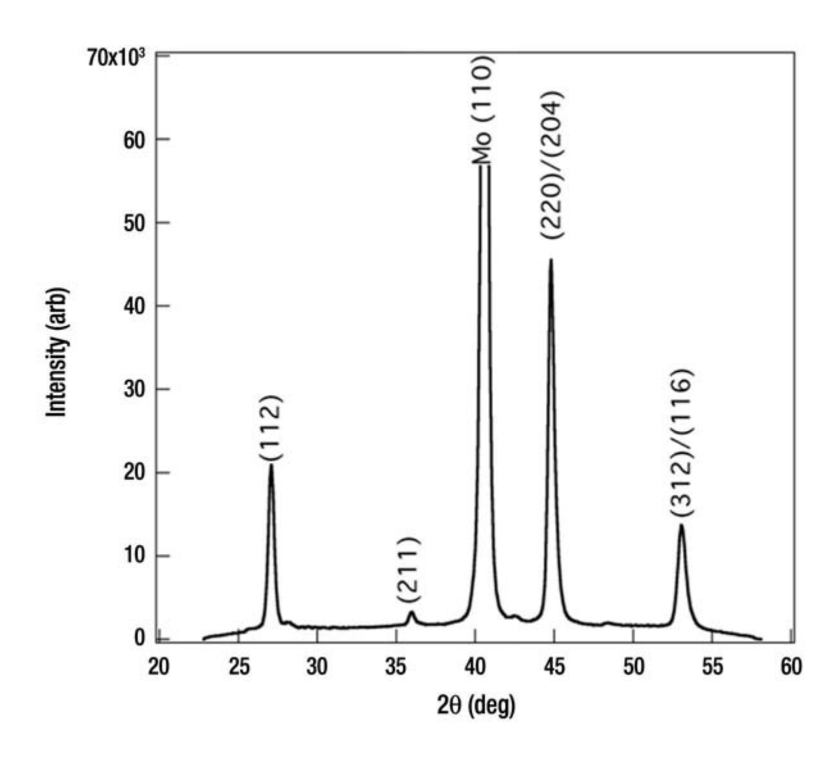


Figure 7. XRD pattern of a CIGS film using a nonvacuum-deposited precursor.

Various In-Se and Ga-Se precursors were developed and used individually and in combination to produce In_2Se_3, Ga_2Se_3, and $(In,Ga)_2Se_3$ films. These films were reacted with solution-deposited Cu-Se to produce CIGS absorber layers on molybdenum/glass substrates. In another approach, a single-source Cu-In-Ga-Se MOD precursor was developed by mixing the binary inks in the proper ratio, then deposited by ultrasonic spray and thermally processed to directly make CIGS.

An important benefit of FASST is that there is no constraint on the combination or type of precursors that can be brought together. The only requirement is that all of the elements in the correct stoichiometry must be present on the substrate and print plate prior to the process.

The tunability, scalability, high throughput, low thermal budget, and capital equipment cost reduction that atmospheric processing of MOD precursors offers is a promising route to the eventual replacement of vacuum deposition methods for CIGS absorber layer fabrication. From a manufacturing

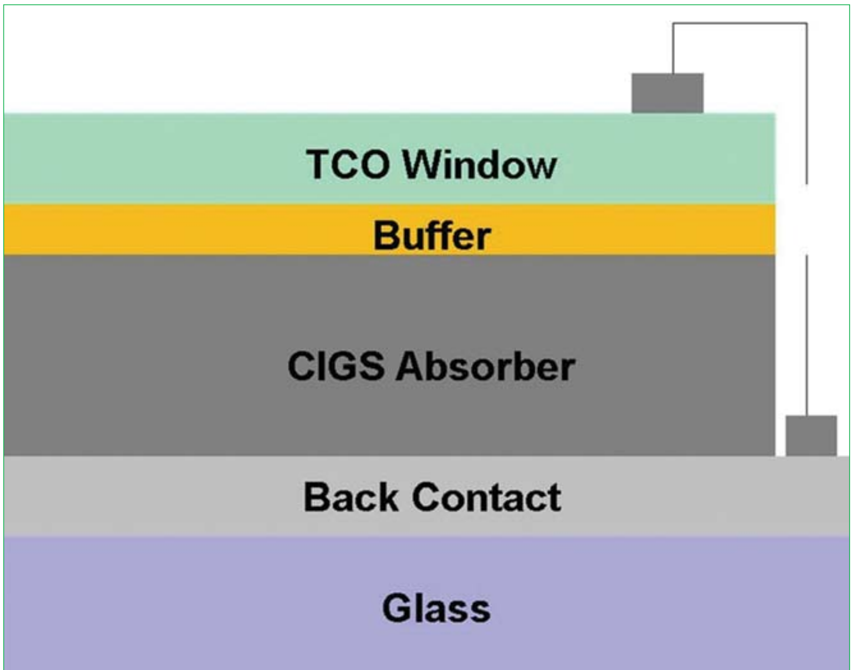


Figure 8. Cross-sectional schematic of a typical CIGS solar cell.

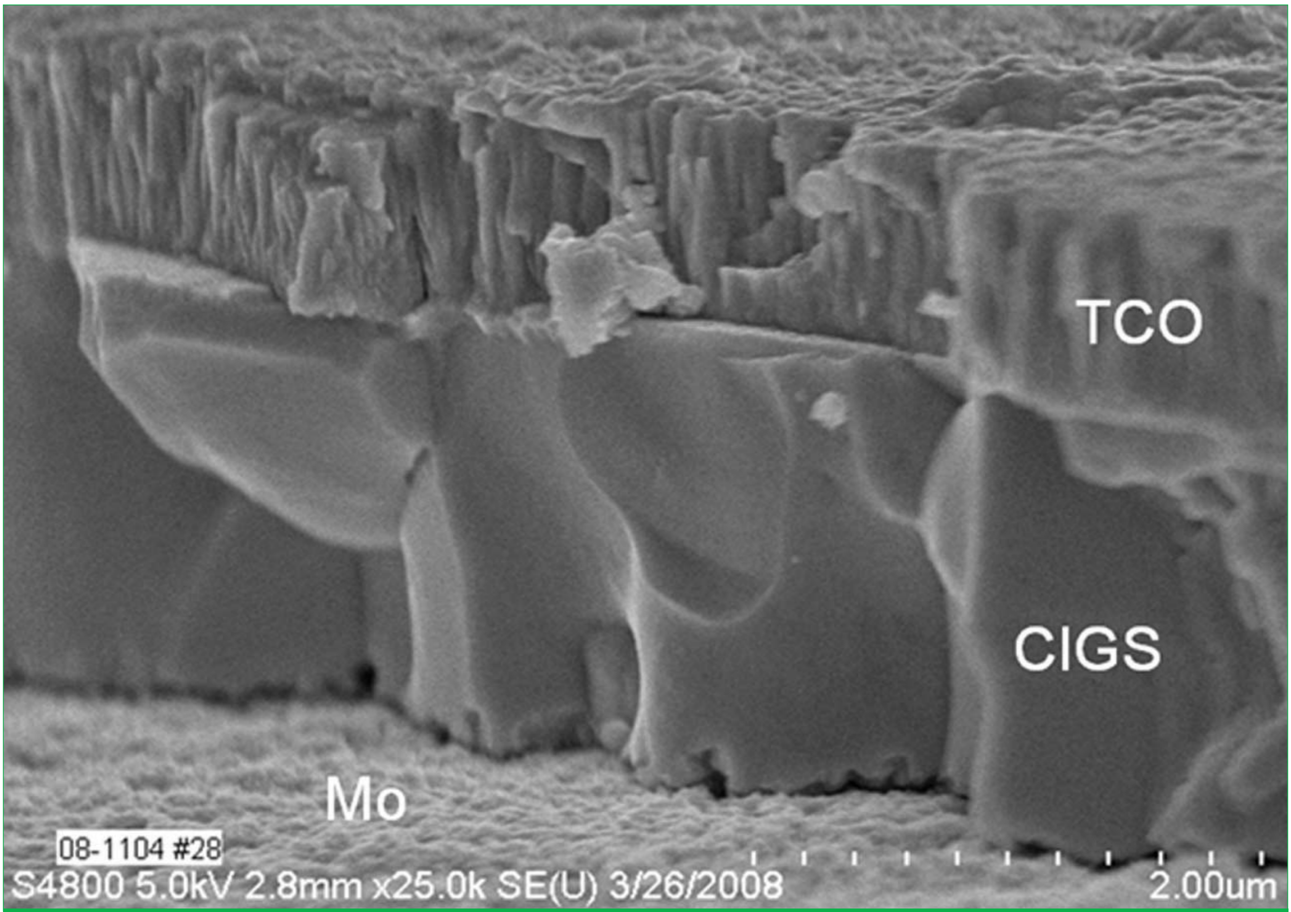


Figure 9. SEM cross-sectional image of a FASST CIGS device.

standpoint, any deposition method, whether it is PVD-based or atmospheric pressure-based, has relative advantages and disadvantages.

While the capital equipment cost for atmospheric-pressure-based systems may be lower than that of corresponding PVD systems, the raw material costs tend to be higher for solution rather than for PVD sources. Therefore, the best choice is ultimately governed by differences in the performance and yield of products manufactured by these two approaches. Because of its better utilisation of materials, atmospheric pressure-based processing offers a compelling CIGS approach, especially once the nanotechnology field matures enough to facilitate the volume availability of low-cost liquid precursors.

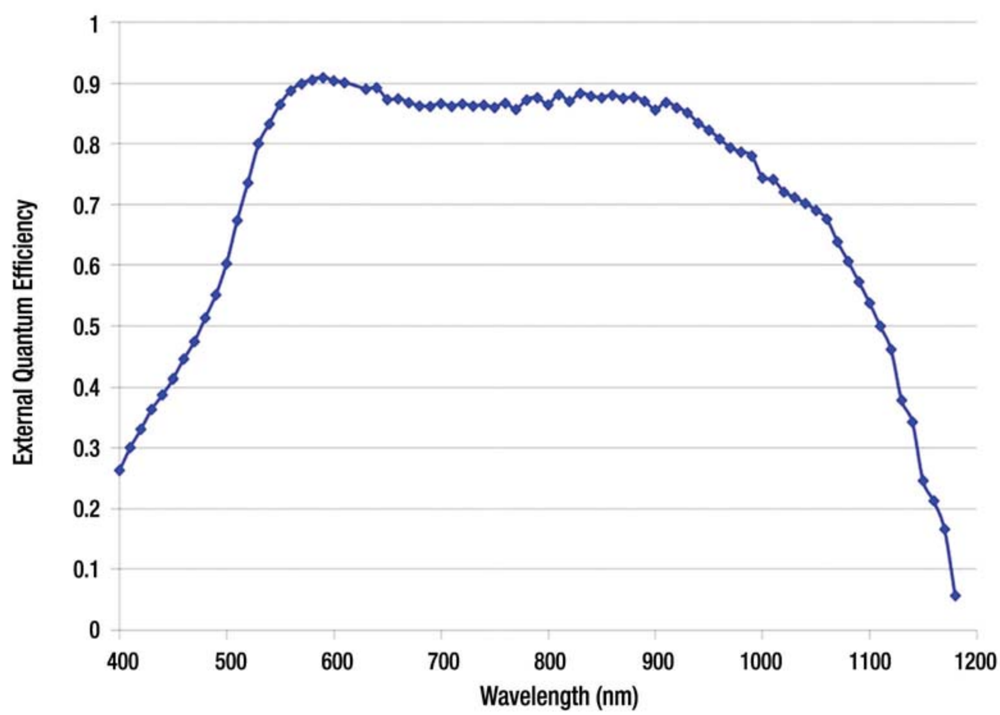


Figure 10. QE curve of a FASST CIGS solar cell.

Analysing CIGS cells, improving efficiencies

As part of the work described in this article, solar cells with a conventional device structure of glass/Mo/CIGS/buffer/TCO were fabricated. The CIGS absorber layers were formed by the FASST process with PVD-based precursors. Figure 8 shows a cross section of a typical CIGS cell, while Figure 9 depicts a cross section of a representative device. As can be seen, high-quality films with large columnar grains were obtained.

Figure 10 shows the external quantum efficiency (QE) versus wavelength for the device without an antireflective coating (ARC). High QE at wavelengths over 550nm reveals very good carrier collection and good performance of the CIGS layer. A low QE at short wavelengths indicates the need to further optimize window layers.

> "An important benefit of FASST is that there is no constraint on the combination or type of precursors that can be brought together."

Solar cells of better than 12% efficiency have been fabricated using the FASST process. A J-V curve of a 12.2% efficient, AR-coated efficient device (based on tests done at Colorado State University) is illustrated in Figure 11. The composition of the CIGS film in this device, as measured by XRF, is 21.8% Cu, 21.6% In, 6.3% Ga, and 50.4% Se, which gives a Cu ratio (Cu/(In+Ga)) of 0.78 and Ga ratio (Ga/(In+Ga)) of 0.22. When the Cu and Ga ratios are optimized, device efficiency should increase using this process. For instance, an open-circuit voltage of 590mV was obtained by increasing the Ga/(In+Ga) ratio to 0.3. Analysis of the J-V data of the device showed a diode quality factor of about 2, and a high saturation current density, which means that the large recombination at the junction region limits the open circuit voltage and fill factor.

Further analysis of the device was carried out by capacitance-voltage measurement [7]. The results from this analytical method revealed a hole density of $2.5\times10^{16}cm^{-3}$ and a depletion width of ~0.2μm. Figure 12 depicts the carrier concentration as a function of distance from the junction, as derived from the C-V data. The hump in carrier density against distance might be a signature of the measurement responding to deep states near the interface [8,9], and direct measurement of deep-level defects would be needed to verify it. Such states have a detrimental effect on the cell efficiency, because they constitute effective recombination paths for forward current opposing the photogenerated current.

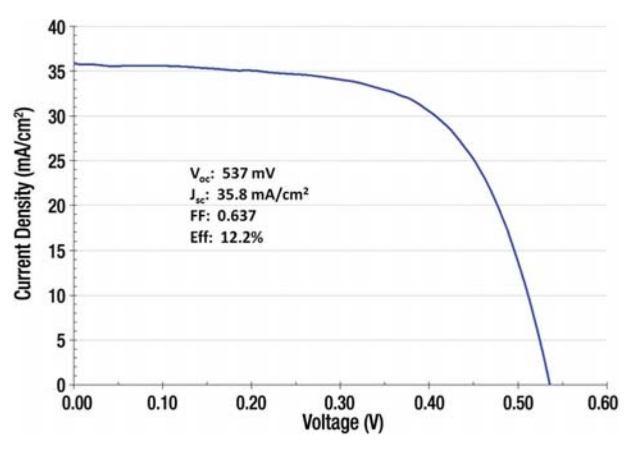


Figure 11. J-V curve of a FASST CIGS solar cell measured by Colorado State University.

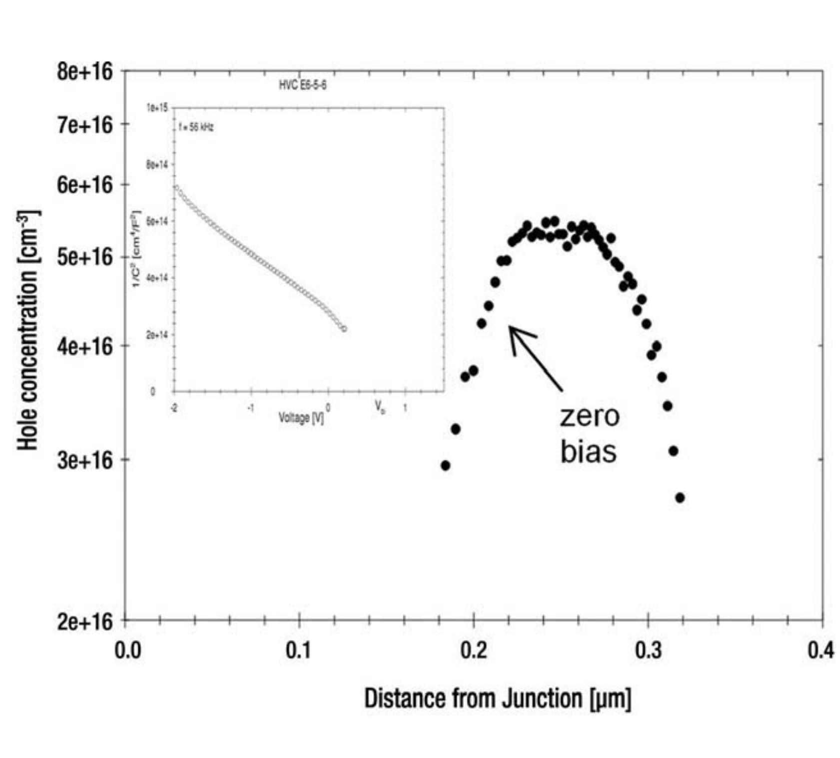


Figure 12. Carrier density as a function of distance from the junction, as derived from a C-V measurement.University.

These kinds of forward currents might also result from enhanced tunnelling recombination through these states [10], suggesting that the interface region, including the CIGS surface termination and post-CIGS treatment, require further optimization. Elimination of these states by improving the CIGS surface termination could significantly improve the open-circuit voltage and the fill factor.

BIPV, solar-powered "skin," and beyond

A novel field-assisted simultaneous synthesis and transfer printing technique, recently deployed in a factory setting, shows great promise for the volume production of high-performance CIGS devices rapidly and at low cost, based on harnessing the key elements required for the creation of high-quality materials. The approach, especially when combined with the use of liquid ink precursors, has the potential to provide a sustainable, long-term technology-based cost advantage and open the doors to further advances in the commercial manufacturing of CIGS thin-film PV.

Since the process is compatible with rigid and flexible glass, metal, alloy, composite, and plastic substrates, it may offer improvements on existing product applications as well as enable many new ones, from traditional glass modules to construction materials that incorporate thin-film PV. True building-integrated PV represents a paradigm shift, paving the way for the construction of buildings with a solar-powered "skin," turning the structure itself into a power plant. Once cost-effective, high-volume manufacturing has been successfully achieved, CIGS-based solar skins could one day become pervasive not only in roofing, curtain walls, and façades, but also in sunshades, skylights, atriums, canopies, and pergolas, with a wide range of form factors, shapes, colours, and transparencies, incorporating dynamic behaviour and innovations in lighting, heating, and cooling.

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Transparent conducting oxides for advanced photovoltaic applications

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ABSTRACT

Transparent conducting oxides (TCOs) are a special class of materials that can simultaneously be both optically transparent and electrically conducting and, as such, are a critical component in most thin-film photovoltaics. TCOs are generally based on a limited class of metal oxide semiconductors such In_2O_3, ZnO and SnO_2, which are transparent due to their large band gap energy and can also tolerate very high electronic doping concentrations to yield conductivities of 1000S/cm or higher. However, these three basic TCOs alone do not meet the TCO performance needs of emerging PV and other applications.

Introduction

Transparent conductors in the form of transparent conducting oxides (TCOs) are critical components in many opto-electronic applications including flat panel displays (FPD) and photovoltaics as well as organic electronics including both organic light-emitting diodes (OLED) and organic photovoltaics (OPV) [1,2]. Unlike most metals which are opaque and most transparent materials, which are insulating, TCOs are a special class of wide band gap (~ 3eV) metal oxide semiconductors such as ZnO, SnO_2 and In_2O_3, which can support high enough free electron concentrations (~$10^{21}/cm^3$) to be effective electrical conductors [3]. Typical good transparent conductors have conductivities of 1000 – 5000S/cm and are transparent from ~ 350 – 1500nm (thereby including the visible portion of the spectrum, 400-700nm). For comparison, we note that copper metal is about 100 times more conductive than a typical TCO. For single-junction PV applications, transparency out to about 850nm is a requirement, which does not put too much of a constraint on TCO materials.

TCOs in photovoltaics

In PV applications, transparent conductors are needed as a contact for collection of the photo-generated carriers while still allowing the light to reach the active solar absorber material. As such, transparent conducting oxides are part of every thin-film photovoltaic technology. The two main PV areas where this is not the case are epitaxial multi-junction III-

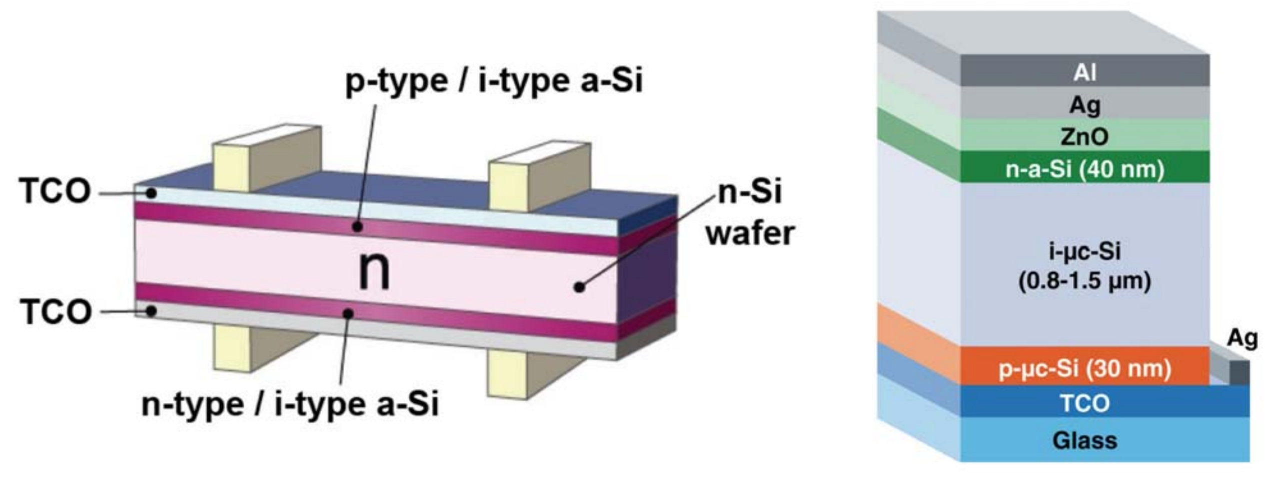

Figure 1. Configurations for Si heterojunction (SHJ) cells with Sanyo HIT cell on the left.

V solar cells (e.g. $GaInP_2/GaAs$) [4] and conventional bulk/polycrystalline Si cells. In these cases, a thin doped top layer of either III-V semiconductor for the former or Si for the latter can provide satisfactory lateral current transport when used in conjunction with a metallic current collection grid. This latter approach is even being integrated with a TCO as discussed later.

Moving onto PV technologies that use TCO contacts, the image on the left of Figure 1 shows the basic structure of a two-sided Sanyo HIT cell (Heterojunction with Intrinsic Thin-layer, [5]). Note the

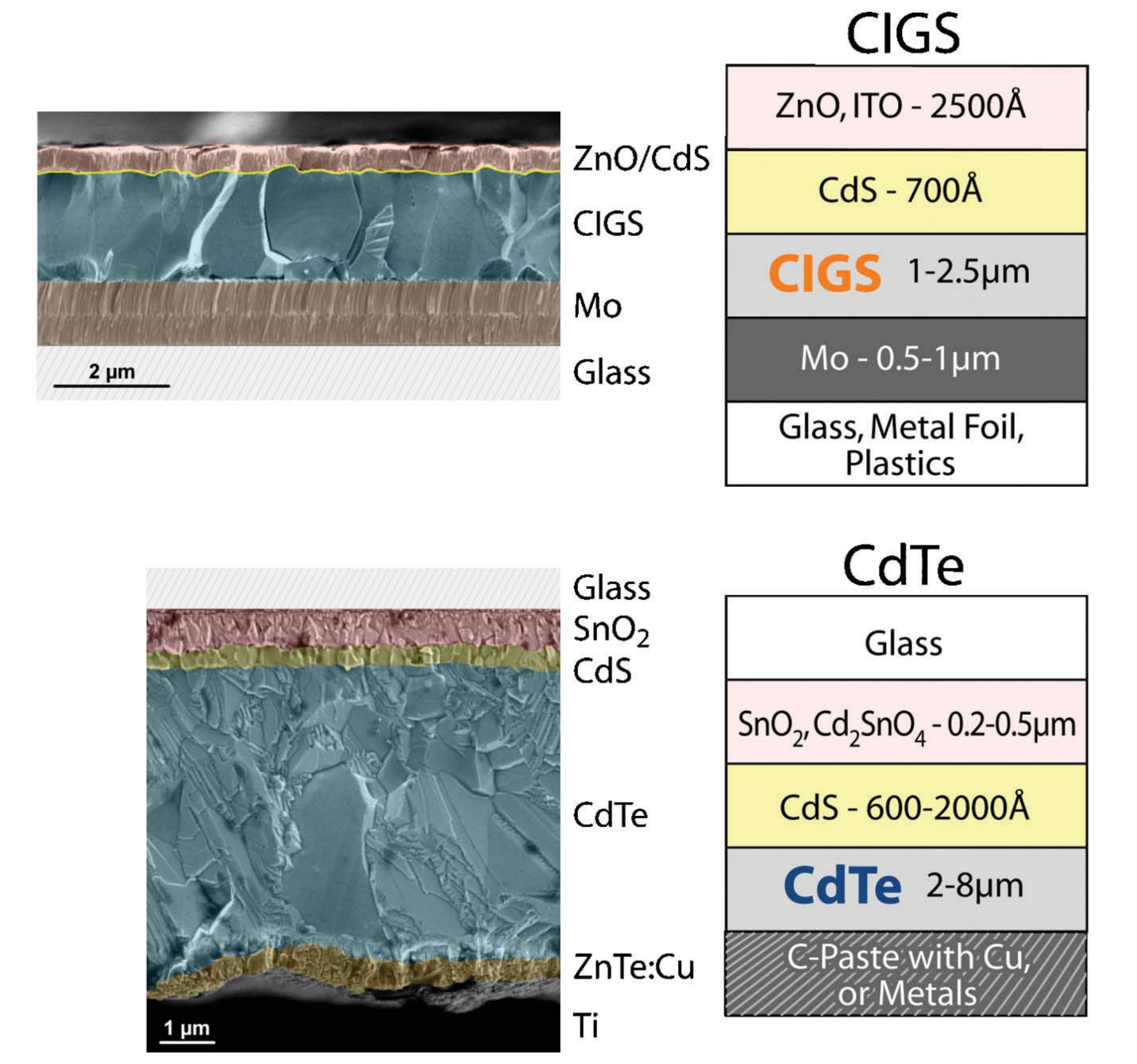

Figure 2. CIGS (top) and CdTe (bottom) PV structures in cross-section.

two TCO layers, one for the top and one for the bottom. The Sanyo-HIT cell is an Si Heterojunction (SHJ) structure which uses thin hydrogenated amorphous Si (a-Si:H) layers in conjunction with a crystalline Si core [6]. The image on the right in Figure 1 shows a more expanded view of a one-sided SHJ structure. Note that even for this structure, there are still two TCO layers. ZnO is part of the top of the TCO/metal multilayer top contact and TCO-coated glass forms the transparent bottom contact for this device. In these SHJ structures, the a-Si layers effectively passivate the c-Si surface, but, due to the low carrier mobility in a-Si, a TCO layer is needed for lateral current conduction to avoid resistive losses. Indium-tin-oxide is typically used in this application [6].

"The range of possible compositions for TCOs is enormous, covering 75% of the tie line between $CdIn_2O_4$ (x = 0) and Cd_2SnO_4 (x=1)."

The upper half of Figure 2 shows a cross-sectional image and schematic for a Cu-In-Ga-Se (CIGS) thin-film solar cell. The primary absorber layer is the CIGS, which has the $CuInSe_2$ structure, but with Ga partially substituted for In to optimize the absorber band gap energy. CdS is deposited over the CIGS to form the junction and then a TCO top layer is used as the transparent electrical contact. In the highest efficiency CIGS cells, a TCO bilayer composed of first undoped ZnO deposited directly onto the CdS layer and then a high conductivity Al-doped ZnO (AZO) on top provides the lateral current conduction [7]. The TCO layer must be deposited at ~ 200°C or lower to avoid degrading the CIGS/CdS junction. Similarly, the lower half of Figure 2 shows a cross-sectional image and schematic for a CdTe/CdS solar cell. In contrast to the CIGS device where the TCO layer is the last layer deposited, the CdTe layer stack begins with TCO coated glass that then becomes the substrate for the subsequent CdS, CdTe and metallic back-contact layers. This allows higher growth temperatures to be used during the TCO layer growth and the F-doped SnO_2 or bilayer Cd_2SnO_4/Zn_2SnO_4 are the standard TCOs for CdTe cells [8,9].

TCO materials and thin-film growth

Figure 3 depicts the conventional five basis set of metal oxides (SnO_2, In_2O_3, ZnO, CdO and Ga_2O_3) which form the majority of crystalline TCOs when appropriately doped. Sn-doped In_2O_3 (ITO), Al-doped ZnO (AZO) and F-doped SnO_2 (FTO) are by far the most commonly used TCO materials at present. CdO can have extraordinarily good electrical properties if neither the yellow colour due to lower band gap energy nor the toxicity of Cd preclude its use. On its own, Ga_2O_3 is not conducting enough to be a practical TCO but it is included as a basis oxide for its role in more complex TCOs such as $GaInO_3$ [10]. Similar binary metal TCO compounds with simple stoichiometries, such as those that lie in the composition space depicted in Figure 3, include Cd_2SnO_4, Zn_2SnO_4, and $In_2Zn_2O_5$ [10,11]. When TCOs formed from three basis oxides are considered, broad ranges of compositions and structures become possible. For examples, in the Cd-In-Sn-O system, $Cd_{1+x}In_{2-2x}Sn_xO_4$ over the range 0 < x < 0.75 can be made [12]. The range of possible compositions for TCOs is enormous, covering 75% of the tie line between $CdIn_2O_4$ (x = 0) and Cd_2SnO_4 (x=1).

With the exception of CdO, which is light yellow in colour, all of these materials just discussed are inherently transparent in the visible when made undoped and fully oxidized. To achieve practical electrical conductivities of 1000S/cm or greater, these TCO host matrix materials must be effectively doped to create free carrier concentrations on the order of 10^{20} – $10^{21}/cm^3$. The simple single basis oxide materials are almost always made with explicit substitutional doping. Both ZnO and In_2O_3 are usually doped on the

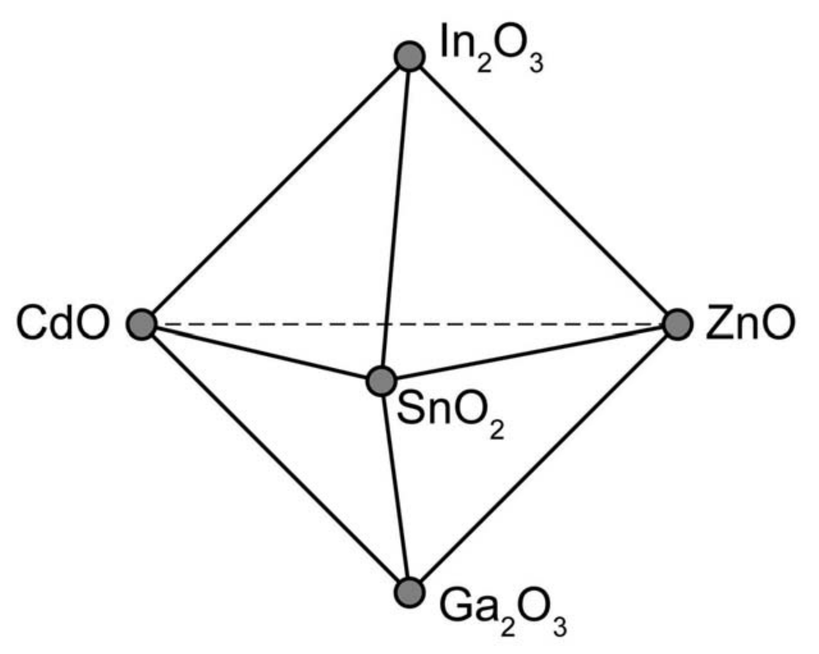

Figure 3. Composition space for conventional TCO materials.

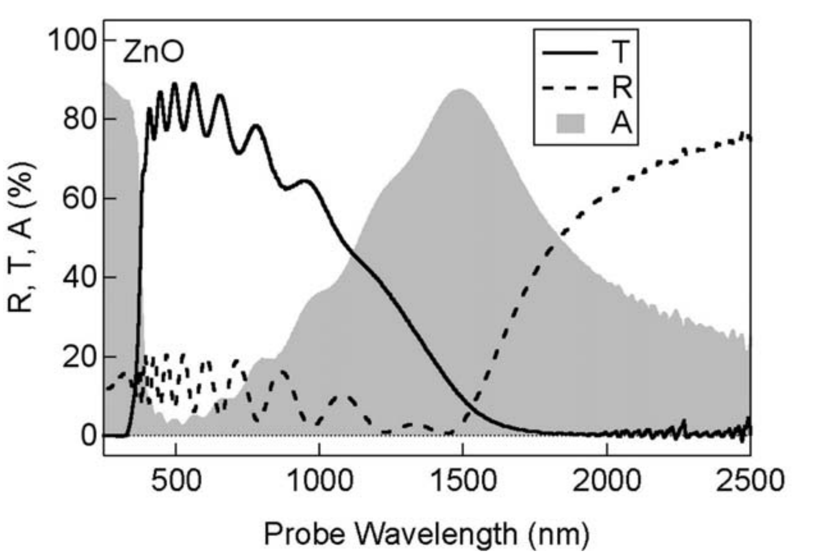

Figure 4. Optical spectra of typical (ZnO) transparent conductor.

cation site with Al to give $Zn_{1-x}Al_xO$ and Sn to give $In_{2-x}Sn_xO_3$ respectively [13]. SnO_2, on the other hand, is generally doped on the anion site using fluorine to give $SnO_{2-x}F_x$ but it can also be doped on the cation site using Sb [14].

For Al-doped ZnO and Sn-doped In_2O_3, sputtering is the most common method of thin-film deposition. High quality thin films can be grown either by sputtering from ceramic metal oxide targets or by reactive sputtering from metal alloy targets. Other physical vapour deposition (PVD) methods used to deposit these and other TCO materials include evaporation and pulsed laser deposition, a technique which is excellent for proto-typing new materials even if it is not yet practical for large-area commercial deposition. In contrast, SnO_2 is generally deposited using spray pyrolysis or various forms of chemical vapour deposition (CVD). Spray pyrolysis deposited SnO_2:F has been a mainstay of the TCO industry for decades, especially for low-e windows and IR selective windows. We note that PVD-deposited SnO_2 is generally less conducting for reasons that are not fully understood at present [14,15].

Basic opto-electronic properties

Figure 4 shows the optical reflection, transmission and absorption spectra for a typical commercial ZnO TCO on glass. Collectively, these show the key spectral features of a TCO material. First, the material is quite transparent, ~ 80%, in the visible portion of the spectrum, 400 – 700nm. Across this spectral region where the sample is transparent, oscillations due to thin-film interference effects can be seen in both the transmission and reflection spectra. The short wavelength cut off in the transmission at ~ 300nm is due to the fundamental band gap excitation from the valence band to the conduction band of the basis semiconductor, ZnO in this case. The gradual long wavelength decrease in the transmission starting at ~ 1000nm and the corresponding increase in the reflection starting at ~ 1500nm are due to oscillations of the conduction band electrons known as plasma oscillations, or plasmons for short. The corresponding schematic electronic structure for a heavily doped semiconductor with a completely filled lower valence band and significant free electron density in the upper conduction band states is shown in Figure 5. What distinguishes TCOs from conventional semiconductors is that the valence band to conduction band (band gap) energy is very large, 3eV or more, which makes TCO materials transparent in the visible spectrum. Furthermore, TCO materials allow for conduction band free carrier densities as high as 10^{21} electrons/cm^3, which enables the high conductivities.

> "One fundamental reality of TCO materials is that there is an inherent tradeoff between conductivity and the long wavelength transparency limit."

Returning to the optical spectra in Figure 5, there can also be substantial absorption due to these plasma oscillations as is the case for this particular sample with the maximum absorption occurring at the characteristic plasma wavelength, λ_p. As the number of electrons in the conduction band, N, is increased, such as by substitutional doping, the plasma wavelength shifts to shorter wavelengths as $\lambda_p \propto 1/\sqrt{N}$ which also effects the electrical conductivity (σ) since $\sigma = Ne\mu$ where e is the electron charge and μ the electron mobility [16]. Hence, one fundamental reality of TCO materials is that there is an inherent tradeoff between conductivity and the long wavelength transparency limit. At very high electron

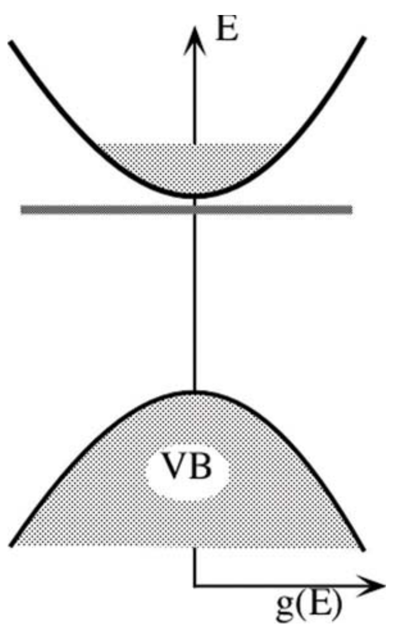

Figure 5. Schematic electronic structure of TCO materials.

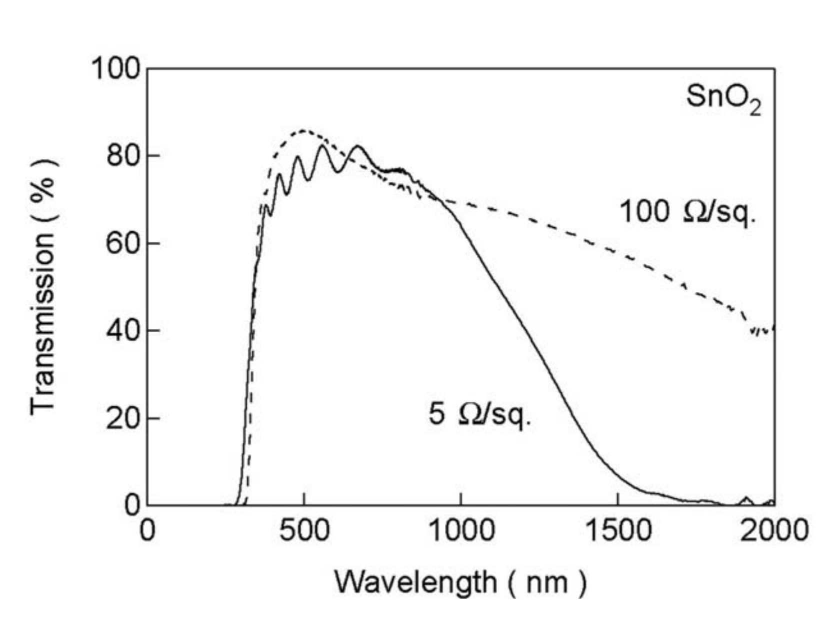

Figure 6. Optical transmission spectra of SnO_2 TCOs with different sheet resistances.

concentrations, this can even decrease the visible wavelength transparency.

For example, Figure 6 shows how the infrared transparency increases for SnO_2 TCOs as the sheet resistance is increased from 5Ω/sq. to 100Ω/sq. Even though both of these SnO_2 samples have similar visible wavelength transparency, the 5Ω/sq. sample would be unusable as a transparent conductor for telecom applications at 1500nm. TCO optimization includes not just the inherent trade-off between conductivity and transparency just discussed, but also many other application-specific constraints such as chemical compatibility, required deposition temperature, stability at the operating temperature and surface roughness, among others. Collectively, these examples should make it clear that there is no such thing as a single 'best' TCO and that TCOs must be tailored to the constraints of the specific application. This includes not just the broad distinction between TCOs for flat panel displays, PV and telecom, but also the distinct TCO requirements for the different thin-film PV technologies. This 'set' of requirements is what is driving the development of new TCO materials in a number of application areas.

Recent materials developments

Three recent trends in new TCO materials research are: 1) The development of high electron mobility materials; 2) The use of amorphous mixed metal oxide TCOs which can be deposited at low or even ambient temperature, and 3) The discovery of TiO_2-based TCOs. The practical industry standard reference point for this new materials development is crystalline ITO with 10wt.% SnO_2 in In_2O_3 deposited at 250 – 350°C which typically has electron mobilities of ~ 30cm^2/V-sec.

Figure 7 shows the electrical conductivity, carrier concentration and electron mobility for Ti-doped In_2O_3 on glass grown by sputtering [17]. Of particular note are the high mobilities, > 80 cm^2/V-sec, observed for films with Ti concentration of 1-2%. This is attributed primarily to the high doping efficiency of Ti in In_2O_3, which is found to be near unity for Ti concentrations near 2%. For comparison, in most ITO the doping efficiency of Sn is about 1 electron per 4 Sn atoms. Mo-doped In_2O_3 is also a high mobility variant on doped indium oxide with mobilities of 60cm^2/V-sec for sputtered films on glass [18] and as high

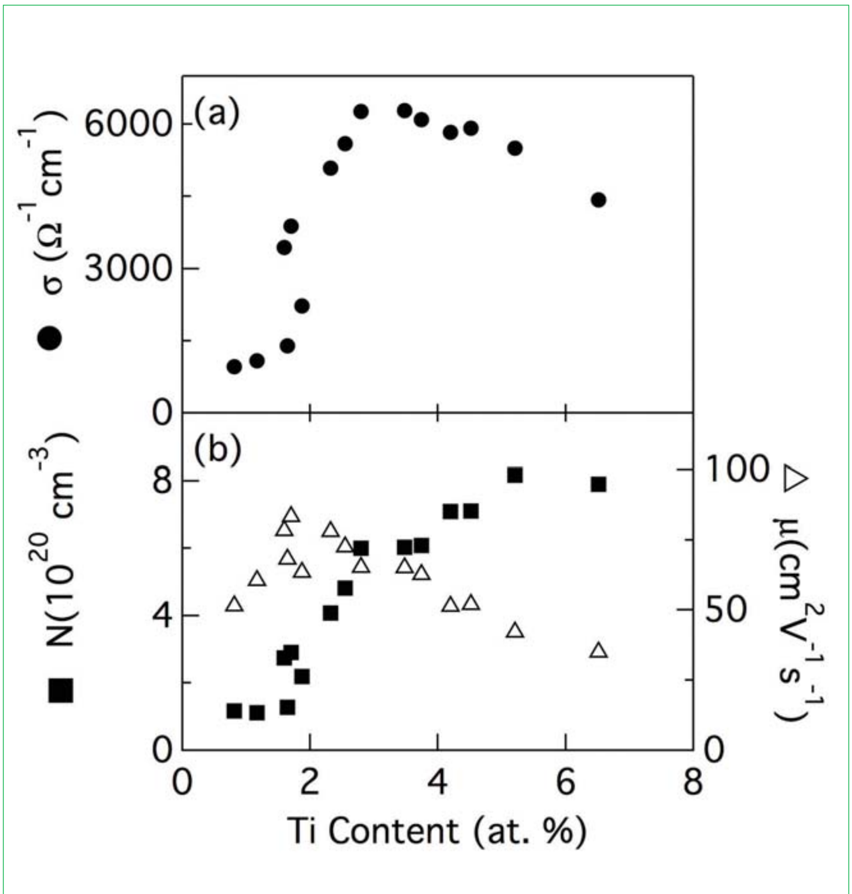

Figure 7. Electrical conductivity (σ), carrier concentration (N) and mobility (μ) of Ti-doped In_2O_3.

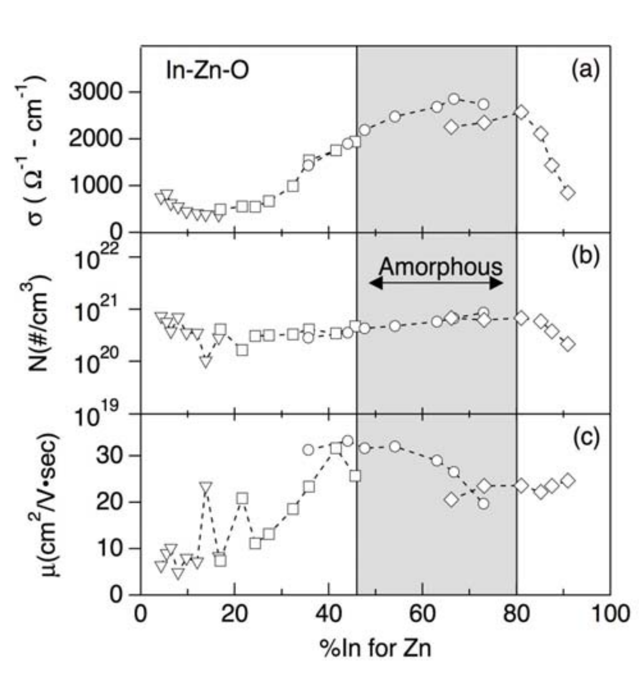

Figure 8. Electrical conductivity (σ), carrier concentration (N) and mobility (μ) of In-Zn-O.

as $125 cm^2/V$-sec for films deposited by PLD onto single crystal substrates [19]. Interestingly, in this case the doping efficiency is less than half of that for the Ti.

While traditional TCOs are highly crystalline, recently, a new class of amorphous TCO materials, typified by amorphous In-Zn-O (a-IZO) and based on double (or triple) oxides of heavy metal cations with ionic electronic configuration $(n-1)d^{10}ns^0$ has emerged [20,21]. These materials typically exhibit an electron mobility of $30–60 cm^2/V$-sec, which is unusually high and is thought to arise from the direct spatial overlap of the large and spherical heavy metal cation ns^0 orbitals and the lack of grain boundaries. For comparison, typical thin-film amorphous Si has mobilities of less than $1 cm^2/V$-sec. Technologically, a-IZO and similar materials are of great interest because they can be easily deposited onto glass or plastic substrates by ambient temperature sputtering, have excellent optical and electrical properties, are very smooth ($R_{RMS} < 0.5$nm) and once deposited, do not crystallize until heated to 500°C or higher [22]. Figure 8 shows the electrical conductivity, carrier concentration and electron mobility as a function of metals composition for IZO films grown by composition gradient combinatorial sputtering [23]. Note that broad conductivity maximum with $\sigma \approx 3000$S/cm occurs in the composition range which is amorphous, ~ 55 to 80 at. % indium in this case. While for transparent conductor applications, a high carrier concentration is needed, we note that when grown in the presence of 5 – 10% oxygen, these amorphous mixed metal oxides have carrier concentrations of order $10^{16} – 10^{18}/cm^3$ and are being developed as channel layers for transparent thin-film transistors (TTFTs) [24,25]. At present, amorphous In-Ga-Zn-O is the primary material of interest for TTFT applications.

Recently, Nb and Ta-doped TiO_2 have been shown to be good transparent conductors with conductivities of ~ 3000S/cm on single crystal substrates and ~ 2000S/cm on glass [26-28]. The highest conductivity has been observed for the Nb-doped materials and some recent theoretical results support this [29]. In a simple electron counting model for TiO_2, the Ti^{4+} has no electrons in the 3d states, which contradicts the conventional wisdom that metal oxide materials for TCOs should always have filled d-shell states. To obtain these good TCO properties, the TiO_2 must have the anatase structure perhaps due to a much lower effective mass than rutile. The more common rutile TiO_2 is not a good TCO. At present, it is not known whether anatase TiO_2 is the first member of a new general class of TCOs or a singular exception to the filled d-states rule.

Organic PV applications

TCO materials are also critical in organic photovoltaics (OPV), where they can be used in a conventional geometry as shown in Figure 9 or in an inverted geometry where the oxide becomes the electron acceptor. Clearly, these two configurations require very different characteristics for the TCO in terms of electron affinity, surface chemistry and even doping level. A typical layered structure for the conventional bulk heterojunction is shown in Figure 9 where the TCO acts as the hole extraction contact in conjunction with either an organic or inorganic hole transport layer (HTL). In this application, reducing the energy level mismatch between the Fermi level of the TCO and the highest occupied molecular level (HOMO) of the organic semiconductor is believed to be central to improving the current collection and operating voltage. In general, for TCOs used in typical bulk heterojunction OPV (Figure 9), higher work function TCOs are needed to improve the energy level matching [30].

Alternatively, TCOs or similar materials may also have applications as the electron acceptors in an inverted OPV device. In this case, lower work functions TCOs are needed to move the conduction band higher and thus increase the open circuit potential. In these devices, due to the strong exciton binding energy and short exciton diffusion length in organic semiconductors, the photo-excited excitons (electron-hole pairs) can only be effectively split by an interface-induced charge separation, where the electron is transferred from the organic absorber to the acceptor. In this case, TCOs with a higher band gap energy (lower work function) are desired to avoid voltage loss when the electron transfers from the lowest unoccupied molecular orbital (LUMO) of the organic to the TCO conduction band. Figure 10 shows both the band gap energy increase in ZnO (shorter wavelength absorption edge) due to substituting Mg in place of Zn and the corresponding increased open circuit voltage in a simple planer OPV device where Zn(Mg)O is used as the electron acceptor [31]. Overall, the substitution of Mg for Zn in ZnO decreases the band offset between the LUMO of the polymer donor and the conduction band of the acceptor metal oxide material. As shown in the inset, the V_{OC} was increased from 500 to 900mV in the P3HT–$Zn_{1-x}Mg_xO$ devices through the substitution of Mg into ZnO over a range of 0 to 30% Mg for Zn. However, to be effectively incorporated into a practical OPV device, this basic materials result would have to be transferable to an intercalated metal-oxide/organic active layer structure with nanometre-length scales. This remains an active area of research.

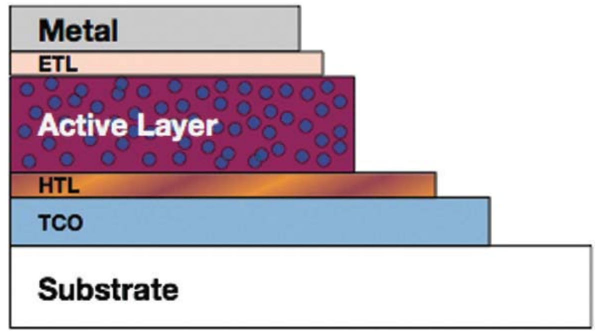

Figure 9. Schematic cross-section of an organic photovoltaic (OPV).

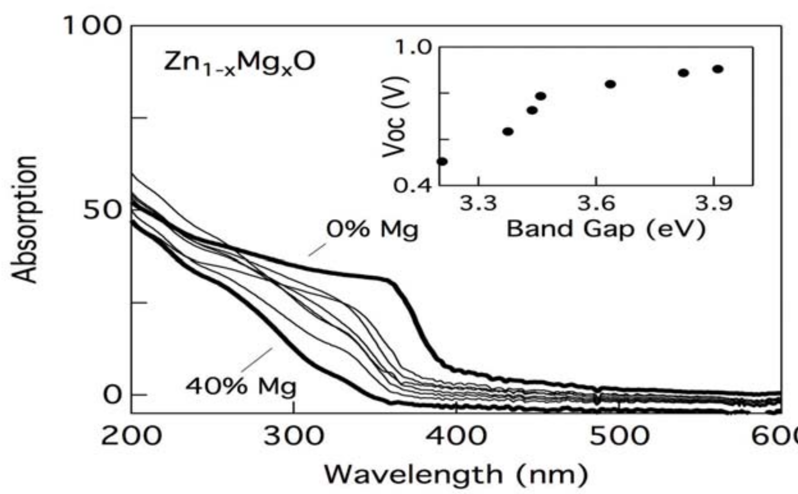

Figure 10. Optical absorption of Mg substituted ZnO. Inset: Effect of TCO band gap on OPV open circuit voltage.

Summary

Thin film photovoltaics require an optically-transparent electrically-conducting contact layer to enable current extraction while allowing sunlight to reach the active PV junction. For most PV applications, this need is met with transparent conducting oxides that are heavily doped wide band gap semiconductors. Crystalline Sn-doped In_2O_3 is the industry standard with Al-doped ZnO and F-doped SnO_2 also being used commercially. However, due to factors such as cost, reactivity, deposition temperature and stability, these three materials are not sufficient to meet the TCO requirements for emerging high performance applications both in PV or other opto-electronic applications. Consequentially, new materials are being actively developed. A few important areas of current TCO materials research include compositionally complex binary, ternary and beyond materials, amorphous mixed metal oxide TCOs, early transition metal series TCOs and higher performance dopants. The past decade has seen a resurgence in TCO research and significant advances are likely in the next five years.

Acknowledgements

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Laser scribing exposed: the role of laser-based tools within the solar industry

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ABSTRACT

Laser-based tools have become increasingly visible within R&D labs, pilot production lines, and as the preferred technology used by many turnkey suppliers. As equipment types however, relatively little is known about the differences in the laser-based tools used for solar applications within each of the c-Si and thin-film segments. This paper explains the key components of a laser-based tool, and how they are adapting to meet the demands from next-generation production line equipment required by the solar industry.

Introduction

Historically, the solar industry has been cautious – indeed, somewhat reticent – embracing laser technology within cell manufacturing production lines; using lasers often as a last resort, not as technology enabling. This reticence is matched by widespread ambiguity as to lasers' functionality, capability, and role within the equipment supply chain. Indicative of this uneasiness is a generic label assigned frequently to any tool that just happens to include a laser: the so-called 'laser scriber'. Therefore, it is perhaps no big surprise that speculation permeates throughout the industry as to what a laser scriber really is. Why would manufacturers actually use them? And how do engineers choose the appropriate combination of scribing tool and laser source to work best in a specific production environment?

This article explains what a laser-scribing tool is comprised of, why they are used by solar cell manufacturers, and where they get utilized throughout the value chain. Their prominence within the industry is then highlighted by analyzing market dynamics specific to laser scribers; how big the market is for solar laser scribers, what the trends are, and what the laser scriber of tomorrow will look like.

Case studies are discussed to best illustrate each of these themes. Nomenclature is proposed to describe more clearly the different processes performed by lasers within the solar industry, and how such a classification provides better labels for different types of laser scribers.

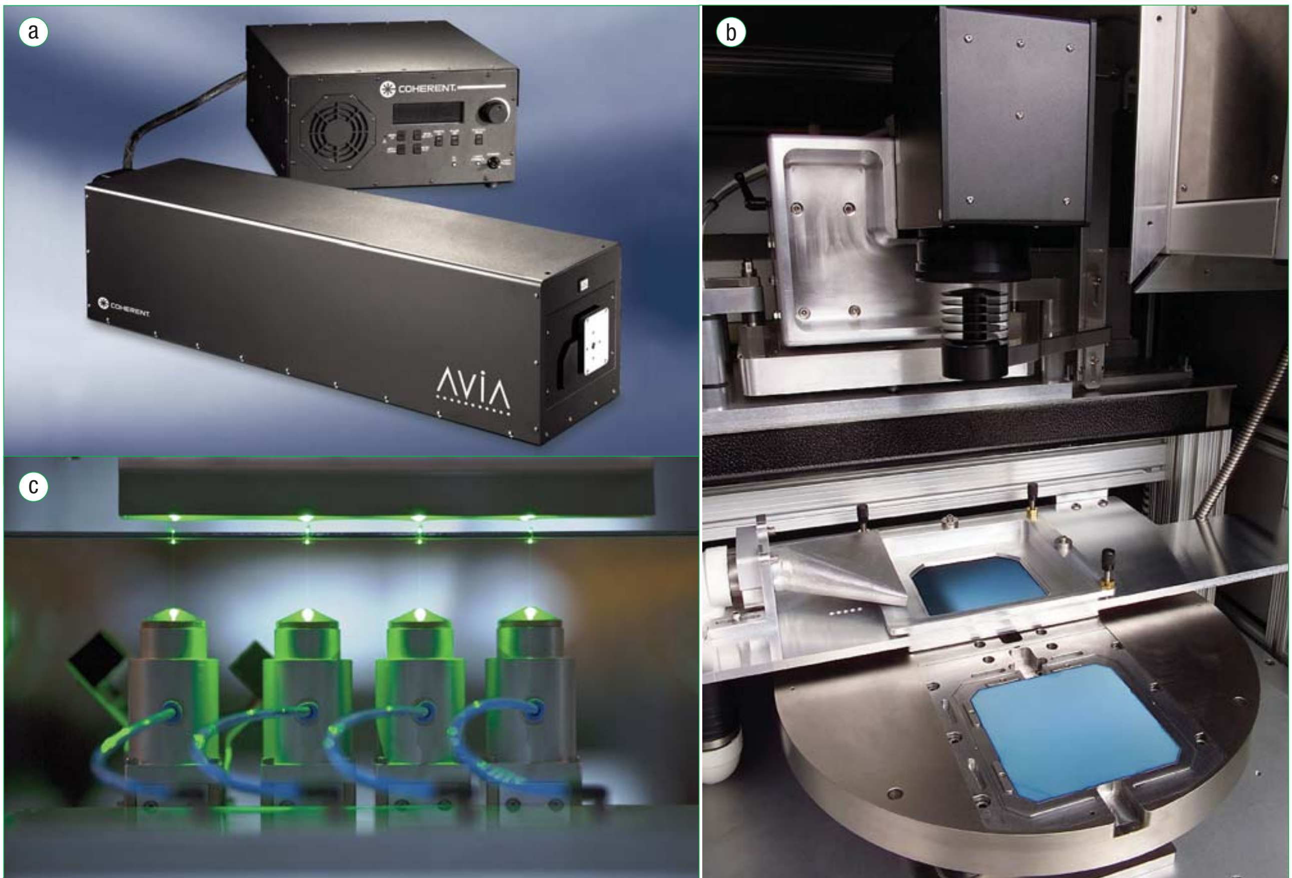

Figure 1. A laser-based tool is typically comprised of a laser source (a), like the Coherent AVIA. (b) shows a c-Si beam-delivery assembly taking the laser beam from source to sample; scanner (black box, top centre), c-Si vacuum chuck and wafer turntable. In thin-film tools, beams can be split for simultaneous patterning (c), courtesy of Oerlikon Solar Ltd., Trübbach, Switzerland.

'Laser scriber' or 'laser-based tool'?

The misleading terminology should first be clarified: 'scribing' simply happens to be one of many different processes that lasers can perform; others commonly used within the solar industry include drilling, melting, cutting and selective ablation. To be consistent with 'non-solar' market segments, and aligned with solar-familiar terms such as plasma-etching tool or screen-printing tool, it is more useful from a top level to refer to any production equipment using a laser source simply as a 'laser-based tool.' Later in the article, a family of laser-based tool names is proposed that encompass all processes enabled by laser-based tools in the solar industry.

Laser-based 'tools' differ from laser 'sources.' And indeed, equipment supply for each of these has historically been different. Laser manufacturers produce laser sources, while tool suppliers make laser-based tools, for which they buy in the most suitable source from a laser manufacturer and then integrate this within a production-ready tool. Of course, some suppliers manufacture both laser and tool. While the laser source is by far the most important line item within the bill of materials of any laser-based tool, there are other key features which influence overall tool performance: beam delivery components to optically couple the laser beam from source to sample; the use of moving (or 'flying') optics or fast scanning mirrors to redirect the laser beam across the target sample; handling and automation of either silicon wafers or thin-film panels into (and out of) the tool workplace.

Figure 2. Examples of some laser-based tools used in cell and panel production lines.

Images courtesy of (2a) M-Solv, Oxford, UK, (2b) InnoLas Systems GmbH, Krailling, Germany, (2c) Schmid Technology GmbH, Schwetzingen, Germany, (2d) Shirai Tech. Inc., Shirai, Japan / Applied Photonics Inc., Arizona, USA.

Figure 1 shows the key components within laser-based tools while Figure 2 includes typical workstations used today within production environments.

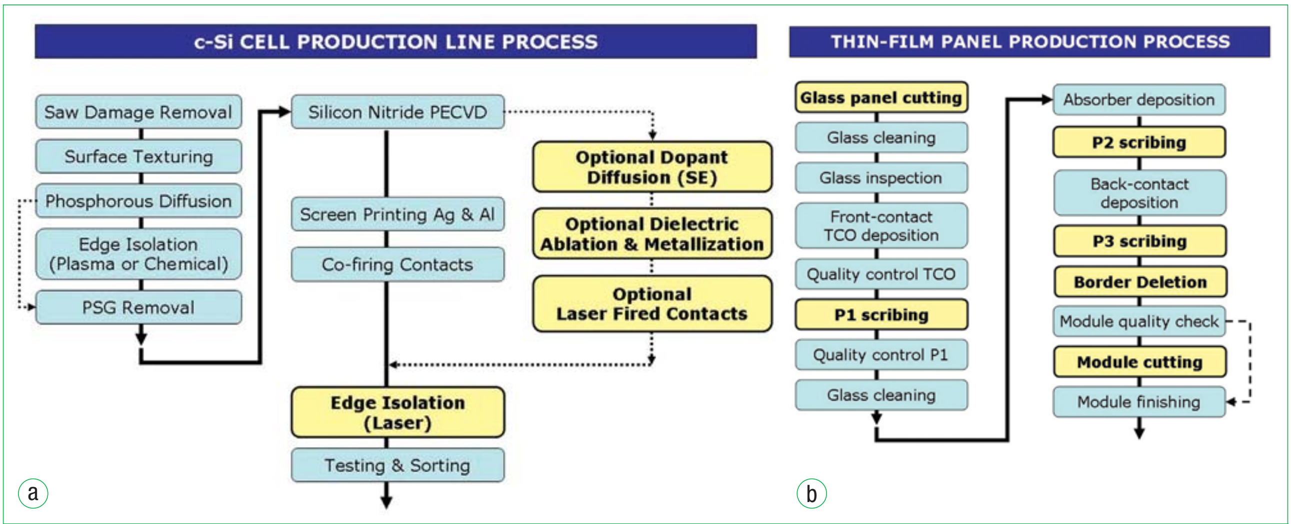

Figure 3. Yellow flow-chart boxes reveal the possible locations of laser-based tools within the value chains for c-Si (a) and thin-film (b). In the c-Si segment, additional laser processes are found upstream (cutting), downstream (module soldering), and during stages specific to back-contact cell designs (e.g. IBC, EWT, or MWT).

Why use laser-based tools?

Understanding why laser-based tools are adopted in production lines is the question most commonly asked by colleagues working at the interface of the solar and laser industries. The reason for this importance is that the tools can be applied to both c-Si and thin-film solar fabs, and also that they bring processes from analogous steps within the microelectronics and flat-panel display sectors. Put simply, laser-based tools enable production steps to be done in a non-contact manner. This results in benefits that are equally applicable to c-Si and thin-film production line users:

- Maximize yield levels in solar fabs. Eliminating any risk of bulk microcrack formation or material strength reduction is of paramount importance both for sub-180μm-thick silicon wafers and large Gen 5 or higher solar glass panels.
- Increase production line throughput. Laser-based tools offer high-speed material processing via automated, inline, horizontal substrate handling.
- Reduce manufacturing costs, best measured by a fully amortized $/wafer analysis, which would factor in capital and operating costs and material process parameters (yield, throughput, utilization rate, etc.) over a typical five-year equipment life-cycle.

- Increase the final panel efficiency. The rationale for implementing laser-based tools diverges here somewhat for c-Si and thin-film production steps. For c-Si cells, the drivers for laser-based tools fall primarily into the category of next-generation, high-efficiency cell concepts; for thin-film panels, the goal is process optimization within simplified production lines.
- Differentiated technology. With so many c-Si manufacturers using etching tools today, those who migrate first to laser-based processes can promote their production lines as 'next-generation'.

While the dual benefits of increased efficiency and reduced cost play directly into the fundamental driver to lower final $/W metrics, ultimately it is the composition of the laser-based tool which determines the return-on-investment to any cell or panel producer. Indeed, this only emphasizes the problem when referring to all laser-based tools as laser scribers, and calls for a much deeper understanding of laser-based tools in general.

Laser-based tools in the value chain

In a recent article by the author [1], the various applications for lasers within the solar industry were reviewed in detail. This included categorizing the processes by segment (c-Si or thin-film) and by their 'production status' (widespread production, partially adopted, or R&D). In this paper, this analysis is moved one rung up the supply-chain ladder, by describing from a top-level where laser-based tools are employed within the value chains for each of c-Si and thin-film production. In Figure 3, the location of laser-based processes is clarified. (The processes shown in Figure 3a include laser-based steps that may be incorporated within a 'standard' c-Si line with discrete front and rear contact formation. Flow diagrams for other cell types, such as back-contact variants, would require individualized representation.) In general, laser-based tools find most widespread application at the wafer-to-cell stage for c-Si production, and at the 'equivalent' panel stage in thin-film manufacturing.

However, the market adoption for laser-based tools within c-Si and thin-film production reveals an important differentiator between these two segments. In thin-film panel production, laser-based tools represent an established and preferred choice of tooling equipment (see Figure 4 for a glimpse of laser tools running inside an Oerlikon thin-film fab). All thin-film patterning stages (referred to as the P1, P2, and P3 process stages) have identified lasers as the optimum production tooling. The exception to this generalization today are the CIGS P2 and P3 stages where research is ongoing to find the optimum laser process window. In current c-Si production lines, the standard c Si cell architecture (with screen-printed and fired front Ag contacts and a full-Al back-surface-field) can readily be manufactured through use of an off-the-shelf turnkey production line, which – crucially – may not contain a single laser-based step. Therefore, laser-based processes within c-Si production fall broadly into categories of 'advanced' (e.g. most of the back-contact cell types, like IBC, RISE, or EWT/MWT) and 'next-generation' (non-contact electroless plated contacts, thin wafers with rear passivation layers, selective emitter designs with localized doping, or LFC) [2]. A final category summarizes processes where laser-based tools are directly competitive with traditional equipment types such as mechanical cutting, etching, or sand-blasting; this covers c Si Edge Isolation, wafer cutting and cell singulation, and thin-film glass cutting and panel border deletion.

The market for laser-based tools

Each of the issues discussed above contributes towards the size and dynamics of the overall market for laser-based tools, both historically (2000-2008) and forecast (2009-2012). In fact, limited market analysis exists today, reflecting the somewhat peripheral entrance of laser-based tools historically within solar production lines. This is partly because laser sources have been introduced at

Figure 4. Laser-based tools within the solar industry are perhaps best represented by the thin-film patterning tools employed within turnkey Oerlikon thin-film production lines (image courtesy of Oerlikon Solar Ltd., Trübbach, Switzerland).

different tier levels in the supply chains, by laser-based tool suppliers or 'integrators' (most common in the c-Si market segment); by turnkey production line suppliers; and, in some cases, directly by cell and panel producers.

Figure 5 uses data from a recent 'laser-source-only' solar market analysis [3], coupled with typical factors known within the laser industry that relate laser cost to tool cost [4]. Close agreement is seen with a 2008 review article from Gaëtan Rull of Yole Développment [5].

The split illustrates the high priority of lasers within thin-film production lines to date: clearly the inverse of typical 'c Si vs thin-film' growth curves from solar market analysts which track c-Si and thin-film production output (or installed base) by year. While laser-based tool revenues clearly reflect the imbalance in the 'established tooling' status between c-Si and thin-film production lines, there is another prevailing factor that impacts on the market size for laser-based tools within the solar industry: the large disparity between CapEx and production output. Not only are many production lines operating well below stated capacity levels (low utilization), but much of the CapEx has been for pilot lines more focused on understanding processes than for module production to end-users. This issue tends to be more common with emerging cell technologies (e.g. CIGS or Gen. 3 cell types) or early-stage, VC-funded start-ups in North America.

Tool label	c-Si applications	Thin-film applications
Scribing	Edge isolation Defect repair Laser grooved buried contracts ID Marking Texturing (direct) Contact isolution (BC-cell) Interdigitated structuring (BC-cell)	Border deletion ('P4')
Drilling	Emitter wrap-through Metal wrap-through	Transparent BIPV
Doping	Dopant diffusion (SEs)	n/a
Firing	Laser fired contacts	n/a
Cutting	String ribbon cutting EFG cutting Singulation	Sheet glass cutting Panel cutting
Patterning	Dielectric removal Contact openings (BC-cell) Texturing (etch-barrier)	P1, P2, and P3 (a-Si, CdTe, CIGS) ITO removal

Table 1. Categorizing laser-based tools by process type, mapped out against the most common applications for lasers within the solar industry. Glossary: BC (Back-Contact), SE (Selective Emitter), EFG (Edge-Defined Film-Fed Growth), BIPV (Building-Integrated Photovoltaic), ITO (Indium Tin Oxide).

Therefore, projecting laser-based tool revenues beyond 2008 is subject to a variety of 'wildcards,' including the transition point from pilot- to production-line status for many CIGS and Gen. 3 cell suppliers; the ability, and timing, of a-Si production line suppliers to ramp up capacity or transition from single-junction absorbers to tandem junctions (in particular a-Si/μc-Si micromorph); the implementation of thin silicon wafers prompting the market entrance of next-generation c-Si concepts; and of course macroeconomic factors influencing short-term CapEx spend at the cell and panel stages.

In summary, the forecast to 2012 highlights several key points:

- Continued strong growth for laser-based tools within the solar industry
- Onset of cyclic trends due to either CapEx delays caused by global macroeconomic factors, or a shift in emphasis on ramping up production output on newly installed lines. (A recent article from Paula Mints at Navigant Consulting captures this succinctly [6].)
- Increased proportion of revenues from c-Si laser-based tools from next-generation c-Si concepts (and possibly aided by a decrease in the average selling price for thin-film laser-based tools).

Trends impacting next-generation tools

If laser-based tools are really to become widely adopted within the solar industry, their functionality must evolve in alignment with the technology roadmaps spelled out by both c-Si and thin-film manufacturers for next-generation equipment. Each of these manufacturing methods is discussed separately in the following section.

Since laser-based tools are already workhorses within thin-film production fabs, changes to tools here are more thin-film-solar-generic than laser-processing-specific. Reducing equipment capital costs within existing fabs may drive advanced optical designs, enabling the use of lower-power (and by consequence, lower-cost) laser sources. Increased panel sizes and fab line capacities beyond ~50MW may require lasers that operate with higher repetition rates (greater than 100kHz) to allow the patterning steps to be done in shorter time periods. Optimizing laser output parameters (most typical being the use of shorter laser wavelengths and pulse-widths) should improve the scribe quality of certain selective ablation processes for P1, P2 and P3 patterning, or when using different TCO layers. The other applications for lasers in thin-film (border deletion, or P4, and glass cutting) represent areas where laser-based tools must show a direct return-on-investment (improvements in yield, quality, and cost-of-ownership) compared to traditional equipment options.

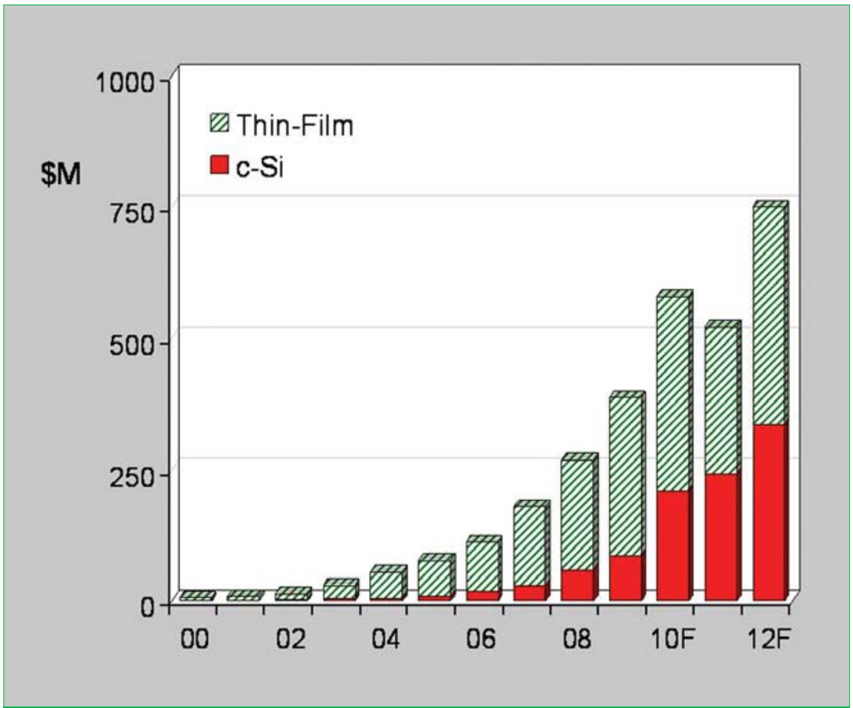

Figure 5. Annual total available market (TAM) for laser-based tools (inclusive of laser sources) within the solar industry, split into c-Si and thin-film segments over the time period 2000 (shown as '00') to 2012 ('12F'). The bias towards thin-film tools is a reflection of lasers' essential role within all thin-film production lines at the three patterning stages.

The c-Si roadmap drivers have a fundamentally different impact on laser-based tools, due partly to the fact that alternative technologies dominate the equipment landscape today. To start with, laser sources must be carefully chosen to reduce bulk c-Si material damage, placing extreme scrutiny on laser source selection. This prioritizes new industrial-grade laser sources operating with short wavelengths (for increased, more localized absorption within c-Si or surface dielectrics, and reduced microcrack formation) and short pulses below the nanosecond-level from picosecond lasers (to reduce the thermal diffusion length, or heat-affected zone around any laser material removal).

In addition to laser source selection, inline tools must process sufficient numbers of wafers per hour to allow possible retrofitting within existing production lines (or as part of any new process step where lasers are required). This latter point highlights another difference between next-generation laser-based tools in c-Si and thin-film. Novel c-Si cell concepts generally require several new process steps, compared to traditional c-Si cell manufacturing. Therefore, the value-added proposition of the laser-based tool is embedded within the overall return-on-investment for the new process steps collectively. For example, moving from a screen-printed full-Al-BSF cell to a rear-passivated, laser-ablated metallized cell must take into account the overall benefit in yield and efficiency specifically when ultra-thin wafers are employed. A similar comparative analysis was performed when Laser Grooved Buried Contact cell production lines were first implemented [7].

"If laser-based tools are really to become widely adopted within the solar industry, their functionality must evolve in alignment with the technology roadmaps spelled out by both c-Si and thin-film manufacturers for next-generation equipment."

Classifying laser-based tools

We return now to the nomenclature for laser-based equipment within the solar industry, and propose terminology that allows better understanding of the different laser tools used. The easiest way to categorize tooling is by reference to the laser/material process (or interaction) performed. Often, different applications that are based upon the same laser/material interaction share similar criteria when optimizing the laser source and beam delivery or handling. One example that comes to mind here is laser Edge Isolation and Laser Grooved Buried Contacts: the differences in laser-based tooling being the laser power level required and the number of lasers per machine for production line wafer-per-hour throughput rates.

"Laser-based tools configured to enable many of these proposed schemes have either become standardized tooling within production lines, or are poised to form part of next-generation production lines within the solar industry."

Once again, it is necessary to differentiate between laser-based tools used in c-Si and thin-film applications. In this scenario, not only is laser source selection application-specific, but the entire beam-delivery and substrate handling could not be more different. For some highly specialized applications (such as dopant diffusion or laser fired contacts), I have taken the liberty of using the application name as a good fit for the laser-based tool itself.

As laser-based tools become increasingly accepted within the solar industry, it will be more intuitive to review specific laser sources and tools that are application-specific and fall under each of the categories shown in Table 1. Furthermore, the relative market size for tools sold into each application will provide a clear metric to assess how well accepted each laser-based application has become within the solar industry.

Summary

Groundbreaking research in laser-based processes is widely known from extensive work undertaken initially at the University of New South Wales dating back to the mid 1980s, and during the past decade from European-led activities at the Fraunhofer-ISE, the ISFH in Hameln, FZ-Jülich, the Laser Zentrum Hannover, HMI-Berlin, Universität Stuttgart, and the ECN and IMEC in Benelux. Laser-based tools configured to enable many of these proposed schemes have either become standardized tooling within production lines, or are poised to form part of next-generation production lines within the solar industry. Understanding what is important within a laser-based tool is essential to ensure process optimization and comparison to alternative technologies already accepted within the supply chain. Providing terminology that captures the laser process and application will assist production engineers to engage with the laser tool supply chain when evaluating optimum lasers and tool suppliers.

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About the Author

Dr. Finlay Colville is Director of Solar Marketing at Coherent, Inc. He holds a B.Sc. in physics from the University of Glasgow and a Ph.D. in laser physics from the University of St. Andrews. Since joining Coherent in 1999, he has held a range of sales and marketing positions worldwide, concentrating on laser applications within the solar industry for the past two years.

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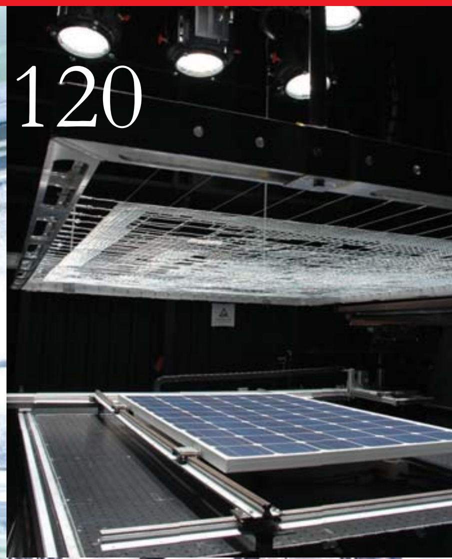
PV Modules



News

Sovello signs 120MW+ in long-term sales deals for string ribbon technology

Sovello AG, formerly EverQ GmbH, signed long-term module supply contracts with three Germany-based distributors worth more than 120MW in module capacity. The new contracts were signed with Elecktro Wärme Solar (EWS) GmbH & Co. KG headquartered in Handewitt, Schleswig-Holstein; PV5 Solarconcept GmbH, based in Kleinostheim and Soleg GmbH located in Zwiesel, Bavaria.

"These long-term partnership agreements underscore our focus on customer-oriented product development, and we will support the distribution efforts of our partners with the appropriate marketing measures," noted Christian Langen, Chief Marketing and Sales Officer at Sovello AG.

The largest of the three agreements is with EWS. The contract represents a five-year sales partnership (2009-2013) with a volume of approximately 50MW. EWS expects to supply modules into Germany, Denmark and Sweden.

A 40MW deal was signed with PV5 Solarconcept GmbH, lasting between 2009 and 2012. The modules are to be sold in Rhein-Main area and Bavaria, Spain and Italy.

The three-year contract with Soleg GmbH runs from 2009 through 2011 with a volume of 30MW. As a wholesaler and large-scale project general contractor, Soleg expects modules to be used in southern Germany, the Czech Republic and Italy.

Sovello modules in production.

Module Production News Focus

Yingli Green Energy retains 550MW-600MW module shipment forecast for 2009

Yingli Green Energy has not altered its 2009 module shipment guidance, despite the global economic downturn and module oversupply in the solar industry. Yingli Green expects module shipments to be between 550MW-600MW in 2009. This represents an increase of 96.1% to 113.9% compared to fiscal year 2008.

However, the company said that gross margins would decline from 24% to as low as 22% as a reflection of the oversupply and falling module ASPs. Yingli Green has one of the lowest cost-per-watt manufacturing business models due to its fully integrated position, which is expected to help the company limit ASP declines and remain competitive in module sales as it aggressively adds to its sales and distribution channels.

Yingli Green reported full 2008 revenues of US$1,107.1 million, an 86.1% increase over 2007. PV module shipments increased to 281.5MW in 2008, compared with 142.5MW in 2007. The average selling price for PV modules in 2008 was US$3.88 per watt, slightly higher than US$3.86 per watt in 2007, the company reported.

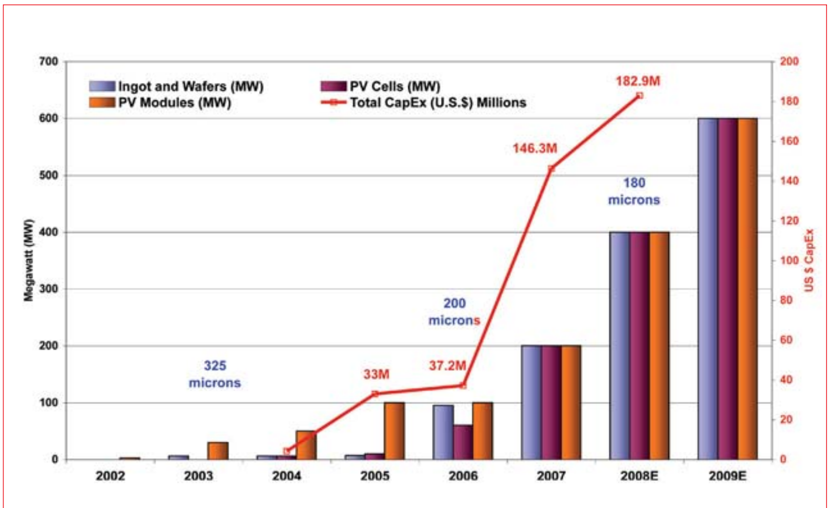
Akeena agrees deal with Enphase Energy for development of AC Andalay panels

Akeena Solar, Inc. signed a cooperative agreement with microinverter company Enphase Energy, that will see the companies co-develop and market Andalay solar panel systems with ordinary AC house current output instead of high voltage DC output.

The agreement also states that Akeena will purchase a minimum of 5,000 microinverters per year for 2009 and 2010 from Enphase, while Enphase will make available up to 100,000 microinverters to Akeena during the same timeframe. The microinverters will then be built into Akeena's Andalay panels, under the terms of the agreement.

Tool Order: TÜV Rheinland North America selects Spire's solar simulator

TÜV Rheinland of North America selected the 4600 Single Long Pulse 'Spi-Sun Simulator' from Spire Corporation for its new test laboratory at Arizona State University (ASU) in Tempe, Arizona. The new 40,000 sq-ft facility has double the capacity of the previous lab and provides full testing and certification.



Yingli Green MW capacity expansion plans through 2009.

Source: Photovoltaics International

Spire invites foreign solar module makers to "Come to America"

In a move to encourage foreign solar module manufacturers to build plants in the U.S., Spire has begun its "Come to America" program. The turnkey PV panel fab provider has tapped Mark Case, VP of photovoltaic factory management, to lead the effort.

The company cites projections that the U.S. will be the most rapidly growing PV market in the world, doubling each year over the next few years until the region reaches more than 5GW through 2011. To take full advantage of the newly signed economic stimulus bill, Spire notes that foreign manufacturers have to produce their modules in the U.S.

Moser Baer primed for production of 5.7m² modules at 40MW plant

At 40MW capacity, Moser Baer's manufacturing plant in Greater Noida is the largest thin-film solar line in India, and preparation for commencement of production of thin-film PV modules is underway. The announcement was made amid news of achievement of final acceptance test (FAT) certification of the company's SunFab Thin Film Line, which was supplied by Applied Materials, Inc. The final certification comes less than a week after AMAT was granted IEC 61646 and 61730 verification for its single and tandem junction (1.1m x 1.3m) PV modules.

Moser Baer was Applied's first SunFab customer, and Moser Baer's single junction SunFab line has shown the highest production capacity to date for manufacturing 5.7m² solar modules.

Spire, HHV enter strategic relationship to serve Indian PV industry

Spire and Hind High Vacuum (HHV) finalized a strategic relationship agreement that will provide an enhanced portfolio of solar manufacturing equipment and service capabilities to the Indian photovoltaics industry.

Module Sales News Focus

Solar Power, Inc. completes first module sale to German integrator

Following the company's receipt of IEC certification for its solar modules by VDE Laboratories, Solar Power, Inc. completed a sale to a prominent German solar integrator. The first supply of 200W solar panels associated with this deal took place in early December 2008, and the panels are expected to be used in the unnamed integrator's Germany-based installation projects.

The recent certification is, according to the company, expected to pave the way for further orders, as the IEC certification guarantees the modules' quality and performance for use in the European market. 2008 saw Solar Power, Inc. break into the Asia market, while its U.S. orders saw strong growth.

More than 25MW of PV module contracts signed for Europe in 2009, says aleo solar

German manufacturer aleo solar has signed 25MW worth of solar PV module contracts with a number of European customers for 2009. The company says it has deals with specialist dealers, installers, and solar technology specialists in core markets throughout the continent.

Heiner Willers, a member of aleo solar's management board, stated that the company is "already in a position to forecast that this trend is likely to continue in 2009, even though the larger digression in the feed-in tariff, which is scheduled to kick in at the turn of the year, will be a challenge for all market participants in Germany."

The company cites a shift towards smaller- and medium-sized rooftop installations in Europe, and the increasing attractiveness of PV installations for safety-conscious investors. Further support for investments in solar electricity systems is also provided in Germany by KfW Bank's loan offerings.

Tool Order News Focus

Applied Materials' SunFab modules awarded IEC Certification

Applied Materials, Inc. was awarded certification by the International Electrotechnical Commission (IEC) for its single and tandem junction PV modules. Standards 61646 and 61730 involve safety testing of PV modules under severe environmental conditions, and the stamp of approval for the products from the IEC will aid in shortening time-to-market for the modules as well as speeding up the certification process for Applied's customers.

The testing of the modules, which involved such conditions as long-term exposure to sunlight, extreme temperatures, wind and precipitation, was carried out by TÜV Saarland of Germany. The 1.1m x 1.3m modules are the most commonly installed module size, with the company's 5.7m² modules comprising four of these smaller modules. Certification of these 5.7m² utility-scale modules is expected within the first half of 2009.

Applied Materials 'SunFab' certified modules.

Solaria places order with Spire for 100MW production line

Spire received its sixth sales contract from Solaria Energia y Medio Ambiente, S.A. that will see Spire supply a 100MW production line to the Spanish company. Spire will supply state-of-the-art assembly machines, laminators, and a module simulator to Solaria for a sum that has yet to be disclosed. The equipment will be installed in Solaria Energia's new facility in Fuenmayor, Spain.

3S Swiss Solar Systems obtains major order for automatic production line

3S Swiss Solar Systems, a subsidiary of 3S Industries AG, received a €11.6 million order from a German customer in Brandenburg to deliver a partial line for the highly automated production of solar modules. The German organization has been producing solar modules on an automatic laminating line from 3S since 2006 and has placed this order to further expand its production.

This new production line, introduced by 3S Swiss Solar Systems in the summer of 2008, includes several type XL laminating lines, which will provide a variety of new technological developments.

Solar Power, Inc. completes first module sale to German integrator

Following the company's receipt of IEC certification for its solar modules by VDE Laboratories, Solar Power, Inc. completed a sale to a prominent German solar integrator. The first supply of 200W solar panels associated with this deal took place in early December 2008, and the panels are expected to be used in the unnamed integrator's Germany-based installation projects.

The recent certification is, according to the company, expected to pave the way for further orders, as the IEC certification guarantees the modules' quality and performance for use in the European market. 2008 saw Solar Power, Inc. break into the Asia market, while its U.S. orders saw strong growth.

Yingli Green Energy wins 15MW module supply deal with German industrial PV integrator

German industrial PV systems integrator, GOLDBECK Solar has signed a 15MW module supply contract with Yingli Green Energy for 2009. Yingli said that GOLDBECK Solar could purchase a further 58MW of modules in 2009.

Joachim Goldbeck, General Manager of GOLDBECK Solar., commented "We aim to provide our customers maximum value with our products and services. Cooperating with top tier suppliers like Yingli is one of our principal strategies for achieving these goals in order to secure customers on a long-term basis.'

Yingli Green Energy has signed separate solar module sales agreements with two leading German PV system integrators, City Solar and Wirsol. The City Solar deal calls for the supply of 20MW of modules in 2009, while the Wirsol contract commits the Chinese company to provide 15MW of panels.

Yingli's agreement with City Solar also includes an option for the integrator to purchase an additional 30MW of modules, and the Wirsol deal features an option to buy an additional 20MW of units in the coming year.

China Sunergy signs PV-cell supply deal with Ajit Solar

China Sunergy signed a one-year agreement to supply multicrystalline solar cells to privately owned Indian module manufacturer Ajit Solar. The deal calls for the PV manufacturer to deliver 12MW of cells to Ajit next year.

The Nanjing-based company said it expects to deliver 5MW of cells to the Jaipur-based firm (which is privately owned by the Gehlot Group) in the first half of the year, and the remaining 7MW in the latter half.

Suntech enters 5MW module supply deal with Standard Solar

A one-year supply deal was signed between Suntech Power Holdings Co., Ltd. and Standard Solar, Inc. that will see Suntech supply 5MW of solar panels to the solar developer over the course of 2009. The companies did not disclose the cost of the agreement, nor did they indicate for which development the modules would be used.

German integrator company places US$1.7 million order with Solar Power, Inc.

Solar Power, Inc. received a follow-on order from an unnamed German solar integrator company for the company's 200W modules. The company had been supplied with a shipment of the modules in early January, and following the products' successful introduction at the integrator company, Solar Power, Inc. has received a further order worth US$1.7 million.

aleo solar brings total European contract volume to over 50MW

Following receipt of new orders from unnamed companies, aleo solar AG announced that its total European order book now totals more that 50MW. The company had revealed new contracts in December 2008 that showed a 25MW order book for aleo's solar modules, and this announcement will aid in realizing the company's target sales for 2009 of greater than €380 million.

Centrosolar Group boosts module sales 50% in 2008

Preliminary financial results published by PV module manufacturer, Centrosolar Group AG, reveal a new revenue record of €331.8 million in 2008, more than a 50% increase in revenue of €220.3 million for 2007. According to the company, sales actually exceeded the revenue target of €310 million set at the beginning of 2008.

GA Solar taps Trina Solar for one-year module supply up to 36MW

A subsidiary of Trina Solar Limited, Changzhou Trina Solar Energy Co., Ltd., entered into a module supply contract with Gestamp Asetym Solar, S.L. (GA Solar). The order will see Trina supply between 20-36MW of modules over the next year. Some shipments of the modules, prices of which have been pre-determined as part of the deal, have already been received by GA Solar.

The agreement, the value of which has not been disclosed, was signed by Trina and the Spanish customer at Abu Dhabi's recent World Future Energy Summit 2009. GA Solar has said that it is on its way to expanding its operations to new markets such as Italy, Greece, the U.S. and the Middle East.

Perfectenergy International inks 50MW solar module agreement with Abidas AG

In a deal said to be worth more than US$150 million, Perfectenergy International Ltd. has signed a one-year module sales agreement with Abidas AG. Perfectenergy will supply 50MW of monocrystalline solar modules to the German company over the four quarters of 2009, at a price that has been fixed until June 2009. The modules will be manufactured at Perfectenergy's 60MW factory in Shanghai, China.

Opel supplies HCPV panels to Betasol for Spanish solar-power plant

Opel International has begun supplying high-concentration PV panels for a utility-grade, tracker-based solar power plant in Spain, as part of a deal with Betasol, a Spanish solar farm installer and seller. The first shipment of modules took place in December. The 440KW project is scheduled for completion in the first quarter of 2009.

ET Solar to supply 13MW in 2009 to German PV integrator

ET Solar Group Corp has signed a 13MW module supply deal with Germany's USE, a distributor and integrator. The deal lasts from January to November 2009. The two companies entered into a strategic partnership in 2008, including module shipments.

Other News Focus

EMCORE to cut workforce due to liquidity issues

Loss-making Environmental Centre Opportunities Resourse (EMCORE) Corporation said in an SEC filing that it is planning a sweeping range of cost-cutting measures and refinancing moves to improve the company's financial liquidity. A workforce reduction will be made to lower operating costs, though how deep the cuts will be was not disclosed.

EMCORE is also selling non-core equity interests to boost its cash position as well as seeking a minority share sale in its photovoltaics business before its actual spin-off, which was announced earlier last year.

EMCORE also said that it would be liquefying remaining auction rate securities, which were approximately US$3 million, according to comments made in EMCORE's 3Q08 financial conference call. The company will also attempt to sell other assets, though these were not specified.

Colorado Governor bestows Excellence in Renewable Energy Award on Ascent Solar

In a move that brings focus on Ascent Solar's contributions to the global clean power effort, the Colorado Governor Bill Ritter has granted the esteemed 2008 Governor's Excellence in Renewable Energy (GERE) Award for the Large Business category to the company.

The Governor's Energy Office (GEO) started these awards last year in recognition of companies that have made outstanding efforts to advance their use and promotion of renewable energy sources in Colorado State.

ersol announces death of Chief Financial Officer Ekhard von Dewitz

Solar Energy AG announced that former Chief Financial Officer Ekhard von Dewitz suddenly died in a car accident.

Mr. von Dewitz was Chief Financial Officer from 2007 to 2008. He was Chief Executive of the Commercial Division of ersol Thin Film GmbH from 2006 to 2008.

Product Briefings

teamtechnik Maschinen und Anlagen GmbH

TT900 Stringer from teamtechnik solders both standard and back-contact cells

Product Briefing Outline: teamtechnik Maschinen und Anlagen GmbH has launched the TT900 fully-automated stringer for high volume cell interconnects. teamtechnik has specialized in contact-free soldering processes with laser or IR light. Both soldering technologies can be integrated as an option into the modular Stringer TT system concept. A key feature is that these systems solder both standard and back-contact cells.

Problem: Module assembly is one the most expensive steps in c-Si cell/module production. Fully automated and integrated tabber/stringer systems need to have high throughput and high yield to support PV manufacturers' cost reduction strategies.

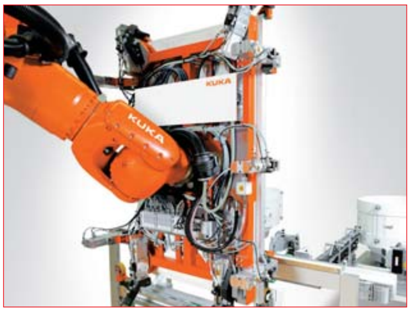
Solution: teamtechnik offers the TT900 and TT1200 models of its stringer platform for a wide range of throughput and capacity manufacturing requirements. One noticeable feature is that these systems solder both standard and back-contact cells, so that after appropriate retrofitting, different types of cells can be reliably run on a system without a special solution. The refit times take only a matter of hours. This high system flexibility is ensured thanks to strict modularization and standardization in the machine construction and in the software. A special hold-down device has also been integrated, functioning as a positioning tool that guarantees the exact position of the connectors on the solar cell. The hold-down device sequences as an auxiliary tool through the entire machine and soldering process, while it fixes the solar cell exactly to the connector.

Applications: Soldering both standard and back-contact cells.

Platform: A particular feature of the systems, which focus on assembly and testing, is their modular, standardized and process-orientated structure. The Stringer TT produces high quality and high performance strings in three or four second cycles. Contactless system using vacuum robotic arms is employed. Available with IR lamp and laser solder technology.

Availability: Currently available.

KUKA Systems



KUKA Systems' ROBO FRAME prevents module deformation and scratching

Product Briefing Outline: KUKA Systems has introduced its new ROBO FRAME module, which uses an industrial robot with a high payload capacity for the automatic framing of solar modules. The main advantages of this production process are the prevention of deformation and scratching, improved quality of the end product, and greater throughput of the production system as a result of precision and high availability.

Problem: The framing of solar modules typically involves slightly over-dimensioned frames in order to accommodate the tolerances of the glass and the frame parts. During the joining process, this means that the laminate must not be pressed right up against the frame, but must be joined according to specified dimensions. The ROBO FRAME system is claimed to handle large tolerance ranges reliably, thereby ensuring high quality of the end product.

Solution: In the ROBO FRAME system, the robot grips the prepared laminate on the glass side and guides it precisely into the prepared frame parts. In a sequence of four steps, the long frame parts are joined first, then the short frame parts are joined into which the corner connectors have already been inserted automatically. Additional clips and a level support plate ensure that the forces applied to the laminate during assembly of the frame parts are kept to a minimum to prevent deformation.

Applications: The tools can be adapted to various frame sizes. The KUKA robot allows combination with additional automation tasks, thus facilitating scalability of the system for lines with an annual power output of, for example, 50 or 100MW.

Platform: The ROBO FRAME unit consists of the KUKA robot with framing gripper, a station for pressing in the corners, two framing tables, an optional vertical buffer for one hour's production volume, an optional corner key separator and the wetting channel for the adhesive tape.

Availability: March 2009 onwards.

Swiss Solar Systems

Self-adjusting clamping bars for 3S laminating lines increase machine up-time

Product Briefing Outline: Swiss Solar Systems has introduced self-adjusting clamping bars for 3S laminating lines that are intended to improve the lifetime of the membrane of all 3S laminators. The bars can lead to a reduction of consumables and increase machine up-time as the time required for membrane replacement is reduced.

Problem: The useful life of the membrane is badly affected by the repeated stress caused by heat, cyclical stretching and chemicals. An even stretching of the membrane in all directions increases the useful life. Another factor is that until now, the installation of replacement membranes has been laborious and time-consuming.

Solution: The cyclical, mechanical stress-resistance of the membrane is increased with the new system in that the natural longitudinal and latitudinal stretching of the membrane is supported. This leads to a significantly longer useful life for the membrane and therefore longer up-times for the machines. Installation of the membrane is also highly simplified – the membrane can now be lifted into the laminator in a folded condition. The benefits are easier handling and a reduced need for space between the laminator and the neighbouring machines.

Applications: Suitable for all 3S laminators; it can be installed into all existing machines.

Platform: 3S laminators use a patented 'Hybrid Heating Plate,' which combines the advantages of both electrical and oil heating techniques that generates higher temperature homogeneity, boosting yields and throughput.

Availability: March 2009 onwards.

Product Briefings

Hermann Otto GmbH

OTTO-Chemie offers customized 'Novasil' silicone module sealants

Product Briefing Outline: Hermann Otto GmbH, globally known as OTTO-Chemie, formulates silicone and components for PV modules. Under the trade name 'Novasil,' OTTO-Chemie produces a broad variety of specially-designed glues for bonding of frames and junction boxes.

Problem: PV module manufacturers are facing rising pressure from competing ventures worldwide. Both large and small PV manufacturers require silicones perfectly tuned to their level of production automation. Fast processing requires completely different silicone compositions than usually asked for by semi-automated manufacturers compared to manually operated lines. Failure during bonding dramatically influences lifetime, functionality and power generation of finished modules.

Solution: The range of OTTO silicones covers two-component formulations as well as highly sophisticated and specially-designed one-component products. OTTO silicones can be customized to customer requirements while retaining all key performance characteristics.

Applications: Sealing and bonding of frames, glass, corners, junction boxes as well as potting of electrical elements of photovoltaic modules.

Platform: Batch manufacturing process secures permanent and equal quality of finished glues and even allows production of extra-small quantities whenever requested by customers.

Availability: Currently available.

Maschinenbau GEROLD GmbH & Co. KG

GEROLD automates edge trimming of PV modules

Product Briefing Outline: Maschinenbau GEROLD GmbH & Co. KG has launched a production cell for automated edge trimming of PV modules. The company claims that the new automated system has less than a one-year investment payback, solving many of the defect problems associated with manual trimming processes.

Problem: In traditional production lines, trimming laminated PV modules is manually performed and is a time-consuming operation. It can also lead to defects that cannot all be adequately eliminated.

Solution: GEROLD's production cell completely automates this operation with module finishing. The compact cell-concept with minimum footprint features a versatile industrial robot and an efficient trimming tool. Typically, labour is reduced by four people with 24/7 operation, the company claims. An easily integrated inspection station is also offered, which is said to reduce manufacturing costs.

Applications: Whether glass-glass- or glass-foil-module, thin-film or crystalline, the robot ensures force-controlled trimming of all module edges within seconds.

Platform: The trimming station can be set up parallel to an existing production line, or integrated into a line. Linking is done by means of angular transfers or by linearly connecting two lines, respectively. The handshake with the upstream component's PLC is limited to a simple start signal. With sound planning and cell configuration permitting, installation can be finished within as little as one day.

Availability: Currently available.

Quality assurance for PV modules: experience from type approval testing

Jörg Althaus, TÜV Rheinland Immissionsschutz und Energiesysteme GmbH, Cologne, Germany

ABSTRACT

Photovoltaic modules and components, due to the nature of their employment, must be designed to withstand the most diverse of environments. The large spectrum of climatic conditions and mechanical stresses that these components must weather merit the application of some standards by which they can be tested for durability, reliability and safety. TÜV Rheinland operates several ISO 17025-accredited laboratories worldwide for type approval testing of flat plate as well as concentrating PV modules, PV components and solar thermal systems. Test data, collected over the past 20 years, shows that there is still a rather high failure rate when it comes to testing of PV modules, and also that there are different failure mechanisms for crystalline and thin-film PV modules. This paper presents data from these tests and draws some conclusions regarding the need for future standards development.

Introduction

Several international type approval standards have been released for PV modules, components, concentrating PV modules and assemblies, but this third party testing and certification is still not required by law in most cases. However, certificates document the adherence to a certain quality level and form the basis for PV project financing. Several test marks have been established to signal to the buyer the satisfactory completion of standards requirements, but a certificate or quality mark alone does not guarantee the high quality of a product. As testing is usually limited to a small amount of samples (typically <10 for a new module design), which in many cases are not even taken from a series production but prototypes of a new series, additional quality assurance measures are needed.

Important standards for PV modules and components

The product certification of crystalline PV modules for open-air climates is based on international standards from the IEC 60068 'Environmental Test Procedures' series. Considerable preliminary work on the definition of special test procedures for PV modules was carried out by the Research Centre of the European Commission in Ispra (Italy).

IEC 61215

Test specification no. 503, 'Terrestrial Photovoltaic (PV) Modules with Crystalline Solar Cells – Design qualification and Type Approval,' developed in Ispra, was adopted in 1993 as the standard IEC 1215 of the International Electrotechnical Commission (now IEC 61215) and in 1995 ratified as the European standard EN 61215. In April 2005, a second version of IEC 61215 was published and named 'Terrestrial crystalline silicon photovoltaic (PV) modules – Design qualification and type approval.' The newer edition of the standard contains some changes in testing conditions and pass criteria as well as additional, more comprehensive tests.

IEC 61215 comprises the examination of all parameters responsible for the ageing of PV modules. Radiation testing, thermal testing and mechanical testing in particular are used to simulate the ageing effects that can occur during the service life of a PV module (see Table 1).

IEC 61646

In 1996, a comparable standard was published for photovoltaic thin-film modules. This standard was revised in 2008 and a second edition was published, namely IEC 61646, or 'Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval.' This draft of the out standard addresses new developments in thin-film technologies and should reduce testing efforts – and in many ways is identical to IEC 61215. The main difference between the two standards lies in the test procedures added to adapt to the special properties of thin-film technologies, such as the degradation behaviour of thin-film modules on exposure to irradiance.

> "Several test marks have been established to signal to the buyer the satisfactory completion of standards requirements, but a certificate or quality mark alone does not guarantee the high quality of a product."

However, the standard only took amorphous-Si thin-film technologies into account. As a result, the behaviour of CIS, CdTe and others after light exposure is not sufficiently covered in the standard

Code	Qualification Test	Test Conditions
10.9	Hot-Spot Endurance Test	5-hour exposure to >700W/m^2 irradiance in worst-case hot-spot condition
10.10	UV-preconditioning Test	15kWh/m^2 UV-radiation (280 - 385nm) with 5kWh/m^2 UV-radiation (280 - 320nm) at 60°C module temperature
10.11	Thermal Cycling	50 and 200 cycles -40°C to +85°C
10.12	Humidity Freeze Test	10 cycles -40°C to +85°C, 85% RH
10.13	Damp Heat	1,000 hours at +85°C, 85% RH
10.16	Mechanical Load Test	Three cycles of 2400Pa uniform load, applied for 1 hour to front and back surfaces in turn
10.17	Hail Test	25mm diameter ice ball at 23m/s, directed at 11 impact locations

Table 1. Overview of selected IEC 61215/IEC 61646 tests.


dyMat®
WE PROTECT
YOUR BEST PERFORMANCES
dyMat® back sheet for PV module protection
· TÜV certified IEC 60664 and in compliance with IEC 61215 and IEC 61730
· Perfect adhesion with EVA and other encapsulants
· Various thickness and colour combinations
TÜV Rheinland
TÜV InterCert
UL
dyMat® PYE (Pet/Pet/Primer)
dyMat® APYE (Pet/Aluminium/Pet/Primer)
TEST THE BEST!
dyMat® TE (Tedlar®/Pet/Primer)
dyMat® cTE (Tedlar®/Pet/Primer)
dyMat® AT (Tedlar®/Aluminium/Pet)
dyMat® EPE (EVA / Pet / EVA)
dyMat® E (EVA)
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as there is a lack of information on these materials. Measurements under standard test conditions (STC) of modules of these technologies therefore require additional considerations.

PV Modules

IEC 61730

The long-term environmental tests of IEC 61215 and IEC 61646 do not adequately cover the aspects of electrical safety. In order to overcome these shortcomings, TÜV Rheinland developed test procedures for the qualification of PV modules as Safety Class II equipment (double or reinforced insulation), which accreditation had gained a reputation globally.

Most aspects of this TÜV Rheinland standard are present in the international standard IEC 61730 'Photovoltaic (PV) module safety qualification.' This standard derives some elements from U.S. safety standard UL 1703 'Flat Plate Photovoltaic Modules and Panels.' Following translation of the IEC 61730 standard into the European standard EN 61730:2007, it was listed under the low voltage directive of the EU, therefore forming the basis for the compulsory 'CE' (Consormité Européenne) standard in the member states of the European Union.

The IEC 61730 consists of two parts:

Part 1: Requirements for construction

Part 2: Requirements for testing

Part 1 of the EN IEC 61730 defines the mandatory design characteristics of the modules (such as minimum distances of conductive parts from the module edges, wall thickness of the junction boxes, etc.) as well as requirements of the materials used in the module (UV stability, temperature parameters of polymeric materials, protection class, etc.).

Since this safety standard insufficiently covers requirements for PV components, TÜV Rheinland aided in the development of a standard that addresses the main safety

Figure 1. Module testing at TÜV Rheinland's PV laboratory in Cologne, Germany.

IEC standards	European or national standards	Standard title
IEC 60904-1:2006	EN 60904-1:2006	Measurement of photovoltaic current-voltage characteristics
IEC 60904-9:2007	EN 60904-9:2007	Solar simulator performance requirements
IEC 61215:2005	EN 61215:2005	Crystalline silicon terrestrial photovoltaic (PV) modules – design qualification and type approval
IEC 61646:2008	EN 61646:2008	Thin-film terrestrial photovoltaic (PV) modules – design qualification and type approval
IEC 61730-1:2004	EN 61730-1:2007	Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction
IEC 61730-2:2004	EN 61730-2:2007	Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing
IEC 62108:2007	EN 62108:2008	Concentrator photovoltaic (CPV) modules and assemblies – design qualification and type approval
–	EN 50380:2003	Datasheet and nameplate information for photovoltaic modules
–	EN 50521:2009	Connectors for photovoltaic systems – safety requirements and tests
–	DIN V VDE V 0126-5:2008	Junction boxes for photovoltaic modules
–	2PfG 1169:2007	Requirements for cables for use in photovoltaic systems
–	UL 1703.3:2003	Flat plate photovoltaic modules and panels

Table 2. Important standards for PV modules.

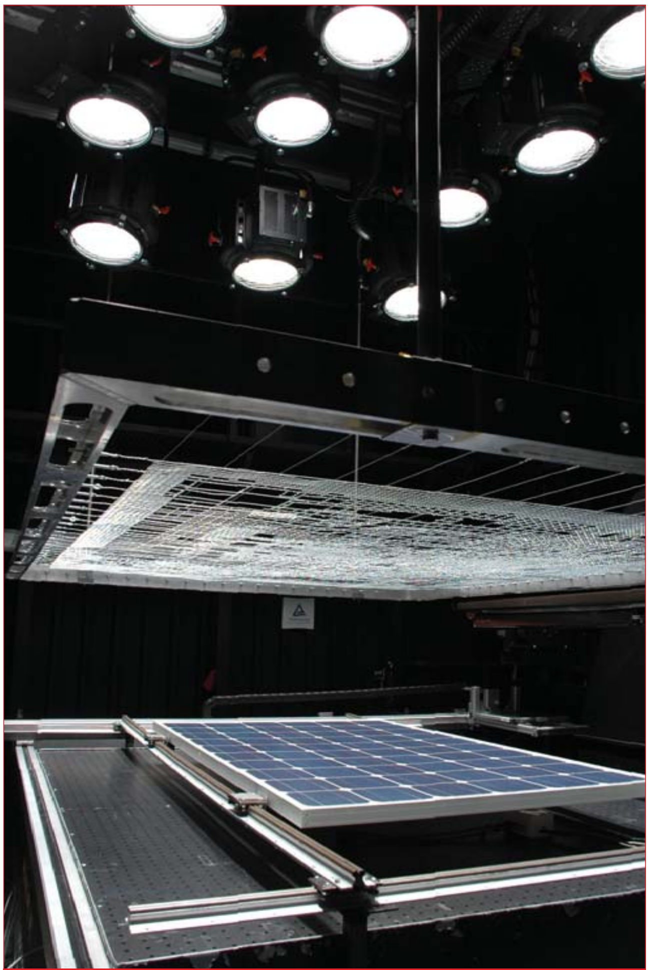

Figure 2. Steady-state solar simulator at TÜV Rheinland, Cologne.

relevant components such as PV cables, connectors and junction boxes. Where IEC 61730 states that a PV cable used on a PV module must be suitable for the application, the TÜV Rheinland standard 2PfG 1169 'Requirements for cables for use in photovoltaic systems' is based on existing IEC standards for cables for outdoor use and includes PV-specific requirements from IEC 61215 and IEC 61730. PV connectors are now tested to the soon-to-be-published European standard EN 50521, 'Connectors for photovoltaic systems – Safety requirements and tests,' whereas a PV-junction box standard has only recently been released as the German pre-standard DIN V VDE 0126-5 'junction boxes for photovoltaic systems – Safety requirements and tests,' which is translated to a European standard. At the same time, the standardization group working on the international IEC level is also placing more focus on material and component testing.

CPV qualification

Product qualification of concentrator photovoltaic (CPV) modules and assemblies is based on the aforementioned standards. Considerable preliminary work on the definition of special test procedures for CPV modules was laid down in 2001 in IEEE 1513: 'Recommended Practice for Qualification of Concentrator Photovoltaic (PV) Receiver Sections and Modules Design qualification and Type Approval.' In late 2007, the international standard IEC 62108 'Concentrator photovoltaic (CPV) modules and assemblies – Design qualification and type approval' was released and proved to be largely based on its IEEE predecessor. An identical European version of the standard was released in 2008 (EN 62108:2008).

Safety testing so far is not part of this standard. A separate safety test for CPV modules is under consideration; in the meantime, the safety qualification standard for flat-plate PV modules could form a basis for CPV module safety testing.

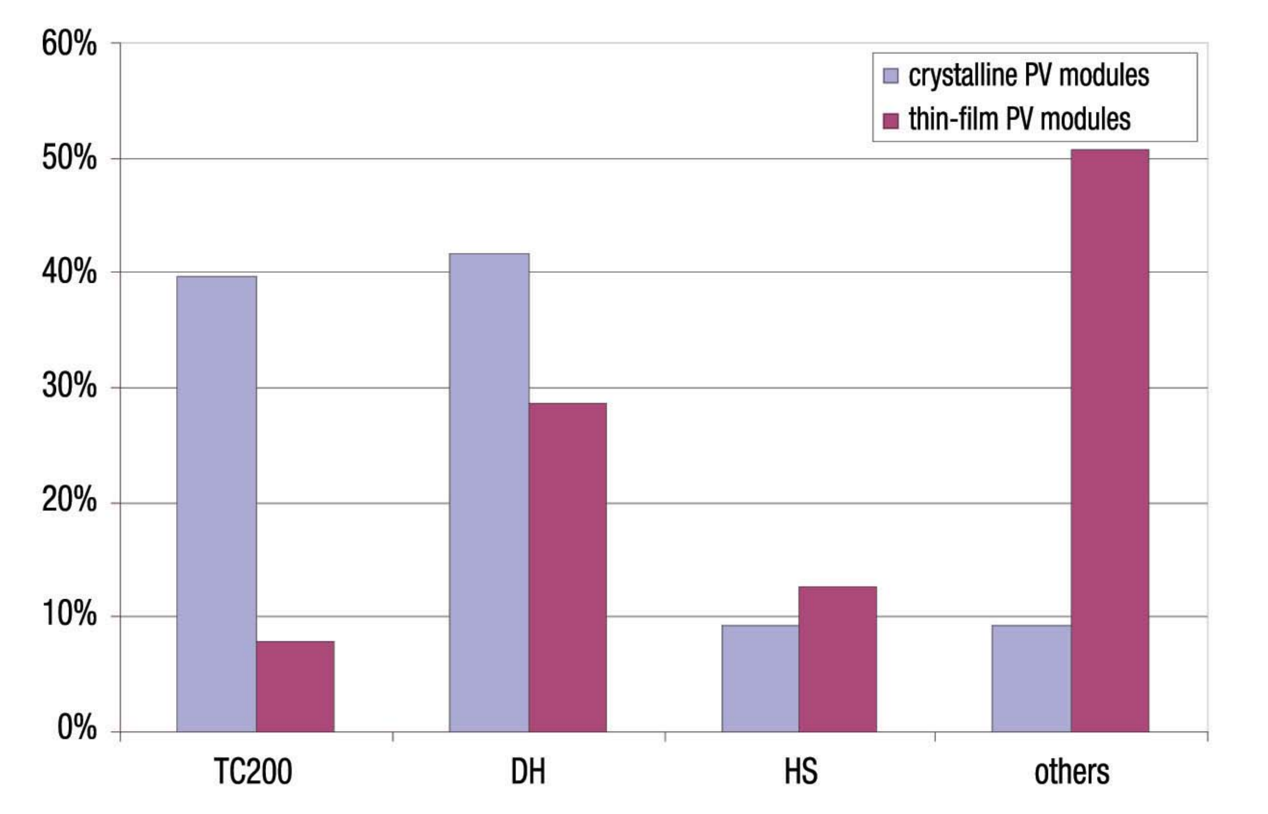

Figure 3. Shares of individual test failures for crystalline PV modules vs. thin-film PV modules.

The fundamentals for the electrical characterization and measurement principles of PV modules are described in the IEC 60904 series of standards. Part 1 lays down the principles for the measurement of the current-voltage characteristics. Part 9 defines the requirements for solar simulators, which are classified according to their performance in the spectrum of the light, the uniformity of the irradiance and the temporal stability in the test area.

Finally, the European standard EN 50380 'Datasheet and nameplate information for photovoltaic modules' defines the minimum requirements for information to be given in PV module data sheets and on their type labels.

Quality assurance in PV module production

A high level of quality is in the interest of the distributor of the PV module, the manufacturer and, of course, the end user. In the current situation, where we are seeing a change from a demand-driven market to a market with overcapacities, quality plays a much higher role than it did only a few months ago. Competition is much stronger: buyers now have more of a choice and a manufacturer can only achieve higher prices through providing products that are well above average quality level.

Many manufacturers have installed quality management systems and accredited their factories to standards required of ISO 9001. However, the accreditation alone is not a sufficient proof of quality, as ISO 9001 audits vary internationally and the standard defines methods only, not product-specific requirements. A module from an accredited factory is therefore not on a par from a quality perspective with a competing product from another accredited factory.

Of even more importance are the type and frequency of the quality measures in the production. Unfortunately these measures are not standardized and the type approval and safety qualification standards do not include in-line testing methods. Through the annual factory surveillance carried out as part of TÜV Rheinland's certification system, many different test methods have become familiar to the PV experts. The most common tests are listed below:

- incoming inspections of components and materials
- solar cell sorting according to power, colour, etc.
- pull test on soldered cell connectors
- electroluminescence (to find shunts or cell cracks and interrupts in the circuitry)
- determination of the gel content of laminated EVA
- elongation or peel tests on encapsulation materials
- visual inspection (at different stages of the production)
- voltage/current measurement on single strings prior to lamination

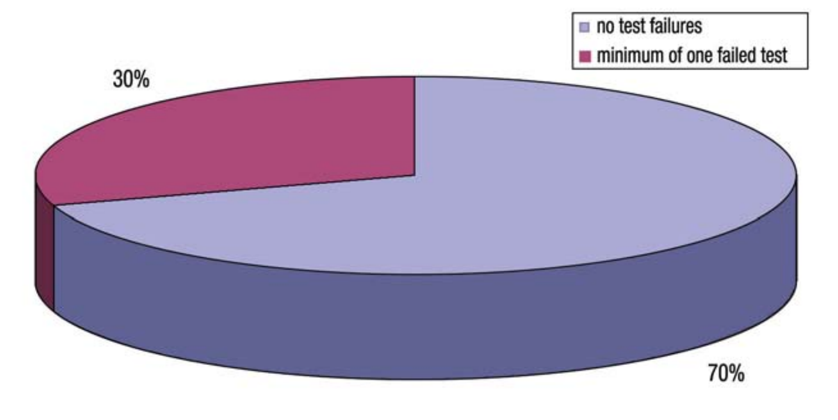

Figure 4. Total failure rate in IEC 61215 qualification testing at TÜV Rheinland, Cologne.

- isolation measurement/hi-pot test (following IEC 61215 or UL 1703)
- determination of the maximum output power (IV-curve)
- ground continuity test (following IEC 61730-2)
- programs for performance of long-term tests following IEC 61215 or IEC 61646.

Sample rates as well as frequency for the afore mentioned tests vary from manufacturer to manufacturer. Regarding personal protection, a 100% control of the insulation properties should be binding.

A possible pitfall here is that the insulation tests described in the IEC standards are too time-consuming to be carried out in an efficiently running production. In UL 1703, therefore, a method was described featuring an increased voltage and reduced testing time, which suited some module types, but not all. It is expected that the soon-to-be-reviewed IEC 61730 will include some guidelines for in-line testing in a future version.

A major issue with the standards is the detachment of power rating from the quality assessment. In the scope of IEC 61215, it is pointed out that power rating is not covered by this standard. The result of this is that only relative power degradation due to the performed tests is checked; the correlation of power rating and real power is thus not considered.

Assessment of PV module performance

Distributors of PV modules and investors of larger-scale PV installations often require verification of the output power of a shipment consisting of a large number of PV modules. The available data sheets and in some cases flash protocols are not sufficient as proof for the real power. A third-party check of a representative sample taken from the delivered PV modules is a more trustworthy source of classification. This missing trust is well grounded in the missing assessment of the power rating as part of the type approval qualification. Unfortunately, PV modules can be labelled with a higher power than they actually provide and still receive an adequate IEC certificate. The reasons for such an efficiency shortfall can be manifold. Some manufacturers use the specified tolerance in the disadvantage for the buyer; others actually take false or imprecise measurements in their factories. The latter might not even be aware of the fact that they over- or even underrate their modules.

Most measurement discrepancies could be avoided were measurement uncertainty calculations done sufficiently and systematic errors avoided. TÜV Rheinland has laid down guidelines for the appropriate use of reference modules in PV module production lines, as well as developing measurement equipment for the assessment and optimization of solar simulators. Such qualification of a solar simulator allows a module manufacturer to check whether a previously agreed classification is actually achieved. Furthermore, the visualized results allow modifications to improve the measurement uncertainties for output power measurements and minimize systematic errors.

> "TÜV Rheinland has laid down guidelines for the appropriate use of reference modules in PV module production lines, as well as developing measurement equipment for the assessment and optimization of solar simulators."

It must be determined how large a sample is required to accurately perform a power check on a module. Based on the assumption that the overall power distribution is unknown, a minimum sample size can be calculated from statistical analysis. A common practice for other products is a so-called 'zero-acceptance level.' This means that from the taken sample, only a given

Figure 5. TÜV's outdoor test facility.

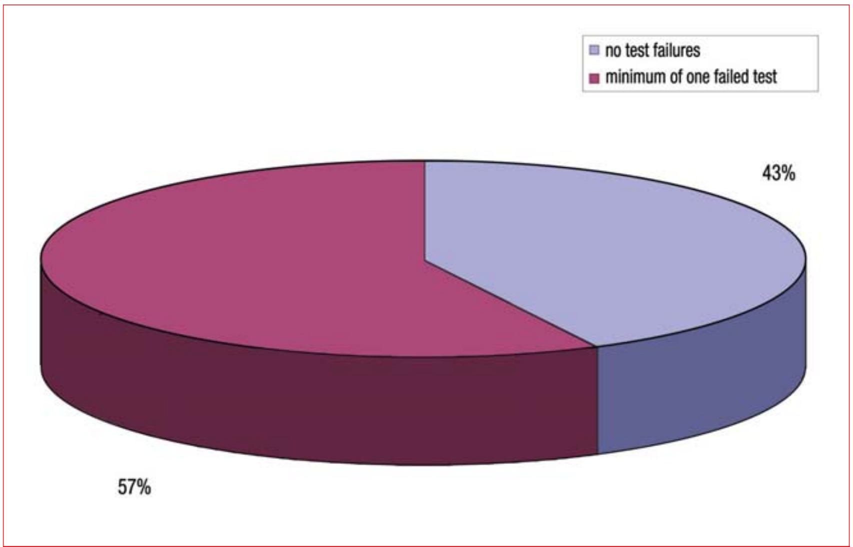

Figure 6. Total failure rate in IEC 61646 qualification testing at TÜV Rheinland, Cologne.

number of modules should be outside the guaranteed values, otherwise the complete charge is to be rejected. TÜV Rheinland together with the Technical University of Aachen (RWTH) has developed software to calculate the sampling sizes depending on P_{max} distribution based on the manufacturer's data. For smaller systems, guidelines for samples sizes have also been calculated [1]. If a system is already installed and its performance suggests a problem with some or all modules, the sample size can be established with similar methods. However, if a fundamental problem with the modules is detected, it is likely that the whole system will be affected.

The equivalence of delivered charges to certified module types is also of interest. Even with the annual factory surveillance being part of the certification schemes, field inspections have shown that modules that are sold under the same type name are sometimes built with different materials and components. In cases such as this it is important to have a competent partner for such inspections that will be able to distinguish materials and looks past the obvious.

Experience from product qualification testing

TÜV Rheinland's experience has seen the company test PV modules according to IEC standards since 1996. In that period, it has collected test data that shows that certain qualification tests are more critical than others. Aging mechanisms simulated by thermal, climatic and mechanical stress in the laboratory can cause certain test failures in the laboratory. There is no clear correlation between laboratory effects and real failures during the module's service life, but while opinion about such a correlation is diverse, the fact remains that the lifetime of a module depends on the actual location/climate and environmental influences during this time (such as wind, rain, irradiance, snow, salt mist, humidity, etc.). The impact of humidity on the cell encapsulation, for example, might not be adequately covered by the so-called damp heat test (see Table 1; 10.13) of IEC 61215. Data indicate that current testing times might actually be too short to simulate a 20+-year lifetime [2]. At the same time, effects seen in installations have been detected on identical modules in the existing laboratory tests. Ongoing research projects at TÜV Rheinland and their partners aim to help better understand the aging mechanisms in PV modules and establish models for simulation.

The most frequent failures are caused by weaknesses in electrical connections and cell encapsulation. In particular, soldering and bonding connections are stressed during temperature cycling due to different expansion coefficients of materials like copper, silicon and glass. Lamination problems as well as material incompatibilities are detected during long-term exposure to high temperature and high humidity such as in the aforementioned damp heat test. Third in line of the three most failed tests is the so-called hot-spot test; failures here are either caused by solar cells with low shunt resistance or an improper bypass diode concept. Interestingly, these tests show the highest failure rates for crystalline silicon as well as thin-film technology PV modules. There is, however, a shift in the frequency of the failures. The hot-spot test has actually proven to be more critical for thin-film modules than for crystalline modules, while the thermal cycling test (see Table 1; 10.11) is less critical.

> "Soldering and bonding connections are stressed during temperature cycling due to different expansion coefficients of materials like copper, silicon and glass."

Of particular note is the fact that for thin-film modules the failures are much more diverse than for crystalline modules. While 90% of the failures of crystalline modules are distributed over these three tests, for thin-film modules about 50% of the failures are in other tests. One major additional reason for failure is the spontaneous glass breakage caused by stress in the not-heat-strengthened glass, in which case a slight waviness of the glass surface can cause non-uniform heat distribution during the lamination and therefore cause internal stress in the glass sheet.

Figures 3 and 4 show that the production of a PV module that fulfils the requirements laid down in the international type approval standards is a sophisticated task. Materials, components and production parameters have to be chosen carefully.

Conclusion

The use of high quality materials/components alone does not necessarily lead to a high quality module. The failure mechanisms for a PV module are diverse; even the well understood failure reasons have a high frequency. Production mistakes that caused failures years ago are still repeated nowadays. In many cases, failures are caused by poor quality control measures in production and are avoidable; in other cases, the reasons for failure are less obvious and a more sophisticated failure analysis is required. For materials issues in particular, it is not immediately obvious from measurements or visual inspections what is the root cause of the problem in question. Further research in PV is required in the field of polymers and their interaction with adjacent materials, as well as in the particular measurement procedures for the different thin-film technologies.

> "Further research in PV is required in the field of polymers and their interaction with adjacent materials, as well as in the particular measurement procedures for the different thin-film technologies."

The assessment of quality and safety of PV installations in the field is quickly becoming more important as the number of installations grows.

Offering services close to both markets and manufacturers, TÜV Rheinland's aim is to establish a worldwide PV network for PV, CPV and solar thermal product testing. Its laboratories in Cologne, Arizona, Shanghai and Yokohama are all increasing test capacities to meet the large market demand. With these multiple locations and an additional outdoor test facility in south Europe, an optimal utilization of expertise is possible, with the future aim of providing test procedures for new technologies such as CPV looking more achievable.

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About the Author

Jörg Althaus is the business field manager for Renewable Energies – PV module Qualification at Cologne-based TÜV Rheinland. He based the final project for his degree in electrical power engineering at TÜV Rheinland on solar cell measurement, and in 2001 started as a project engineer in the PV laboratory in Cologne. Today he coordinates PV module testing in his team and communicates with the other TÜV Rheinland laboratories internationally. Mr. Althaus has presented works on the topic of module testing at several conferences. He is currently participating in standardization work through the IEC working groups for flat-plate photovoltaic modules (IEC TC82 WG2) and CPV modules (IEC TC82 WG7).

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Developments in high throughput integrated cell connection equipment

Mark Osborne, News Editor, *Photovoltaics International*

ABSTRACT

The rapid expansion of high volume manufacturing to meet growing demand in recent years has highlighted the development of increasingly higher throughput machines. This is particularly true in the critical bottleneck process of module assembly, specifically characterised by tabbing and stringing steps. Significant productivity improvements have come about with the development of integrated, highly-automated tabbers and stringers from a range of equipment vendors. However, module assembly remains the most expensive step in conventional c-Si cell production. Equipment suppliers are also challenged to meet the evolving demands of processing thinner wafers and to address overall production cost reduction strategies while meeting yield/throughput goals that are seen as a significant enabler of reducing the cost per watt. This paper provides an insight to the tabbing and stringing processes featuring contributions from some of the major equipment suppliers.

Cell and module production has grown rapidly over the last four years as existing major PV manufacturers have scaled production. New entrants have benefited from low interest finance for jump-starting large-scale production and become cost competitive with larger manufacturers. Not only have the number of new production facilities grown significantly, grid parity goals have driven PV manufacturers to build and operate facilities on an ever-increasing scale.

As can be seen in Figure 1, Suntech, Sharp and Q-Cells are approaching 1GW nominal capacity levels, with other major manufacturers nearing 500MW nominal capacity. Interestingly, the market share of the top 10 manufacturers is declining as new entrants rapidly expand production. According to VLSI Research, the top 10 had a combined market share of 40.1% in 2006, a figure that is expected to decline to only 29.1% by the end of 2009. The market for tabbers and stringers used in PV module assembly grew by over 60% in 2008 to reach a value just over US$200 million, 80% of which is for silicon wafers, the remainder for thin-film and other PV cell technologies.

The market is highly fragmented, says John West, Managing Director of VLSI Research Europe. There are over 20 companies supplying equipment capable of connecting solar cells, with the top five companies accounting for 50% of the hotly contested market. The key players in 2008 were 3s Industries, Komax, NPC Corporation and Spire Corporation.

Rapid capacity expansions have quickly led to a need for highly automated and combined tabber/stringer systems (CTS) that can also provide high throughput. As throughput is determined by the amount of wafers that can be processed per hour, a key focus for equipment suppliers is the speed of the systems, a major factor in reducing manufacturing costs.

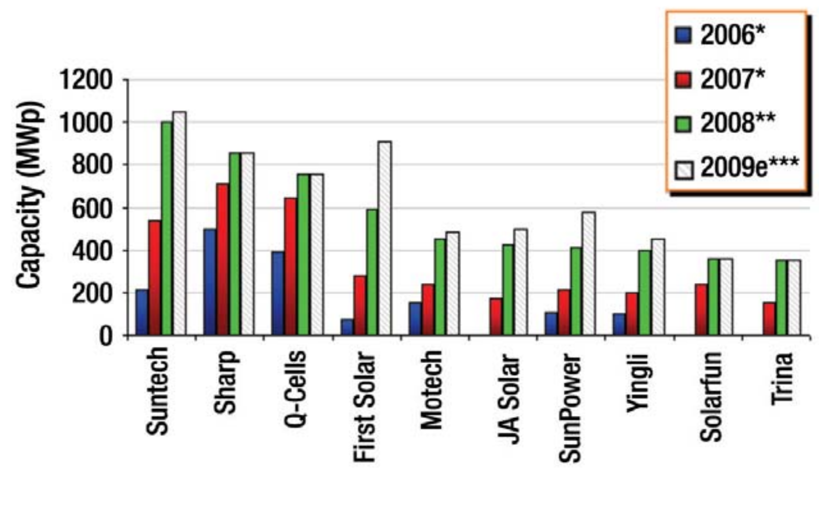

Figure 1. Top 10 PV manufacturers by revenue.

Source: VLSI Research, 2009.

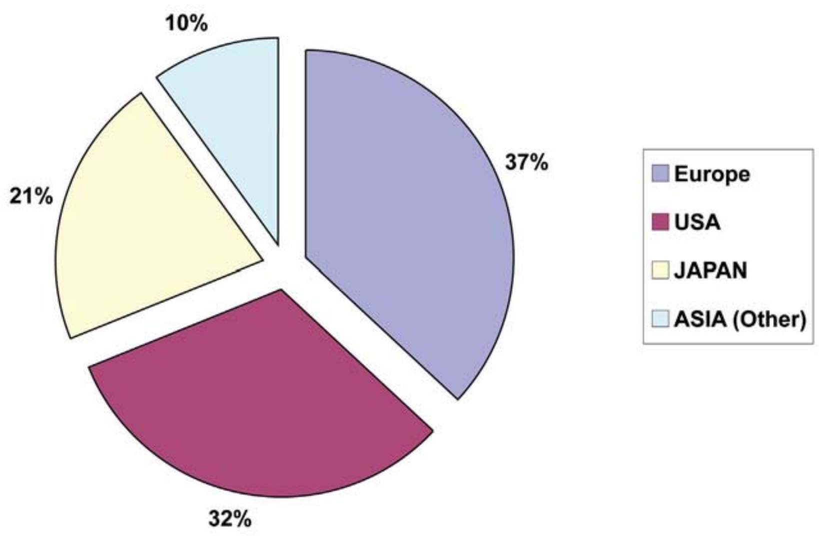

Figure 2. Combined Tabber/Stringer (CTS) equipment suppliers by region.

Source: VLSI Research, 2009.

However, many of the yield losses encountered in cell processing are found during cell interconnection and therefore impact overall module performance. Electrical and optical losses are introduced at the module assembly stage and can impact typical multicrystalline H-pattern cells' performance by as much as 2.5% [1].

A recent study by CrystalClear [2] calculated that in the production of a typical silicon wafer (multicrystalline, 156x156mm^2, 220µm thickness), the cost of the module alone was €0.67 per Wp.

The study, which started in 2004, found that crystalline silicon PV technology has the potential to reach module manufacturing costs of around €1 per Wp within approximately five years. Efficient silicon utilisation (g/Wp module power), high total area module efficiency, high throughput and high-yield production are factors that will need close monitoring to achieve such a cost in the given timeframe.

High throughput

In a sample survey of some of the leading CTS equipment suppliers, including Spire Corp., Mondragon, Somont and teamtechnik, respondents reiterated that high throughput of their systems continued to be a key customer requirement, especially for high volume manufacturers. teamtechnik's Michael Bay noted that the company's main customer base consists of high-volume PV producers, who tend to assess equipment throughput data in great detail prior to purchasing.

"For high volumes we offer and sell our TT1200, which can run at a cycle time of 3 seconds, or 1200 cycles per hour. At a string of 10 cells, this would mean an output of 1090 cells per hour," noted Bay.

Another leading equipment supplier, Mondragon is well known for its high throughput systems. Mondragon's Xabier Otano noted that throughput had become a key customer concern, and in response developed its TS1200 machine, capable of achieving 1,200 six-inch cells per hour and 1,300 five-inch cells per hour. The company has also seen sales of its TS2400, which provides double the throughput and is essentially two of its TS1200 machines combined.

But Otano cautioned that high throughput is not the sole requirement of customers, and that the contrary is sometimes the case. "On the other hand we are seeing companies that prefer having more machines with lower throughput in order to be able to have parallel production," Otano explained.

Matthias Ruh, SOMONT's head of sales, was another proponent of the importance of looking at other factors that affect purchasing decisions, commenting that "as high throughput at low breakage rates and very good soldering results decide on the profitability, there is a clear trend towards high output. This is key even if you want to install a smaller line for, let's say, a 10MW or a 100MW facility."

SOMONT has developed a high-throughput modular platform, dubbed 'RAPID,' which is suitable for 10MW, 20MW and 40MW (and higher) lines. This corresponds to production rates of 600, 1,200 and 2,400 (and more) cells per hour, respectively, on 10 x 6" cells/string.

By using this modular concept, a smaller production for modules of, for example, 10MW can work with the 'RAPID ONE,' a single soldering line system that has a capacity up to 600 cells per hour. The base version of this system comes with a string phase-out belt. Very large facilities would tend to order, for example, three 'RAPID FOUR' stringers in order to reach capacity of 120MW.

Figure 3. SOMONT's CTS equipment manufacturing facility.

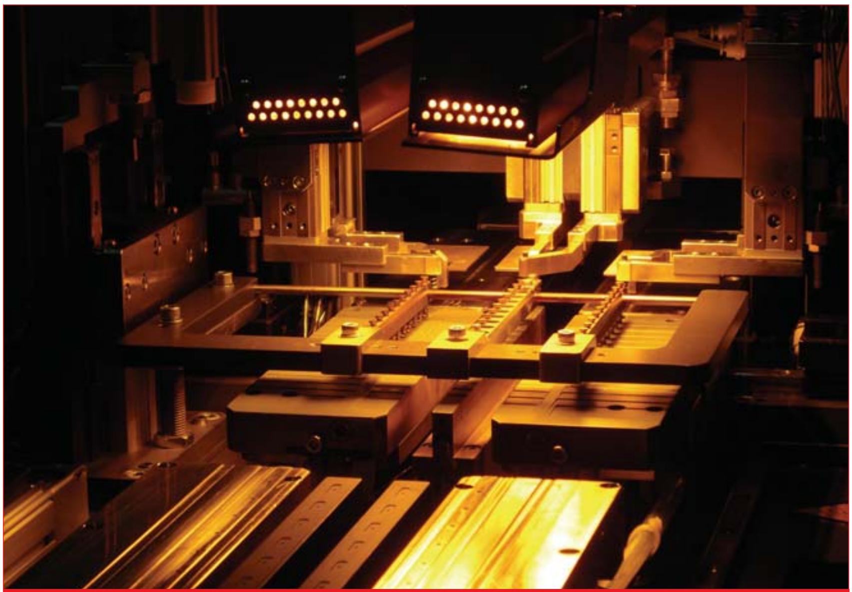

Figure 4. Mondragon preheating station, soldering station and cell holding elements.

Flexibility

David Wissoker of Spire Corp. noted that another key requirement of PV manufacturers is an inbuilt level of flexibility in the CTS.

"Versatility of the system is important," explained Wissoker. "Cells come in different sizes – two or three bus bars – and the equipment lasts for over 10 years so it should accept a variety of cells."

teamtechnik's Michael Bay confirmed the importance of flexibility.

"From our point of view, the key is flexibility regarding material such as new cell types and combinations with new ribbons or flux material. There we have the best possible solution with our laser soldering. Our customers also say that this is the best possible soldering tool for future applications," noted Bay.

Currently, teamtechnik also offers IR lamp soldering technologies (other than laser-based technologies) that can be integrated into its modular machine concept. Nevertheless, the company believes that IR has limited variability as it can only be turned on or off, and sees laser soldering as the technology of the future as it is widely regarded as being much more flexible, allowing the operator to alter the depth, strength and position of the solder beam.

Spire also offers IR lamp soldering for both front- and back-cell contacts in a single step on its Spi-Assembler 6000, addressing another aspect of CTS customers' requirements for platform flexibility.

SOMONT uses a 'soft touch' soldering process for use with very thin cells that can be handled at high productivity rates. The system has a temperature management feature that reduces thermal stress for the cells to a minimum, at the same time guaranteeing quality soldering joints. Refined lay-up stations have been developed for onward string handling.

Figure 6. SOMONT's 'soft touch' soldering technology.

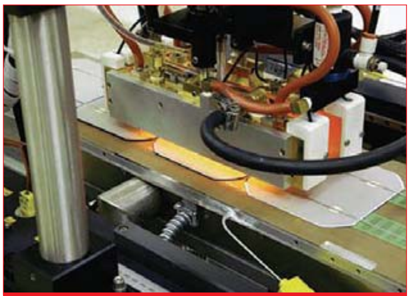

Figure 5. Spire offers single-step IR lamp soldering for both front- and back-cell contacts.

SOMONT's Ruh also stressed the need to have CTS systems capable of handling two and three bus bars, while making the switchover as simple and as fast as possible to improve the overall flexibility of the system, even in high volume environments where changeovers may not be so common.

Mondragon's Otano was also quick to emphasise fast changeovers, as this allows greater flexibility for customers' module designs, something that is becoming increasingly important in the highly competitive marketplace.

"Flexibility is one of the key criteria that our customers are seeking. In the solar market lots of the modules are very similar from one to another. Having a difference in the module design enables our clients to have a different product. Our machine has been developed from the beginning to ensure a quick change on module design, being able to produce very different modules on size and shapes, with a complete variety of personalized parameters (number of cells on string, gap between cells, length of ribbon, gap between strings, angle of the strings on the glass (for BIPV),...), with just the change of recipe on the machine HMI," remarked Otano.

Yield

Throughput and flexibility requirements of CTS systems may have rightly gained more attention from PV manufacturers in recent years. However, suppliers are now being expected to meet the evolving demands of processing thinner wafers.

Although significant declines in polysilicon prices are anticipated as more production comes on-stream over the next few years, the wafer material remains a significant fixed cost. As a result, PV manufacturers are expected to keep wafer cost reduction strategies focussed on the migration to thinner and thinner wafers.

But this approach can lead to higher breakages, both during handling between processing steps but also at the CTS, which generates both mechanical and thermal stresses on the cells. Developments are ongoing to keep breakage at current low levels (approximately 0.5%) when processing 200–220-micron thick wafers in high volume production.

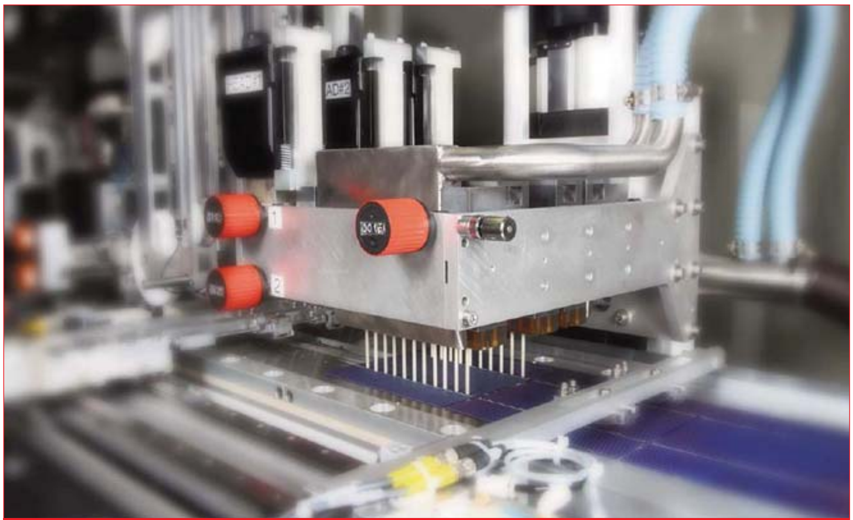

Figure 7. Komax's innovative solder head system.

teamtechnik noted ongoing developments that reduced the number of handling steps as well as minimisation of stress during processes to limit damaged cells. Camera systems that sort out any defective cells from the start are used in the CTS processes. But, as soldering thin cells has become problematic, greater use of tight temperature control in a closed loop environment has become a must, and is now another reason for using lasers over IR lamps, according to teamtechnik.

It stands to reason that poor or faulty contacts are another yield limiter. All of the major CTS suppliers have tackled this fundamental issue, with many new innovations. The Komax Xcell 3400, for example, employs an innovative solder head that uses non-metallic ceramic hold-down pins and non-contact closed-loop thermal feedback to tackle solder bond consistency and quality. Komax also employs a spray fluxing technique, which it claims will accurately apply the exact amount of flux to the top and/or bottom of the cell for correct soldering.

As with the other CTS suppliers, SOMONT took note of technologies that limited yield losses, while highlighting the yield loss potential from material quality, whether at the cell or with different types of ribbon used. The company also emphasised operator training and ease of use of the CTS operating systems as an important contributor to yield, noting that even operators in the most remote locations must be able to work with the systems. The menus for operation must be logical and easy to understand, and in case of a problem the operator must be able to be self-sufficient to retain throughput of the line.

"For this purpose SOMONT offers extensive training and support in our Service & Technology Center (STC) which went operational early this year. The personnel of our customers get a comprehensive training on a full-scale production line," noted Ruh.

Future developments

Driven by new cell designs and thinner wafers, CTS equipment is continuing to adapt to customer needs. The need for flexibility has seen the emergence of lasers for solder bonding though throughput remains a critical factor. Development is ongoing to improve the laser changeover times and shorten refilling cycles to push throughput of this type of technology, as noted by teamtechnik.

Matthias Ruh commented on how improvements in lay-up, cell testers and string testers are ongoing. Elements such as vision control, easy line integration and the corresponding standardised interfacing are being implemented as part of the company's continuous improvement programme based on customer feedback.

Generally, there seems to be a growing demand for Advanced Process Control (APC) capabilities on CTS machines as understanding and consideration of cost of ownership evolves.

"The outlook for 2009 is uncertain, but based on current order backlogs and capex plans of module manufacturers, sales of tabbers and stringers should be at levels comparable to 2008," remarked John West at VLSI Research.

Continued innovation and focus on throughput while lowering cost of ownership has become a key part of the CTS market. Dedication to this cause will be required in the coming years to enable reductions in cost per watt to meet and then exceed grid parity.

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Snapshot of spot market for PV modules – quarterly report Q4 2008

pvXchange and **eclareon**, Berlin, Germany

ABSTRACT

Solar enterprises will each be faced with the occasional surplus or lack of solar modules in their lifetimes. In these instances, it is useful to adjust these stock levels at short notice, thus creating a spot market. Spot markets serve the short-term trade of different products, where the seller is able to permanently or temporarily offset surplus, while buyers are able to access attractive offers on surplus stocks and supplement existing supply arrangements as a last resort.

Introduction

A spot market always shows the up-to-date prices of solar modules, because it does not consider the long-term delivery contracts of the producers. These days, the spot market for PV modules is global, because the short-term satisfaction of local supply deficits is possible with short transportation times and relatively low logistics costs.

pvXchange provides a closed online trading platform for sellers going 'public' with a short-term offer. Other participants of the market can decide if they want to buy the goods at that price, while potential buyers may post their interest and in turn be contacted by interested sellers.

Each issue of *Photovoltaics International* will enable the tracking of spot prices of modules through statistics provided by the pvXchange trading platform.

Clear decrease of trade volume

A total of 2MWp of PV modules were sold on pvXchange's spot market platform in December 2008. This corresponds to a sharp decrease of 60% when compared to the figures seen in the previous month (5.6MWp). Low trade volumes throughout the years are common on pvXchange; this year, bad weather conditions prevented many new installations, as did the current economic climate that saw many buyers waiting for further price decreases. The closing of long-term contracts has been postponed by many PV companies that are concerned that they will not find customers given the current circumstances. Again, First Solar's CdTe thin-film modules were the most traded technology item on the pvXchange platform for the month of December.

Decreasing price trend

The decreasing price trend noticed in October and November was confirmed in December; in fact, price drops accelerated further for the last month of the year.

The sharpest slump was again noticed for less well-reputed Chinese brands (average price 2.78€/Wp), due to a consequently loose price policy on the part of suppliers and the very high availability of offers on the spot market. Since November, a downward price trend has also been very evident for more established Japanese (average 2.97€/Wp) and German brands (average 3.11€/Wp). Even First Solar's thin-film modules showed a considerable slump to an average price of 2.27€/Wp, a change that can be put down to the fact that the largest supplier of these modules

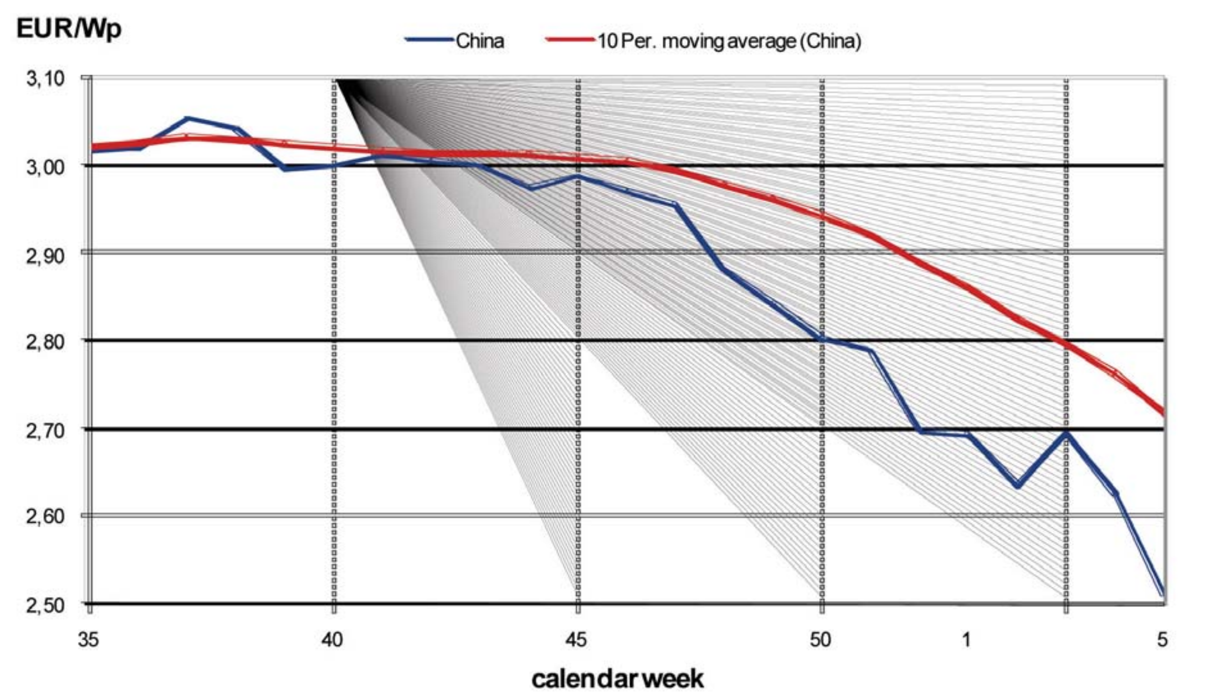

Figure 1. Development of market prices for modules produced by Chinese manufacturers in 09-12/2008 (in EUR/Wp).

decided to sell out its warehouse towards the end of the year. Even Sanyo's high-efficiency HIT lost their previously stable price position – average prices fell from 3.7€/Wp in October to 3.54€/Wp in December.

For the first quarter of 2009, we expect further sharp price decreases by at least 10-12€ct/Wp for the most wanted Chinese modules; up to 10€ct/Wp for Japanese modules; 5-10€ct/Wp for European and 3-5€ct/Wp for German modules. On the other hand, we expect a slight increase of prices for First Solar modules, resulting in no further decrease overall for these products.

Price analysis: price trends by countries of origin

In this section we analyse the split of average prices for modules traded on pvXchange in regard to the different countries of origin, in particular:

- Well-established and reputed premium brands from Germany, Japan and Europe on the one hand,
- Less established brands, mainly by Chinese manufacturers, on the other hand.

Figures 1, 2, 3 and 4 show the development for Chinese, Japanese, European and German modules, respectively, over the last four months.

Average prices for modules traded in latest month by country of origin

In the last period of each of the countries' respective data charts, the following average prices and ranges can be seen for the different modules by country of origin:

- Average price for Chinese modules in total: 2.78€/Wp (December)
  - All Chinese manufacturers had to cut prices. There is hardly any difference between different brands anymore; all suppliers follow decreasing price policies, with even Suntech modules slowly becoming cheaper.
- Average price for Japanese modules in total: 2.97€/Wp (December)
  - This average is representative for all Japanese brands traded on pvXchange (Mitsubishi, Kyocera and Sharp). A clearly downward price trend for Japanese modules is noticeable since November.
- Average price for European modules in total: 3.02€/Wp (December)
  - This average is representative for all brands traded on pvXchange – effectively, REC Solar, as well as one Spanish and one Italian manufacturer.
- Average price for German modules in total: 3.11€/Wp (December)
  - This average is representative for all brands traded on pvXchange (Solarworld and Schott Solar in particular).

In general, there are now large capacities of high-quality modules available on the spot market. Opportunities for newcomers or no-name brands are much worse than they were before, especially if prices for brand modules are facing further reductions in the coming months.

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PV Modules

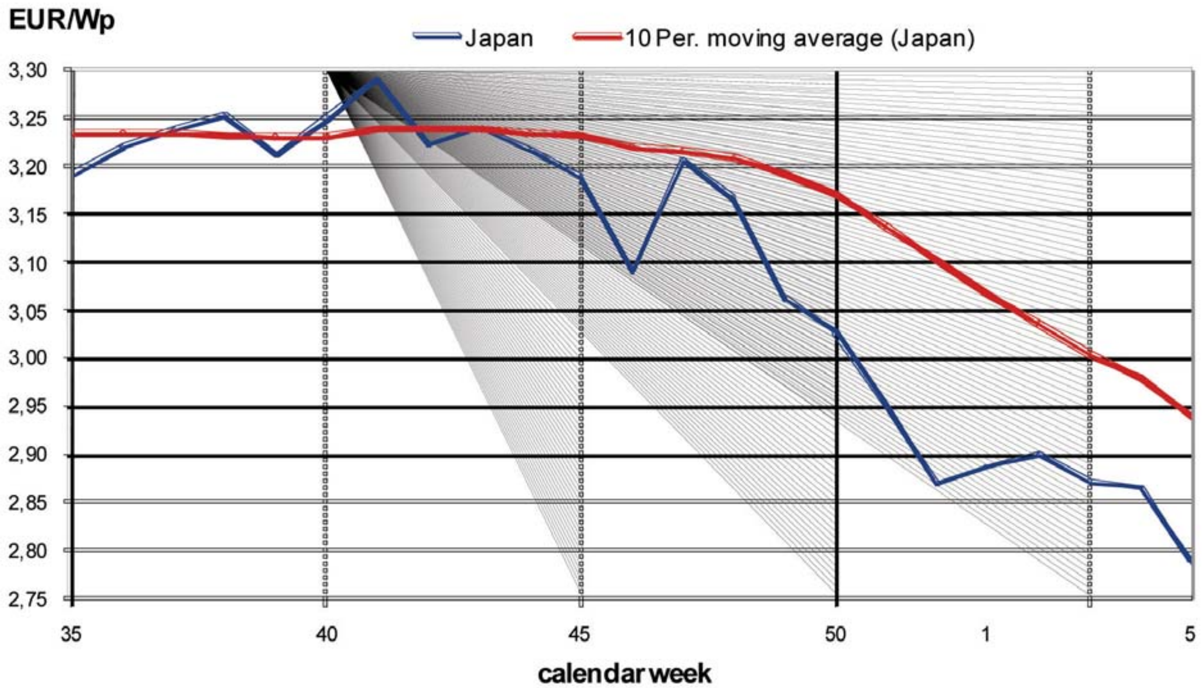

Figure 2. Development of market prices for modules produced by Japanese manufacturers in 09-12/2008 (in EUR/Wp).

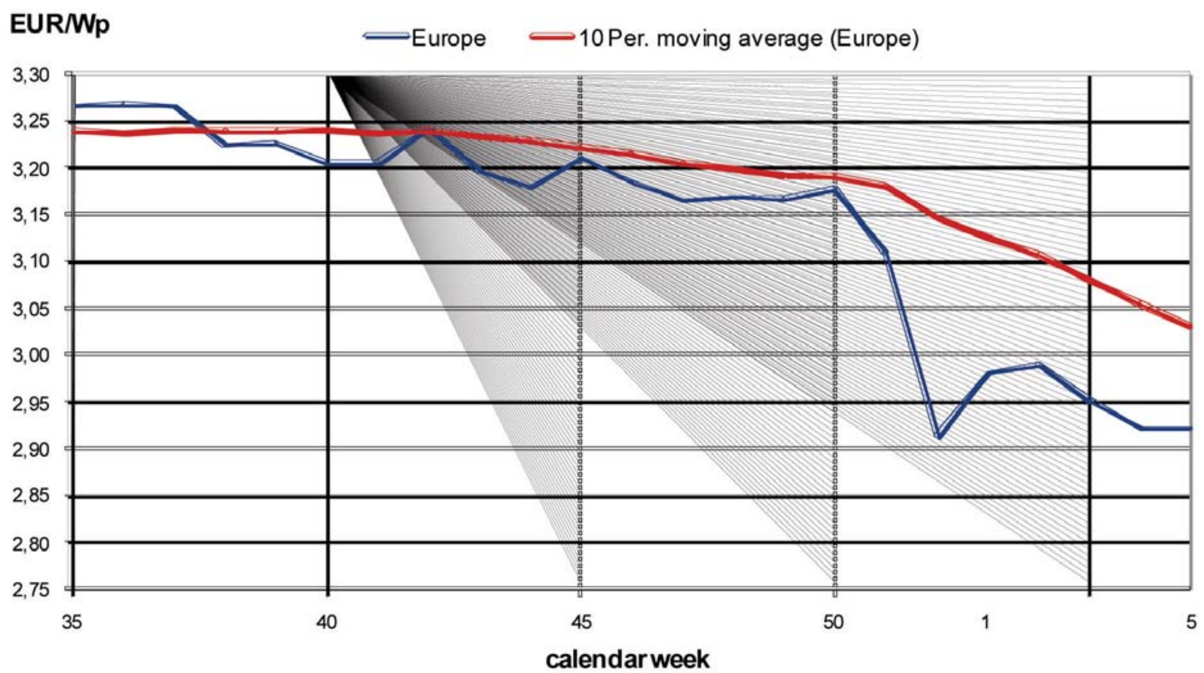

Figure 3. Development of market prices for modules produced by European manufacturers in 09-12/2008 (in EUR/Wp).

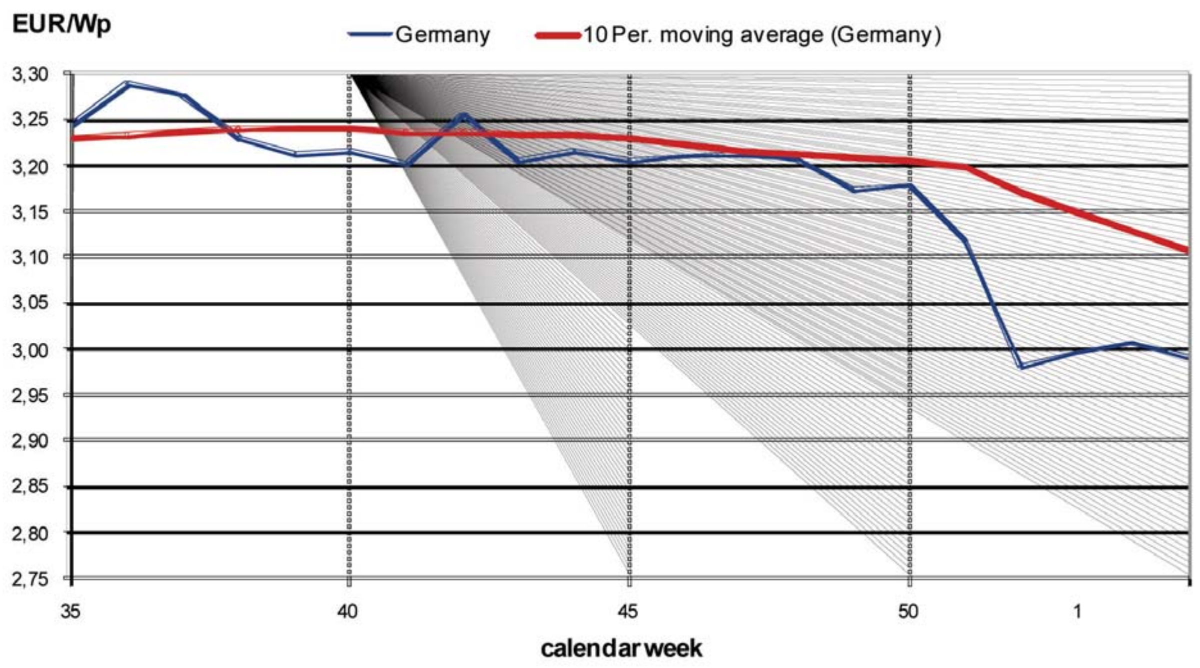

Figure 4. Development of market prices for modules produced by German manufacturers in 09-12/2008 (in EUR/Wp).

Current trends: comparison of average prices to previous months

Regarding the price development over the last few months (September-December 2008), the following observations can be made:

- Chinese modules: extreme price reductions since September
- Japanese modules: first price cuts noticeable in November and December.
- German modules: compared to other groups, there seems to be a slow price decrease noticeable so far. However, data showed a clearer downward price trend than in the previous month.
- US modules (mostly First Solar): available in considerable volumes again since October/November. In November and especially in December, the first price cuts were seen.

About the Authors

Founded in Berlin in 2004, **pvXchange GmbH** has established itself as the global market leader in the procurement of photovoltaic products for business customers. In 2008, the company procured solar modules with an output of around 100MW. This represents a trading volume of approximately €300 million. With its international network and complementary services, pvXchange is constantly developing its position in the renewable energy market, a market which continues to grow on a global scale. Based in Europe, pvXchange also has a presence in Asia and the USA. This market report is a quarterly synopsis of a monthly updated analysis made in co-operation by *pvXchange* and *eclareon*.

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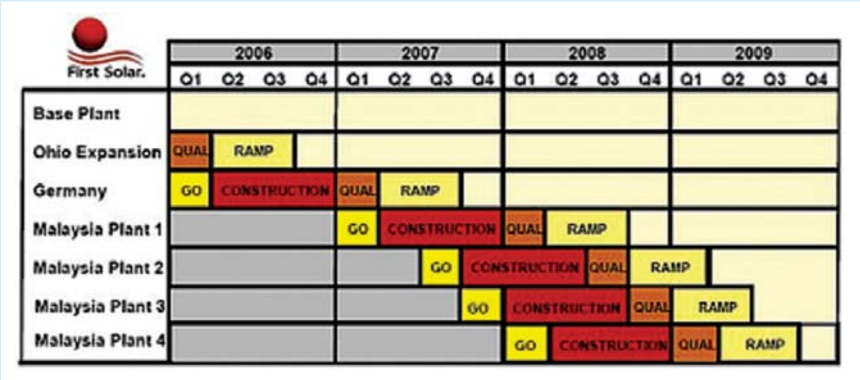
Power Generation

News

First Solar achieves US$1 per manufactured watt, 10.8% efficiencies and perhaps grid parity

Photon Consulting may have recently projected the PV industry to reach the US$1 per watt manufacturing cost threshold in 2012, but First Solar has ignored such projections and reached this important milestone in the fourth quarter of 2008, with a cost per watt of US$0.98. Not prepared to sit back and wait for competitors to catch-up, First Solar expects further reductions in the coming years that could see a cost per watt below US$0.65 by 2012 or earlier.

"We're capable of further significant cost reductions based on the yet untapped potential of our technology and manufacturing processes," noted Mike Ahearn, First Solar Chief Executive Officer, in a conference call with financial analysts. "In fact, the long term financial models we have previously discussed suggest manufacturing cost targets of $0.65 to $0.70 a watt by 2012. We picked those as interim milestones...but we believe reductions below these levels are clearly possible beyond that timeframe."



The progressive fall in manufacturing costs of its CdTe thin film modules was attributed to the company's continuous focus on cost reductions as production scaled to significant MW levels in only a few years.

First Solar's annual nominal production capacity will double in 2009 to a planned 1.1GW as manufacturing plants, specifically in Malaysia ramp to full production. Plants 3&4 in Malaysia are now ramping, with capital spending expected to be between US$270 and US$300 million. Each of the Malaysian plants or lines has a nominal capacity of approximately 190MW.

With over 1GW capacity, First Solar can leverage the cost of materials and productivity improvements to a much greater extent than in previous years.

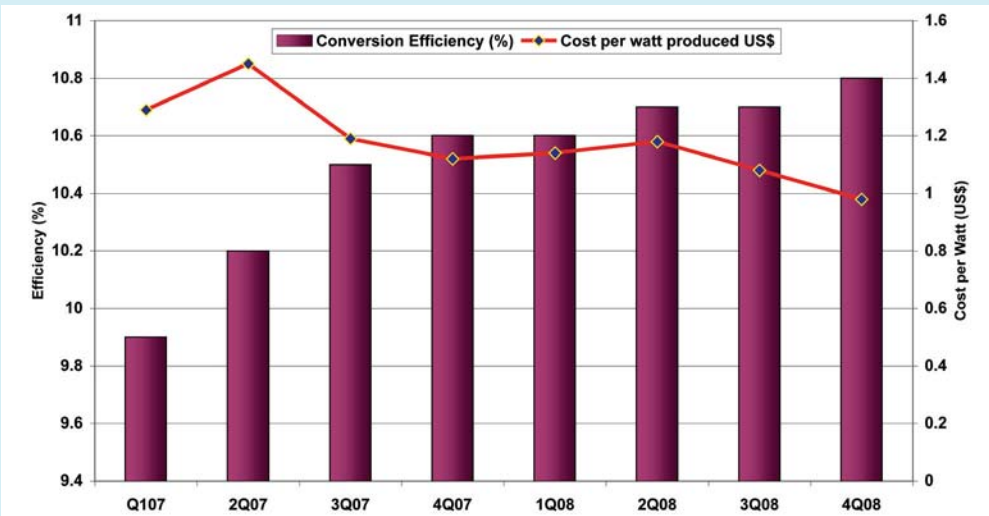
"I'd say that our ongoing improvement plans are really to continue to drive the efficiency that helps drive the costs down, drive the run rates of the factories, and then of course continuing to focus on the raw material costs as we purchase them," commented Bruce Sohn, President of First Solar, in response to an analysts question in the conference call. "Continuing to scale facilities like our Malaysia operation helps significantly as we build out the line. And continuing to see the market develop certainly aids in our ability to drive down those costs, so we continue to stay focused on it. We think it's a reasonable challenge for us to get there in this 2010 to 2012 timeframe," noted Sohn.

However, First Solar didn't just reach a company and industry milestone with the cost per watt but also achieved its highest stable conversion efficiencies in the fourth quarter of 2008. According to the company, efficiency levels reach 10.8% in the quarter (see graph), further testament to First Solar's continuous productivity improvement programmes during a period of rapid capacity expansion.

According to Greentech Media's report earlier in the quarter, it seems that First Solar has managed to achieve grid parity with its 12.6MW system in the Nevada desert, installed for Sempra Generation. Mark Bachman, a senior research analyst with Pacific Crest and a specialist in cleantech energy, has aggregated the numbers in the Greentech Media report.

Bachman claims that the Nevada desert system costs US$0.075 per kWh to install without any subsidies, compared to costs incurred by 'conventional' power of US$0.09 per kWh.

First Solar has managed to produce large numbers of panels at a low cost for the past few years, claiming previously that it had lowered the cost-per-watt of production of its modules to US$1.08 per watt. According to Greentech Media, this figure is an amalgamated average of the individual costs of production in each of the company's manufacturing facilities, although First Solar has reached a low cost of US$0.075 per watt in its Malaysia-based plants.



It should be noted that the installation for Sempra actually cost around US$3.17 per watt. The price incorporates the cost of frames and installation as well as the cost of the modules themselves.

US Region News Focus

News

Pacific Gas and Electric to add 500MW of solar PV power; SEPA applauds plan

Pacific Gas and Electric has annnounced plans for a five-year program which would lead to the development of up to 500MW of solar photovoltaic power in its northern and central California service area. The proposed program consists of up to 250MW of utility-owned PV generation – the utility's first direct investment in renewable generation in more than a decade – and an additional 250MW to be built and owned by independent developers under a streamlined regulatory process.

If all projects are up and running by 2015, they would deliver more than 1000GW-hours of power each year, equal to the annual consumption of about 150,000 average homes. In all, this program would meet more than 1.3% of PG&E's electric demand.

PG&E's solar program will target midsized projects, typically between 1 and 20MW, ground mounted or on rooftops, within its service area. Where feasible, projects developed and owned by the utility would be built on land already owned by PG&E or near its substations to minimize the cost and delays of interconnecting them to the power grid.

California commercial rooftop installation.

Projects developed by independent parties would be offered a standard contract and pricing derived from the utility's own costs to streamline review of their applications, according to the utility.

"This program represents an unprecedented commitment of our capital and expertise to speed the delivery of clean, renewable energy to our customers," said Peter Darbee, PG&E's CEO/President. "With many renewable-energy projects delayed, we can't afford business as usual when it comes to protecting the environment and meeting our customers' expectations."

Gov. Arnold Schwarzenegger commented on the PG&E plan. "By bringing renewables online as quickly as possible and advancing the development of green technologies, this effort will advance California's aggressive push to meet our long-term energy and climate change goals while keeping California on the leading edge of this booming industry."

PG&E said it is currently submitting its plan to the California Public Utilities Commission for approval, which could come later this year.

enXco and Carrier Clinic sign Power Purchase Agreement for solar array

enXco, a subsidiary of EDF Energies Nouvelles, signed a 25-year Power Purchase Agreement with the non-profit healthcare system Carrier Clinic, located in Belle Mead, New Jersey. This agreement will spur the development of a solar photovoltaic array that could reach 1.9MW when completed. enXco will own and operate the system and will supply its output to Carrier Clinic on a net-metering basis.

Construction is scheduled to commence this spring, with energy production expected to begin in 2Q 09. The ground-mount fixed-tilt solar array will be built on 12 acres, to be the largest solar system on a New Jersey hospital campus, and will utilize First Solar modules deployed from EDF EN's global supply agreement.

New Jersey utility to spend US$774 million on solar energy project

In order to meet New Jersey renewable energy requirements, Public Service Enterprise Group, Inc. will spend US$774 million over a period of five years to install solar panels on power poles and government buildings.

The PSEG project will add 120MW of clean power generating capacity, enough for 100,000 homes. Rates will be raised 10 to 35 cents a month on customers' bills in order to recover the cost of the project.

New Jersey requires 22.5% of the state's electricity to be generated by renewable sources by 2021, one-fifth of which must come from solar. This will require 1800MW of new solar capacity, or enough power for 1.45 million homes.

Los Angeles Unified School District launches US$350-million solar energy program

In response to the economic crisis, The Los Angeles Unified School District launched a US$350 million solar energy program in order to meet its goal to generate 50MW of solar electricity by 2012 and to reduce its annual US$80 million electricity bill.

The "We Build Green" program will place solar panels on schools and other district buildings. The installations are expected to save the district approximately US$12.5 million per year for 20-25 years, which is up to US$320 million in total. Randy Britt, the district's director of sustainability, also expects the program to create jobs and provide a substantial economic stimulus.

DuPont research, PV powered

DuPont installed its largest photovoltaic solar energy plant at its Pioneer Hi-Bred Waimea Research Center in Kauai, Hawaii.Completed in December 2008, the Waimea plant is made up of 1,500 panels produced by Evergreen Solar and installed by REC Solar. The array spans one acre and is expected to produce 706,205kWh annually, approximately 85% of Waimea's required energy.

This is DuPont's third photovoltaic power system, after its R&D and business facilities in Wilmington, Delware and Taoyuan, Taiwan.

Dupont's Pioneer Hi-Bred Waimea Research Center in Kauai, Hawaii.

Entech Solar uses Xantrex inverters in solar power system for water district

Xantrex Technology, Inc., a subsidiary of Schneider Electric, supplied four Xantrex GT Series Three Phase Grid Tie Solar Inverters for a utility-scale 1.1MW solar power system in Valley Center, California.

This solar power system, designed and installed by Entech Solar Inc., will offset up to 20% of the electricity required by the Valley Center Water District's largest pumping station, or 2.1 million kWh of electricity per year.

BP Solar finishes final installations of Wal-Mart PV systems in California

BP Solar has completed the final three photovoltaic systems specified under the terms of its solar power construction program agreement with Wal-Mart. The company recently finished building a 493.7kW system at the Sam's Club in La Habra, a 605.9kW array at the Wal-Mart Super Center in Palm Springs, and a 675.2kW system at the Beaumont Super Center.

With these three systems totalling over 1.7MW, this fulfills BP Solar's 4.1MW commitment to Wal-Mart as part of the retailer's solar pilot project. The project consists of nearly 24,000 crystalline-silicon solar panels, which are expected to produce 6.7 million kW-hr of electricity per year.

SunPower's Sunlight division and SunEdison are also partnering with Wal-Mart to install solar power arrays on rooftops of stores and centers in California and Hawaii.

Suntech signs solar roof membrane licensing deal with Open Energy

In an exclusive agreement, Open Energy teamed up with Suntech Power for the licensing of Open Energy's building integrated solar roof membrane product. This cooperative move will see Suntech manufacture, distribute, and oversee sales and marketing of Open Energy's solar membrane product, which will carry the title SolarEze once this agreement is finalized, highlighting the product's relative ease of installation.

It consists of a frameless flat roof membrane, which is light in weight yet waterproof, hail and wind resistant and without any penetrations.

More California commercial sites add solar PV power systems

The number of commercial solar PV power systems in California continues to increase, with the recent activation of several new installations throughout the state. The latest arrays account for more than 3 MW of capacity and will produce hundreds of thousands of kilowatt-hours of clean energy.

The largest of the new installations can be found in Fresno, where SunPower teamed with Grundfos Pumps on a 1.1MW plant at the customer's site. The ground-mounted arrays are comprised of the solar company's own modules integrated into its Tracker dual-axis system.

The Grundfos project is funded through a SunPower Access power purchase agreement, with Grandfos buying the electricity from Morgan Stanley, which will own and operate the system.

In another example of the photovoltaic revolution in California viticulture, Premier Power designed, built, and commissioned a US$5.3 million 825.4KW solar system at two locations owned by the Trinchero Family Estates winemaking concern.

Most of the PV can be found on three rooftops at the company's Lodi winery, with 1024 GE and 2420 SunPower panels combining for more than 761KW of installed DC power, all of which runs through a set of five Xantrex inverters, according to Premier sources. The remaining 320 GE modules connected to two Satcon inverters power a 64KW array running pumps at the company's irrigation pond near its Clements vineyard.

The Trinchero systems will provide some 1.1 million KW-hours of electricity annually.

The Marshall Medical Center in Cameron Park now has a 669KW PV array, capable of producing more than 938,600 KW-hr of power per year. The system was designed, engineered, and installed by Solar Power Inc., which financed the project through a PPA with Solar Power Partners.

SPI used 3344 of its own modules, produced at its Chinese manufacturing plant, for the project, deployed in fixed mounts on several car-park structures.

Lithographix's facility in Hawthorne near Los Angeles International Airport (pictured above) claims to have the largest PV power system of any commercial printing plant in the U.S. The newly commissioned 650KW installation was envisioned and put together by integrator ThinkSolar in cooperation with contractor Pacific Solar Energy.

The rooftop arrays at the 250,000-square-foot building feature about 2240 Schott ASE300 panels, chosen because of their durability and double-glass encapsulation, according to the project partners. Solectria inverters and an integrated set of Unirac ballasted racking make up other key elements of the balance of system.

The solar array is expected to offset up to 30% of the Lithographix facility's electricity needs.

European Region News Focus

Ferrari factory Maranello, Italy.

Ferrari plant revs up solar PV power

A solar photovoltaic power system has been activated at Ferrari's engine mechanical machining facility in Maranello, Italy. The 198.85kW-peak array was installed by EnerRay on south-facing flat rooftop areas at the plant.

The PV system, comprised of 1075 fixed Mitsubishi 185Wp panels and two Siemens Sinvert Solar 100 inverters, is expected to produce more than 210,000kW-hours of clean electricity per year. The installation comes as part of Ferrari's ongoing environmental sustainability and renewable resources investment program.

juwi completes 40MW Waldpolenz plant

The juwi group announced the completion of the Waldpolenz energy park in Brandis, in eastern Germany, ahead of schedule in December 2008. The 40MW plant has a surface area of more than 100 hectares and consists of over half a million thin-film modules supplied by First Solar. juwi acted as general contractor, overseeing the site's construction, planning and logistics management.

juwi's installation at Waldpolenz solar park.

Econcern project in Italy.

Econcern to add 42MW capacity in southern Italy

Sustainable energy solutions company Econcern intends to install 42MW of solar capacity in southern Italy. Located in Puglia, the initial seven 1MW solar parks that comprise Phase 1 of the project are expected to be completed and in operation by early 2010. Project Trullo, as the €200 million venture is being dubbed, will contribute an additional 15% of installed capacity to Italy's current level of 280MW.

Phoenix Solar AG extends contractor agreement with KGAL for €150 million

KG Allgemeine Leasing GmbH & Co. (KGAL) agreed to the extension of Phoenix Solar's contract through to 2011 and the raising of the volume of the framework agreement by a minimum of €150 million. The agreement, signed in September 2007, states that the Phoenix Solar Group will continue to act as general contractor in the development and construction of large photovoltaic plants on KGAL's behalf. The overall value of the investment from 2009 to 2011 is placed at at least €375 million.

Sopogy enters agreement to build 50MW MicroCSP plant in Toledo, Spain

Sopogy, Inc., the proprietary MicroCSP concentrating solar thermal energy system manufacturer, has signed an agreement for the development of a 50MW solar power plant using its MicroCSP technology in Toledo, Spain. The agreement is with solar project developer INYPSA Informes y Proyectos, S.A., a Spanish company, and Germany-based solar project financer Omniwatt. The plant is set to be completed by early December, 2010.

Xantrex launches large-scale solar inverters for Italy

Schneider Electric subsidiary Xantrex Technology, Inc. announced the launch of the Xantrex GT500E and the Xantrex GT250E Three Phase Grid Tie Solar Inverters for the Italian market.

The 500kW Xantrex GT500E and the 250kW Xantrex GT250E solar power inverters earn industry-leading efficiency ratings with the latest switching devices and are designed to meet the technological requirements of large-scale applications for utilities and businesses. They can be integrated into a 1MW turnkey configuration.

Toshiba enters photovoltaic systems integration market

Toshiba Corporation plans to enter the solar photovoltaics market as a large scale utility and industrial systems integrator and components supplier. Toshiba has formed a dedicated business unit (Photovoltaic Systems Division) within its global Transmission Distribution & Industrial Systems Division. The company said that is would be targeting sales of approximately US$2.2 billion by fiscal year 2015, through its existing global sales channels.

SunEdison pockets 38MW portfolio with Business Institute Solar Strategy acquisition

In a move that signifies the company's initial foray into the European market, SunEdison has purchased Business Institute Solar Strategy GmbH (BISS). The company has brought with it 38MW of PV projects that are currently under development in Italy and Spain and opens the door to 300MW of development opportunities in Europe.

Phoenix Solar subsidiary takes over Italian project company Scarlatti Srl.

A wholly-owned subsidiary of Phoenix Solar AG, Phoenix Solar Energy Investments AG announced its acquisition of all of the shares of Scarlatti Srl., an Italian project company headquartered in Eppan an der Weinstraße, Italy. Scarlatti currently has shares in four companies, which have plans develop five projects in Sicily, totalling around 27MW.

COLEXON signs 15MWp development acquisition deal with TNP

Thin-film PV power plants developer COLEXON announced its decision to enter into a strategic cooperation agreement with TNP, an investment company. The new deal stipulates that COLEXON will offer solar development projects of at least 10MWp to TNP by 2010, while TNP will in turn provide between 7MWp and 15MWp of solar projects, depending on the extent of the equity available.

COLEXON installation.

The two companies will cooperate on development and construction of turnkey solar power plants. Additionally, both companies have committed to completion of solar projects from the 5MWp Wiesenhof portfolio. COLEXON has already completed a quarter of its obligations in this respect, and the remainder of the rooftop projects from the Wiesenhof portfolio are scheduled to be delivered and grid connected by the end of 2009. The new partners expect to generate a sales volume of at least €40 million through this collaboration.

Acciona Energy connects massive 46MW solar PV power plant to grid in Portugal

What is being called the largest solar power plant of its kind was connected to the grid by Acciona Energy in the Alentejo region of Portugal. The 46MWp farm, located on 250 hectares in Amareleja parish near the Spanish border, was built in 13 months and represents an investment of about €261 million by the company (which 100% owns the plant).

EDF Energies Nouvelles inaugurates 7MWp solar farm in La Narbonnaise, France

EDF Energies Nouvelles officially opened a 7MWp solar power plant in La Narbonnaise, in the Aude region of France. The plant, which was fitted with 95,000 First Solar thin-film modules, is the biggest solar power plant in operation in France and is built on land owned by the Narbonne local community authority.

Middle East Region News Focus

Israeli government issues first PV plant licenses; gives go-ahead to 4.9MW plant

National Infrastructures Minister Binyamin Ben-Eliezer has granted Israel's first licenses to build and operate PV and solar thermal plants in the country. The Arava Power Company has received the go-ahead to build a 4.9MW solar plant at Kibbutz Ketura in the Eilot region of the Arava desert, while EDIG Solar will build the country's first 100kW solar thermal plant. The Public Utility Authority is said to have worked on the granting of the licenses. It seems that the licenses, once granted, are active for 18 months, after which time it is expected that the facilities will have been built. The Arava Power Company plans to begin construction of the 4.9MW plant as soon as the new feed-in tariffs for medium-sized plants are approved, and expects to invest approximately NIS120 million. It has been agreed with the 15 kibbutzim in the Negev and Arava areas that the land can be used for the construction of the solar plant, which is planned to become operational in March.

Arava Power wins approval for world's largest PV field

Arava Power, a joint venture of Kibbutz Ketura and foreign backers led by Yosef Abramowitz, announced that is has won approval from the Israel Electric Company (IEC) to build an 80MW solar PV field on kibbutz land in the Arava. IEC issued its approval once it had determined that it could run a line from the Arava to the national grid.

Once built, the Arava PV field will be the largest in the world, twice as big as the current largest field in Germany, which has a capacity of 40MW. The solar panels will be built on about 1500 dunams of kibbutz land within four years and will cost US$400 million.

SolFocus to co-develop 1.6MW CPV array in Greece

SolFocus signed an agreement that will see the concentrated phovotoltaic technology company work with engineering company Samaras Group on the construction of a 1.6MW installation.

Using the SolFocus 1100S system, installation of the CPV plant will begin in spring 2009, with the first power output expected in summer.

Suntech solar panels to power largest PV solar project in the Middle East

Suntech Power Holdings Co., Ltd. announced it has supplied 5MW of solar panels for a 10MW solar electricity system to power Masdar City, UAE. This follows a previous announcement that First Solar will provide the other 5MW.

The panels will form part of the largest solar plant in the Middle East and is being built and designed by Abu Dhabi-based solar power system integrator, Enviromena Power Systems. The installation has been designed with 5MW of First Solar's thin film CdTe modules and 5MW of Suntech's crystalline modules.

Masdar to use 5MW of First Solar modules in new 10MW plant in Middle East

The Abu Dhabi-based Masdar initiative plans to construct a 10MW solar power plant in the Middle East area, which will be the first and largest grid-connected solar photovoltaic plant in the Middle East and North Africa region. The plant will consist of 50% crystalline modules and 50% thin-film modules, which, it was announced today, are to be supplied by First Solar.

Construction on the Dh185 million (~US$50Million) project is underway and is scheduled for completion by the end of the second quarter of 2009. The PV plant will power the construction activities in Masdar City and the Masdar Institute, which opens in late 2009, while any surplus energy generated will be connected to the Abu Dhabi grid.

First Solar selected for Masdar City project.

Asia Region News Focus

TEPCO plans to build 10MW solar power plant in Japan

Tokyo Electric Power Company (TEPCO) announced its plans to build a 10MW solar power plant in the Yamanashi prefecture of central Japan in an effort to reduce greenhouse gas emissions. TEPCO hopes to begin partial operations in April of 2011 with a goal of 12 million kWh of electricity per year. The estimated costs of this project have not been released.

Refex Energy sets sights on Gujarat for 50MW solar plant

Mumbai-based Refex Energy has signed an MoU with the energy and petrochemicals State department of Gujarat approving its plans to construct a 50MW solar power plant in the region. The company intends to start work on the first phase of the 50MW capacity in 2009, with the remainder of the phases to be completed in stages.

1GW solar power plant planned in China

China Technology Development Group Corporation (CTDC) has signed an initial contract with the local government of Qinghai Haixi Mongolian-Tibetan Autonomous Region for the construction and operation of a 30MW on-grid solar power plant at a cost of US$150 million. Construction is expected to start sometime in 2009 and has a targeted capacity of 1GW, according to CTDC, without providing a timescale or further financial details of the ambitious and potentially the largest single PV based power plant in the world.

CTDC claimed that the power plant will integrate both crystalline silicon and thin-film solar modules in the initial 30MW plant, which would be the largest facility of its kind in China.

Masdar City to use 50:50 thin-film and c-Si modules .

News

Product Briefings

Kipp & Zonen

Kipp & Zonen pyranometers offer accurate irradiance measurement

Product Briefing Outline: Kipp & Zonen offers a range of instruments to measure the total irradiance on a plane surface. Combining the irradiance with the outcome of a PV system gives an insight to the efficiency and helps evaluate optimal location for arrays and solar farms. Kipp & Zonen's 'CMP' series of pyranometers can be used in a wide range of applications within the PV industry.

Problem: The high costs of solar cells, panels and arrays keep the research into new materials and improvement of efficiency ongoing. Monitoring the solar radiation plays an important role in analyzing both the efficiency of the cells and evaluating optimal locations for 'solar farms.' PV panels are specified under Standard Test Conditions (STC). These conditions are 1000W/m² of solar radiation, 25ºC, air mass 1.5 and no wind. Because these conditions are far from those experienced in the real world, additional measurements are required to show the PV panels' typical performance.

Solution: Pyranometers are also used for checking PV panels and cells under laboratory conditions. Because CMP pyranometers are specified up to 80ºC (or 150ºC for the CM 4) they can monitor the output of the high energy lamps used in solar simulators. However, for applications such as monitoring the efficiency of a PV installation, it is sufficient to use a single pyranometer measuring the total solar energy available. This could be permanently installed (horizontally or at the same angle as the PV panels) or used with a hand-held display for field checks.

Applications: Wide range of PV cell and module irradiance monitoring.

Platform: To achieve the required spectral and directional characteristics, CMP Series pyranometers use thermopile detectors and glass or quartz domes. All models have built-in bubble levels and adjustable levelling feet. The waterproof connectors have gold-plated contacts and are fitted with 10m of high-quality signal cable as standard. The instruments do not require power and are supplied with comprehensive calibration certificates.

Availability: Currently available.

Act Solar, Inc.

Act Solar's Powerstring power management system boosts PV system yield

Product Briefing Outline: Act Solar, Inc., a power management optimization company, has launched 'PowerString', a patent-pending system that complements central inverters by dynamically re-circulating small amounts of electricity, as needed. The company claims that field testing, yield improvements of 6-11% were achieved and are projected to cumulatively deliver 40-80% more total power over 25-40 years of system operation.

Problem: Generally, monolithic systems have minimal instrumentation beyond the AC output as measured at a utility metre and the summary DC input reported by the inverter. If the system's output is diminished it might be noticed at the AC metre, but there is no practical way of identifying the cause. This is a result of primary losses in a few excessively worn components combined with the fact that accumulated variations across all of the system components has a magnified penalty on system output due to secondary losses at the string level and tertiary losses at the array level. Not only is power lost from worn or broken components, but substantial power is lost from the remainder of a PV system's components since many can no longer achieve maximum power.

Solution: PowerString breaks a single large monolithic array into multiple independent strings. Each string can have different electrical characteristics, conditions, solar angles and can even use different panel technologies. This adds flexibility to system design, independently optimizes the power of each string and localizes any degradation to the directly-impacted panel, preventing a fault from impairing power output from the rest of the system.

Applications: All types of medium- to large-scale PV systems.

Platform: The PowerString Active Power Management system gathers and analyzes real-time data from millions of components including panels, strings, trackers, inverters and weather instruments.

Availability: Currently available.

Advanced Energy Industries

Advanced Energy introduces utility-scale 500kW solar inverter

Product Briefing Outline: Advanced Energy Industries has introduced its newest Solaron branded transformerless inverter with a 500kW capability, specifically designed for utility-scale, grid-tied photovoltaic applications. Extending the Solaron portfolio beyond inverters for commercial and small-scale utility installations, the 500kW inverter achieves similar efficiencies of 97.5%, pending a CEC-weighted (California Energy Commission) efficiency rating.

Problem: In addition to delivering more power per inverter for utility-scale installations, the newest Solaron model delivers previously unachievable return on investment (ROI) – from installation through decades of energy harvests. Specifically, before installation is complete, integrators can save tens of thousands of dollars per panel section because multiple Solaron inverters can be routed into a single medium-voltage station.

Solution: Designed for utility-scale installations, the Solaron 500kW inverter features a durable, transformerless, grid-tie design, converting raw DC power from solar-cell arrays to high-quality AC-grid electricity. With its robust controls and patented, soft-switching technology, the Solaron inverter achieves 97.5% CEC efficiency (pending). A wide MPP (maximum power point) tracking window is designed for maximum, day-long power processing. Both local and remote communications and control are available via AE's Solaron IDS integrated data system.

Applications: Utility-scale and grid-tide PV systems.

Platform: Features such as AE's 'Integrated Data System' (IDS) with instant access to Solaron data and AE's SafeGuard wholly-customizable service program are part of the Solaron optimized balance-of-system (BoS) architecture.

Availability: Currently available.

Photovoltaic converters: challenges for the next decade

Prof. Johan Driesen, K.U. Leuven, Heverlee, Belgium

ABSTRACT

Power generation is a rapidly changing process. Owing to evolutions in power electronics, sustainable electricity generation and consumption came to the fore and now it is nearly impossible for photovoltaics to operate without this technology. This holds true for efficient consumption such as plug-in electric and hybrid vehicles or compact efficient lighting. Power electronics need to be taken into account in relation to grids, for example in novel voltage-source HVDC connections. Photovoltaic energy conversion requires power electronics in order to adapt the floating DC-output to a fixed DC-level and typically further to a grid-compatible AC electricity. These converter (mainly inverter) technologies have evolved considerably over the past few years, in much the same way as has PV cell technology, but in a much less apparent fashion. It is, however, expected and required that the technologies will evolve even further to meet the demands of the future market and the electricity grid to which they will be connected. This article intends to give an overview of the challenges ahead for power electronics in photovoltaic energy conversion.

Technological challenges

Novel components and higher switching frequencies

The vast majority of power electronic circuits in use today convert electrical power from one form to another through modulation involving switching. Such circuits also contain a considerable amount of passive components such as inductors, capacitors, performing filtering, galvanic separation or energy buffering functions, as well as interconnectors. Additionally, (digital) electronics provide control at different levels ranging from switching timing to high-level energy flow management and active protection.

Switches in use today are Si-based components such as power-MosFets of IGBTs. Novel switching components are under development; however it seems that it will be some time before they will become suitable for mass production. These switches will be based on wide band-gap semiconductors such as SiC or GaN. SiC-based diodes are readily available, having been experimented with for quite a few years, but they still prove difficult to produce. GaN should be easier to process, but is still evolving towards relatively low switching frequencies from its original application domain of high-frequency telecommunications.

The advantages of these new components are that they are more efficient (lower losses in switching as well as conduction losses); they sustain elevated

Figure 1. Inverters installed in the shadow of a PV array.

Courtesy: Prof. Johan Driesen.

Figure 2. Artist's impression of the future Smart electricity Grid.

Source: European Technology Platform Smart Grids [1].

temperatures and are able to switch at considerably higher frequencies; and they are more abundant in different ranges up kHz to the MHz range, compared to the currently common lower kHz range. Nevertheless, this increased switching frequency (and its harmonics) can be regarded as a disadvantage as well, since electromagnetic compatibility problems will increase. Design of the inverter circuits will have to account for the radiative effects causing disturbances and additional losses. Whereas power electronic circuit design has been using analogue circuit techniques, high frequency or even microwave design knowledge will now have to be applied.

The impetus to aim for still-higher frequencies is that any volume and weight reduction linked to the reduction of the characteristic values of the required inductors and capacitors would mean an easier life for many people. Imagine thin, lightweight inverters softly buzzing in cabinets hanging somewhere on the wall, instead of the current heavy, bulky and cumbersome inverters. An illustration of this effect is the size difference between a 50Hz system and a high-frequency galvanic separation transformer. High-frequency inductors are built around core materials such as ferrites, which will need further development when the move to the MHz range takes place. Classical conductors can no longer be used due to troublesome skin effects.

The temperature and reliability challenge

Current power electronics technology and PV inverters in particular can be developed further still, even with Si-based components and kHz-range switching frequencies. In green power conversion, the overall system efficiency of the panels and associated control algorithms including maximum power point tracking (MPPT) are paramount. The role of the inverter is often underestimated in this sense, as traditionally this circuit is optimised alone and rated on performance, rather than for the entire conversion chain with realistic influx. Experience from other application domains (mainly electric drives) has shown that there is still a quite a bit of room for improvement, for instance at partial load performance. Rated performances were typically not mentioned and weighted efficiencies composed of measured values at different conversion levels rarely used.

Nevertheless, in grid-connected systems, the changing grid conditions have an effect on voltage levels, which can vary between ±10%, and can lead to voltage harmonics and imbalances and neutral conductor leakage for three-phase systems. It has been observed that these power quality issues can affect the inverter's internal losses and decrease the efficiency by several percent. Additional functionalities such as reactive current injection also come at a price, and can lead to a need for enhanced efficiency validation techniques.

In an attempt to decrease losses, enhanced switching techniques and low-loss passives are being researched. Techniques to optimize the operational losses of the system can be further implemented. It is important to note that lower losses can help control the internal temperature and hence simplify cooling, yielding an indirect volume and weight reduction, as well as cooling fins and fans shrink.

The evolution towards wide-band gap components is important as these components can sustain higher operating temperatures, possibly up to 200-300°C, it is said. In applications such as hybrid cars where elevated temperatures occur, this is a clear advantage. But is this feature necessarily an advantage for inverters in PV applications? Classical PV inverters can have a higher internal temperature level within the switching components. With an unchanged outside temperature, higher temperature gradients exist, yielding smaller heat exchangers to evacuate the losses. This reduced volume advantage has a downside, however, as internal PV-inverter components should eventually work at a considerably elevated temperature. Currently available passive components and circuit assembly techniques are not yet suited for these conditions. In fact, the characteristic values of the inductors and capacitors can heavily detune when exposed to a large temperature range, causing a totally different system performance and efficiency, making it even more difficult to keep up correct functioning. Obviously, in special PV applications such as CPV, the higher temperature conditions will be welcomed.

Keeping temperatures under control is not only an efficiency-related issue, but could more importantly be considered an inverter longevity issue. As today's PV modules can easily last a 20-year lifetime of operation, it makes sense to be able to expect the same lifespan from inverters. In practice, however, some installations require additional insurance to cover the cost of replacing the power electronics after a couple of years. Thanks to technology evolution, the new state-of-the-art inverter will typically be a better performing one and hence energy-wise it will be an improvement. From a customer's perspective, though, this is not an ideal situation as not everybody performs regular checks on the system's state of operation.

Inverters, though statically mounted, operate in permanently changing external conditions invoked by the day-night and seasonal cycles. This reliability challenge occurs elsewhere in many different power electronics applications, and is certainly within the focus of research. However, there

Courtesy: Prof. Johan Driesen – EU-FP6-VSYNC project, [2].

Figure 3. Internal view of a power electronic system coupling a distributed energy resource and storage units to the grid.

are not many small-scale implementations of switching power electronics – especially not on the electricity consumption side – that are foreseen to be in quasi-continuous operation for several decades as is the case in renewable electricity generation.

When these technological evolutions are all brought together, perhaps a bright future for efficient 'hot' panel integrated modular inverters will come about. Obviously, the PV-module technology will evolve as well, imposing new challenges upon the power electronic inverter. CPV brings in power at a different scale, while multi-layer cells working in different conditions perhaps require a more enhanced MPPT. The characteristics of organic cells can be completely different from semiconductor cells, so why should the inverter be the same?

Changing role in the Smart Grid

Additional functionalities for the PV inverter

After discussing the 'internal' evolution of the PV inverter, one would almost forget that next to the PV-modules, the output side of the inverter is also changing spectacularly. Several trends force the electricity grid to rethink itself. In the frame of this article, one is inclined to think that only the move towards a more decentralised sustainable electricity production is driving this, but one should not underestimate the impact of the implementation of liberalised energy markets that demand more flexibility of the system. The consumption of electricity will increase in the coming time, despite the ever-more efficient power consumption. One of the drivers of this growth is the move towards cleaner energy forms, examples of which include electrothermal processes instead of gas combustion, or new loads such as heat pumps, charging electric vehicles, etc.

In future, the electricity system will see co-existence of large plants of a new generation, such as clean coal units, with decentralized generators and next-generation loads, probably augmented with energy storage systems. This sketch of the future poses many different technical and operational challenges to the electricity system, which will be built around an intelligently operating "Smart Grid" [1]. Making all of this work together at an affordable price is perhaps the biggest challenge of all.

For grid-coupled photovoltaic inverter systems, this synergy will have important consequences. In the past, when the penetration of such systems on the grid was low, they did not have much of an effect on the overall workability as they silently injected power without a care for voltage stability and the related reactive power exchange. The extent of the required conservative safety principles consisted of a "shut down and back off in case of an incident" philosophy. The evolution of wind power and its impact on the transmission grid in many European countries has shown that the ever-increasing share of decentralised generation systems, mostly with power electronic interfaces, should obey a more limiting grid code as soon as a critical level is reached. They are also asked to provide grid support by delivering so-called "ancillary services", such as stabilizing the voltage by injecting reactive power, ride-through incidents, etc. Unfortunately, determining that critical level proves to be an extremely difficult exercise.

PV systems are often more dispersed and connected to the distribution system, which is totally different in nature from the meshed, high-voltage transmission grid. Since the distribution feeders are radial and mainly made of cables, keeping the voltage profile under control is a more complicated challenge. This necessary form of grid support can only be successful when additional functionalities are added to the PV inverters. Ride-through of transients such as voltage dips is a minimum requirement; contribution to voltage profile stabilisation is due to follow soon.

To implement this, the converter technology will have to be adapted up to a certain point. The changes to be applied are not dramatic: firstly, the power (current) rating of the grid-connected front-end will have to be increased to allow for the additional reactive currents and short-term enlarged injections. The power required to do this will have to come from internal energy storage, mainly implemented with supercapacitors and possibly batteries such as Li-types or hybrid storages. Using the latter has additional benefits in terms of power smoothing, for example. However, it should be noted that storage integration is still a technical challenge and a control challenge in delivering balance (long-term) and stability by creating "virtual inertia" (short-term) [2].

Towards aggregation of systems

Finally, a higher level of control will have to be added on top of all these changes inside individual converters. The current PV converters are in general undispatched, meaning there is no supervisory adjustment to the operation from a control centre; hence they inject power when there is solar input. Since the level of sunshine is geographically dependent in an area the size of a typical distribution grid section, the injection can be massive with destabilizing consequences when the local loads do not pick this up and the power cannot be exported to the rest of the grid. As such, a partial curtailment of solar electricity production will sometimes be unavoidable. Obviously this should stay compatible with the liberalized market and be an exception to the rule to as great an extent as possible, but these actions can be beneficial as it is a remunerable grid support service.

The coordination of solar power injection should not stay limited to emergency measures. In general, it is a good idea to aggregate distributed energy resources, including active loads such as remotely adjustable heat pumps or charging electric vehicles. When a good portfolio is gathered, the aggregated energy balance is smoothed, becomes more predictable and may even be adjustable. Such a joint configuration can be considered a 'Virtual Power Plant' (VPP). With such a tool in hand, true market participation will become a reality. To make this possible, the smart grid will need dependable intelligence and communication. Within this setting, the aforementioned storage may also play a role in making the power injections controllable and time shiftable.

Conclusion

Power electronics as implemented in photovoltaics will evolve significantly over the coming years. On the one hand, novel components force a rethink of the entire circuit and its components. Classical systems need to enhance their reliability. On the other hand, additional control features have to be implemented in order to stay grid-compatible (and market-compatible). But perhaps the most important challenge has not yet been mentioned – the challenge of keeping this evolution affordable. The massive deployment of the technology scale-advantages will probably keep the price low, but is there actually an alternative?

References

[1] European Technology Platform's *Smart Grids* [available online at http://www.smartgrids.eu].

[2] "Virtual Inertia" research project [available online at http://www.vsync.eu].

About the Author

Johan Driesen received his M.S. degree in electrotechnical engineering from the K.U. Leuven, Belgium in 1996. His Ph.D. degree, also from the K.U. Leuven, focussed on the finite element solution of coupled thermal-electromagnetic problems and related applications in electrical machines and drives, microsystems and power quality issues. Currently, he works as an associate professor and teaches power electronics and drives at the K.U. Leuven. From 2000-2001 he was a visiting researcher in the Imperial College of Science, Technology and Medicine, London, after which he worked at the University of California, Berkeley, USA. His current area of research is in distributed energy resources, including renewable energy systems, power electronics and its applications in drives, electrical transportation and power quality.

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Installations of PV power plants in 2008

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ABSTRACT

The past year was characterised by the realisation of many MW-range solar power plants as well as the highest ever market growth related to large-scale photovoltaic systems. These systems were constructed in several regions, some of which saw significant increases in cumulative installed power. In the European Union, progress was observed among countries such as Italy, Czech Republic and France; the German market, however, decreased slightly. In terms of capacity of installed power output, Germany's figures were almost unchanged from 2007's figures, despite the market explosion in Spain. This paper provides a round-up of the major PV installations of 2008.

Introduction

Very few scientific studies or reliable journalistic research articles related to large-scale photovoltaic plants were published over the past few years. Four studies are worthy of mention, however: journalistic research studies published in *Photon* magazine in 2005 [1] and 2008 [2]; a study commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [3]; and a study performed by the Task 2 working group of the IEA-PVPS programme [4]. Unfortunately these reports cover only specific types of photovoltaic plants and/or a particular region, or the evaluated data covers only a relatively small number of PV power plants.

Data that represents the basis for this paper was collected during long-term research related to large-scale photovoltaic power plants, performed by the report's author. Note that only photovoltaic power plants producing more than 200kWp are considered herein. This report is based on detailed data of more than 1,700 large-scale PV plants with a cumulative peak power more than 3.3GWp that were put into service during the last 20 years. Due to the specific situation in the photovoltaic market – the number of large-scale photovoltaic plants is increasing very rapidly, such a fast-moving market makes it very difficult to maintain such a report and keep it totally up to date. In this paper the majority of photovoltaic power plants that were completed by December 31st 2008 are considered; provided press releases or other official statements were made prior to the date of publishing. Because there are no reliable databases, or other national or international sources of information concerning large-scale photovoltaic power plants available, statistical data presented here should be considered as 'conservative'. (As of January 1st 2009, new photovoltaic power plants in Germany must be announced to Federal Network Agency/Bundesnetzagentur.) Based on experience from past years and on comparison with the aforementioned reports, reliability of data presented in this report is estimated to be in the worst case in the range from -10% to -15% for regions with highest market growth and -10% or better for other regions. Uncertainty is factor among all of the absolute data presented in this report.

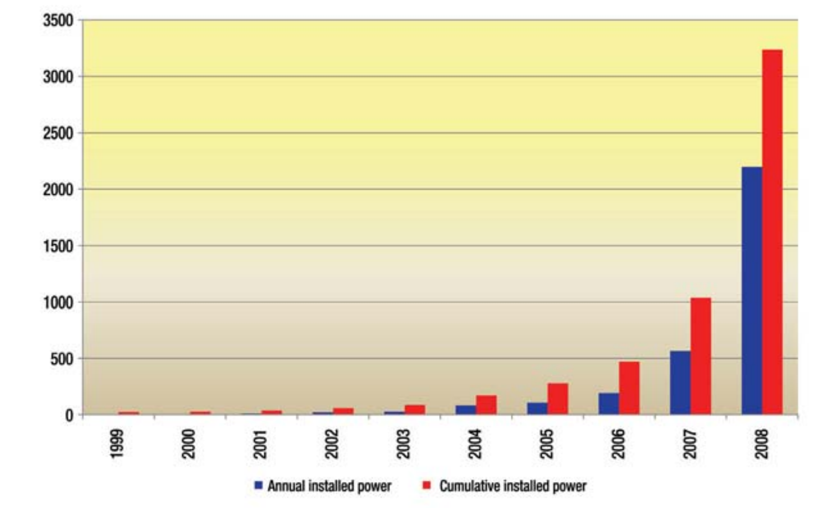

Figure 1. Large-scale photovoltaic power plants: estimated annual and cumulative installed power output capacity in MWp worldwide in the last 10 years.

Annual and cumulative installed power output capacity

2008 showed the largest market growth in large-scale photovoltaic power plants, with more than 2GWp of new power plants constructed and put into service (see Figure 1). Spain was the market leader with more than 1.8GWp installed in the last 12 months. More than 500 large-scale photovoltaic plants are located in Germany, 360 in USA and more than 630 in Spain, clocking an average plant power output capacity (plants > 200kWp) of about 1.9MWp. These countries also represent the most important markets worldwide.

The market share of large-scale grid-connected PV power plants as a proportion of cumulative installed PV

Annual installed power output capacity (MWp) 1996 – 2008												
1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
2.03	2.2	1.9	2.5	4.9	9.7	20.6	29.1	82.2	109	193	567	2200
17.3	19.5	21.4	23.9	28.8	38.5	59.1	88.2	170.4	280	473	1040	3240
Cumulative installed power output capacity (MWp) 1996 – 2008												

Table 1. Large-scale photovoltaic power plants (>200kWp): estimated annual and cumulative installed power output capacity worldwide from 1996 – 2008.

power has been increasing continuously over recent years. In 2005, for example, market share stood at less than 10% of the annual installed PV power capacity, and by 2007 market share of large-scale PV power plants had risen to almost 25% of the annual installed power [5,6], and it seems that in 2008 market share is even larger. More precise estimations for the past year will be possible over the coming months when reliable data about the annual installed power in 2008 will be more readily available.

Large-scale photovoltaic power plants installed by region

More than 85% of all large-scale photovoltaic plants (power-related) are installed in Europe (2870MWp). The USA has about 7% (245MWp) while Asia accounts for a little less than 4% (130MWp). The most dynamic market performance for the past year was that of Spain. Fast growth in the country has taken place over the last three years with extreme growth in the past year, where in the third and fourth quarters alone about 1GWp of new PV power plants were put in service. In summer 2008, Spain's installed power capacity was estimated at 600MWp [7]. Further progress in Europe (Italy, Czech Republic and France, and Greece as a market with future promise) and in Korea was also observed. Italy hosts more than 60MWp of large-scale PV power plants; however, the future of subsidies in Italy is not yet clear. In Czech Republic and in France, another promising market for 2009, several MW-range PV power plants were put into service. The rest of the world (Africa, South America, Australia...) represents less than 1% of total capacity worldwide; these regions show significant potential for solar energy use in future.

At the end of 2008, more than 85% of all large-scale photovoltaic power plants (power-related) were ground-mounted. Whilst about 23% of all power plants (power-related) have tracking systems (single- or double-axis tracking), 70% have fixed arrays.

MWp	Country	City	Region/province
60	Spain	Olmedilla de Alarcon	Castilla-La Mancha
50	Spain	Puertollano	Castilla-La Mancha
46	Portugal	Moura	Alentejo
40	Germany	Brandis	Saxony
34.2	Spain	Arnedo	La Rioja
30	Spain	Trujilo	Extremadura
30	Spain	Merida	Extremadura
26	Spain	Fuente Álamo	Murcia
24	Korea	SinAn	Southern Jeolla
23.2	Spain	Lucainena de las Torres	Andalusia
23.1	Spain	Abertura	Extremadura
23	Spain	Jumilla	Murcia
22.1	Spain	Almaraz	Extremadura
21.2	Spain	Villarrobledo	Castilla-La Mancha
20.2	Spain	El Coronil	Andalusia

Table 2. Largest photovoltaic power plants (data correct up to December 2008).

Market share

Countries with total power output capacity of more than 10MWp from large-scale photovoltaic power plants (only photovoltaic power plants >200kWp considered here) are listed in Table 3.

In France and Czech Republic, more than 10MWp cumulative power output capacity was installed in 2008. Among Asian countries it is worth mentioning Korea, which has almost 100MWp power capacity installed, most of which were put into service in 2008. Moderate growth was observed also in California, the state with most PV power capacity installed in the USA.

Economic indicators

With a significant increase in power capacity installed, it makes sense to analyse some economic parameters such as power output capacity per capita installed. In regions with the highest power capacity per capita installed, this value ranges from 0.02kWp to 0.35kWp per capita. The most power capacity per capita is installed in the autonomous Spanish regions of Extremadura, Castilla-La-Mancha and Andalusia. Bavaria takes first place in Germany as does Southern Jeolla province in Korea. California has similar levels of power capacity installed as some Spanish regions, but due to high population density the power capacity per capita is still much lower than values in attributed to Spain or Germany. Table 6 shows a breakdown of rough estimated values of installed power capacity per capita in these regions. Please also note that these per capita figures are only valid for large-scale PV power plants >200kWp; total PV power capacity installed per capita in some regions may be much higher than values presented in this paper.

Most important markets

The most important world market in 2008 was Spain. In the EU, despite the relative decrease in market share, Germany is worth mentioning. Korea was an important Asian market in 2008, displaying a significant increase in market share in the past year. Korea is also the only non-European country with three PV power plants among the world's 50 largest PV installations. Among Asian countries, Korea is the only

Country	Power output capacity (MWp)	Market share (%)
Spain	>2020	63
Germany	>650	20
USA	245	7
Korea	100	3
Italy	60	2
Japan	21	<1
Czech Republic	15	<1
Belgium	12	<1
France*	11	<1

Table 3. Large-scale photovoltaic power plants of countries with more than 10MWp power output capacity installed. (*Not inclusive of overseas territories.)

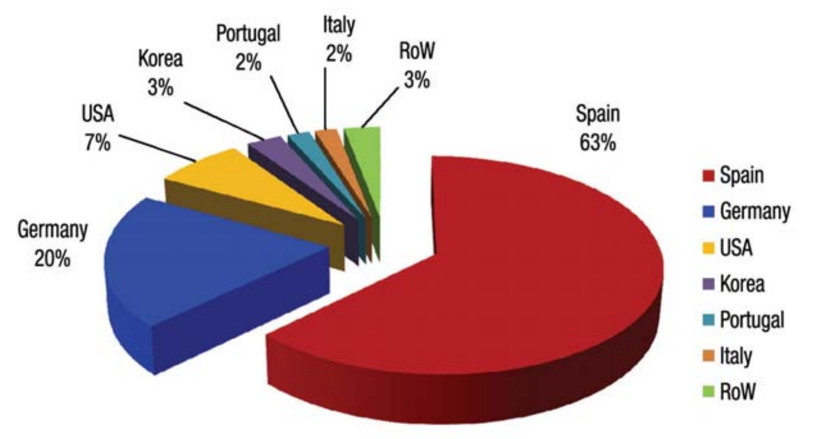

Figure 2. Large-scale photovoltaic power plants – market share by country up to December 2008.

Courtesy: Suravia, S.A.

Figure 3. Olmedilla de Alarcon, Cuenca, Spain, a 60MWp installation, was the largest PV power plant constructed in 2008.

Power Generation

one that boasts well-defined feed-in tariffs, so even further progress of the Korean market might be expected [9]. In the USA, growth had been moderate yet constant in the last few years; however, the majority of the country's PV installations are concentrated in relatively few federal states, a point that is illustrated clearly by the fact that California has been the country's PV market leader for more than a decade. From a long-term point of view, India looks to be becoming a promising market for Asia. Due to actual feed-in tariffs in Germany and Spain, large-scale roof-mounted PV plants will tend to dominate the EU's output this year and beyond. Similar regulations also exist in France, where the first large-scale MW-range PV roof-mounted plants were put into service in the last year. Further plans for large numbers of MW projects are already being planned.

Conclusion

In the period from 2005 to 2007, annual growth in large-scale photovoltaic plants was on average 100% annually. In 2008, market growth related to large-scale PV power plants was almost 400%. Average installed plant power has increased from 400kW in 1997 to 1.9MWp in 2008. Expectations for 2009 include a general market decrease, but in particular regions market growth can be expected, even taking the current economic climate into account. Promising markets within the EU in 2009 include France, Greece and Czech Republic, while for some other countries it is also believed that strong market growth will continue, although in most cases the outlook is

Country	Power output capacity 2007 (MWp)	Power output capacity 2008 (MWp)
Spain	270	>2020
Germany	452	>650
Italy	18	60
Portugal	12	60
Czech Republic	2.1	15
France*	<2	13
Belgium	3.3	12

Table 4. Large-scale photovoltaic power plants: comparison of estimated installed power capacity for some EU countries in 2007 and 2008 [8]. (*Including overseas territories.)

Country	Power output capacity 2008 (MWp)	EU market share (%)
Spain	>2020	71.5%
Germany	>650	22.5%
Italy	60	2%
Portugal	60	2%
Czech Republic	15	0.5%
Belgium	12	<0.5%
France*	11	<0.5%
Netherlands	11	<0.5%

Table 5. Large-scale photovoltaic power plants – estimated EU market share. (*Not inclusive of overseas territories.)

Region	Country	Power (kWp) per capita
Extremadura	Spain	>0.3
Castilla-La-Mancha	Spain	0.29
Andalusia	Spain	0.054
Bavaria	Germany	0.024
Southern Jeolla province	Korea	0.023

Table 6. Large-scale photovoltaic power plants: power capacity installed per capita (kWp) (estimated).

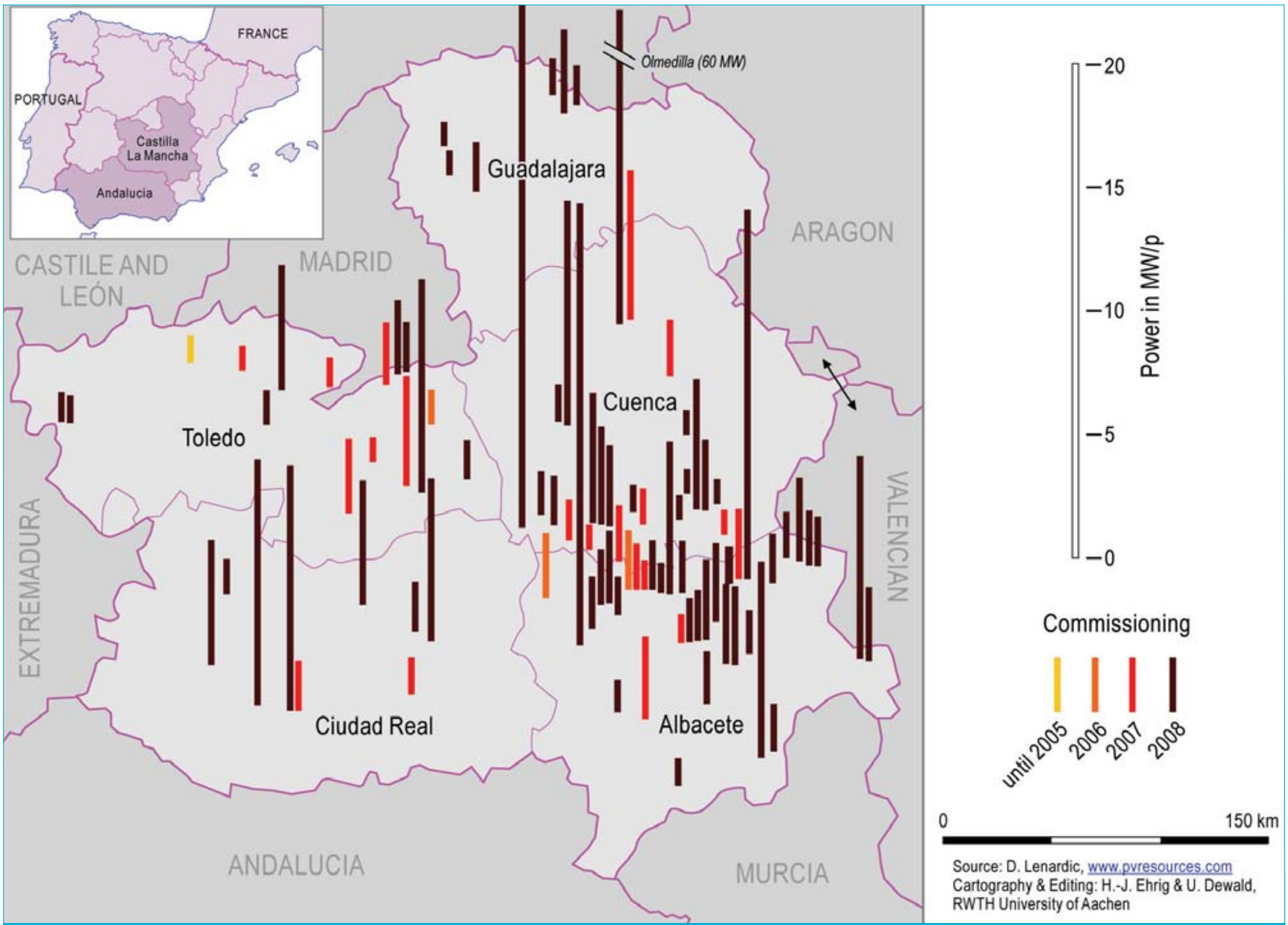

Figure 4. Locations of MW-range power plants in the Spanish region of Castilla-La-Mancha as at December 2008.

Map courtesy: Ulrich Dewald, Hans-Joachim Ehrig, RWTH University of Aachen.

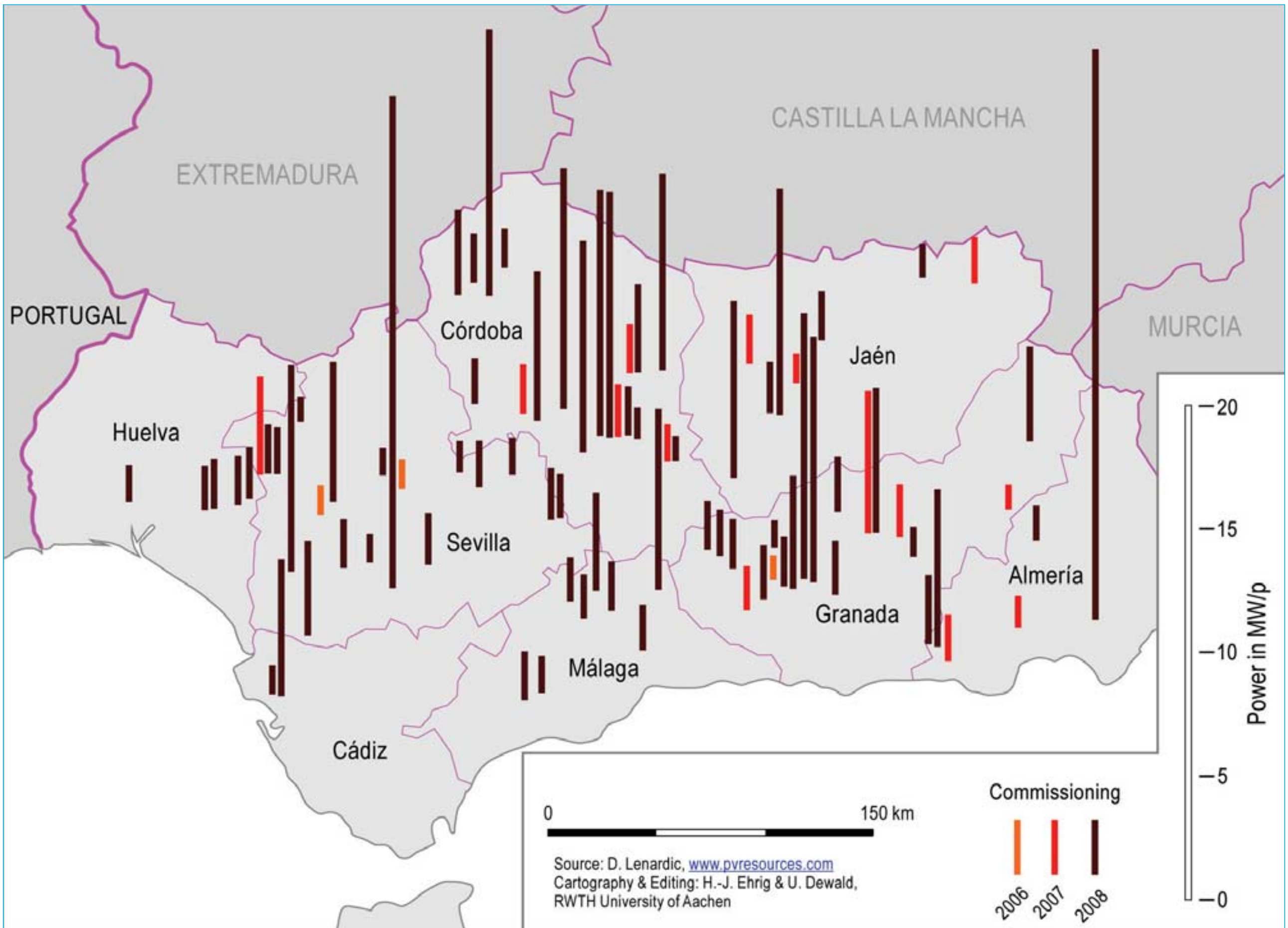

Figure 5. Locations of MW-range power plants in the Spanish region of Andalusia as at December 2008.

Map courtesy: Ulrich Dewald, Hans-Joachim Ehrig, RWTH University of Aachen.

not clear (Italy, for example) and therefore unpredictable, due to bureaucratic obstacles. All data presented in this report are calculated on data as available in December 2008, so slight changes of all presented data and statistical values in the forthcoming months cannot be excluded. Analysis of additional economic indicators related to large-scale PV plants, such as investment, CO_2 emission reduction and electricity prices will be published in a report to be made available in the forthcoming months.

Acknowledgements

The author would like to express his very special thanks to **Ulrich Dewald** and **Hans-Joachim Ehrig** from RWTH University of Aachen for preparing the charts and to Spanish company **Suravia S.A.**, Madrid, for their kind permission to use the photo of the Olmedilla de Alarcon PV plant published in this report. The data collection that represents the basis of this report is published at http://www.pvresources.com/en/top50pv.php and is available to the public free of charge.

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Solar employee purchase programs: generating volume sales and improving operating efficiency

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ABSTRACT

The U.S. residential solar market is poised for growth. For solar companies seeking to capitalize on the growth potential of this market, the keys to success will be sales volume and operating efficiency. Solar employee purchase programs (solar EPPs), which have been initiated by companies as diverse as SunPower, REC Solar, and SolarCity, represent a new and potentially important channel for increasing sales and improving sales efficiency. Driving these programs are increasing corporate sustainability initiatives and growth in voluntary employee benefit offerings, especially employee purchase programs and green benefits. This article provides an introduction to solar employee purchase programs, analysis of the business ecosystem, and discussion of an example program. It is based on the industry's first report to identify and analyse this emerging trend, which was published by AltaTerra Research in November 2008 [1].

Value chain efficiency in the residential solar market

In the United States, residential solar is growing more economically attractive, especially in states with solar incentives, high electricity rates, and favourable regulations. In addition to these external conditions, the solar industry itself is developing a number of service delivery innovations to improve operational efficiency, lower the cost of sales, and spur higher rates of adoption. These include new financing mechanisms (such as municipal loans, power purchase agreements, and leasing) and new product and installation concepts (such as installation in new housing developments and building-integrated photovoltaics). There are also sales and marketing innovations such as aggregated volume discounts for existing homes (retrofits) by geographic area, new housing development construction installation, and system sales through large retailers, such as Home Depot and Costco.

Solar EPPs represent a new method of solar sales and marketing for the retrofit market that approaches the employees of a business as a pool of potential residential solar buyers, much like a neighbourhood or other community. Bringing ideas from neighbourhood aggregation programs together with the established concept of employee purchase programs, solar EPPs offer a way to inexpensively increase awareness by leveraging corporate education efforts and boost affordability by means of manufacturer, installer, and/or employer discounts. They can also be combined with consumer financing arrangements, including power purchase agreements and leasing.

Corporate sustainability initiatives

Around the world, organisations are demonstrating their commitment to sustainability with a growing range of environmental initiatives, many of which are focused on saving energy and reducing carbon emissions. Investment programs are typically focused on internal company facilities and operations. Addressing and reducing the personal carbon footprints of employees are efforts that have been mostly viewed as 'out of scope,' except for general concerns regarding employee business travel and the commute to the workplace.

"Among human resources executives, there is a growing consensus that corporate concern for environmental sustainability is necessary to attract and retain high-value workers."

Yet employee priorities and values are changing. Numerous volunteer green teams have sprung up in many corporations, working to reduce environmental impacts through changes to company infrastructure and policy and by influencing personal choices. As noted in a June 2008 AltaTerra report: "Green teams are a natural fit with this need, offering a personally meaningful way for employees to simultaneously contribute to their company, and to the broader community in which they live – and in the process, reinforcing the employee/company relationship" [2].

Among human resources executives, there is a growing consensus that corporate concern for environmental sustainability is necessary to attract and retain high-value workers. A survey conducted by faculty members at Stanford University and the University of California at Santa Barbara found that 97% of graduates from 11 top U.S. business schools would give up nearly 15% of their anticipated first-year salaries to work for a company that demonstrates "exemplary environmental performance, ethical business conduct, and good employee and stakeholder relations" [3].

Solar employee purchase programs

To date, there is no industry-standard term for solar EPPs. We use the phrase solar employee purchase program because the 'employee purchase program' phrase and concept are now established in the corporate marketplace.

A solar employee purchase program is a voluntary employee benefit organized by solar power companies to enable eligible employees of participating employers to purchase residential solar products and services at a reduced cost.

Through a solar EPP, a participating employer can reinforce its commitment to environmental sustainability and even gain increased employee loyalty, improved corporate image, and, ultimately, higher productivity. The value proposition for employees is similar to the value proposition for anyone installing residential solar: they can gain greater energy independence, feel good about doing their part to fight global warming, reduce their monthly electric bills, protect themselves from escalating

Company Name	Company Business	Employer Partners	Example Deal Structure	Results
SunPower	Manufacturing	~15 (e.g., HP)	Post-installation rebate; tiered (based on employer matching); volume-based performance bonuses	HP – one of most successful programs – over 200kW installed

Table 1. Summary of SunPower's solar employee purchase program.

electricity rates, increase the value of their homes, and take advantage of federal and state incentives. However, solar EPPs add value, with employees benefiting financially to varying degrees, depending on the incentives offered by the employer and the solar company. Employees also benefit through the positivity gained from their employer's social and environmental responsibility and the perks it provides.

An employer may launch a solar EPP in a subsidized or unsubsidized form. Some employers provide a modest cash incentive to their employees who purchase solar. This incentive is additional to the discount from the solar company and tangibly underscores the employer's commitment to being a green company. Alternatively, the program can be launched with no employer cash incentive. Either way, it is expected that employers will facilitate employee communication and support marketing for the program. These are necessary elements of success. Furthermore, many solar EPP providers have agreed that solar EPPs are most effective when they are part of a larger solar deployment and green vision that provides education, generates enthusiasm, and drives activity. In addition to providing a discount, successful programs engage employees with information and education.

Solar EPP business ecosystem

There are three primary parties in any solar EPP:

- The solar power company that is providing the solar EPP – either a manufacturer (A) or an integrator/installer (B)
- The employer
- The employee beneficiary of the solar EPP.

Programs are being initiated by a few turnkey manufacturers (manufacturers/integrators), and by installers that may also be integrators.

> "An employer may launch a solar EPP in a subsidized or unsubsidized form. Some employers provide a modest cash incentive to their employees who purchase solar."

Participating employers are referred to as employer partners. This does not denote a legal partnership; rather it conveys the formation of an ongoing (multiple-transaction) arrangement between the solar company and employer in offering the program to the employer's employees. The term partner also reflects the ideal relationship, which involves a cooperative effort.

In implementing solar EPPs, manufacturers (A) arrange to have systems installed through their dealer network. Depending on a given manufacturer's business model, distribution network, and vertical integration, there may be more or fewer players involved, from dealers to distributors, integrators, designers and installers.

System installers (B), who may be integrators as well, also offer solar EPPs. When installers offer solar EPPs, they sign up employers to participate and install the systems themselves.

Often, the solar power company offers an employee purchase program to the employer in the context of a bigger commercial solar project. However, some solar companies are also offering solar EPPs to employers that are not commercial customers.

The employer either manages the solar EPP directly or contracts its supervision to a benefit management company. When program administration is outsourced, the employer will typically provide an internal point of contact for the solar provider, usually from the human resources, sustainability, or environmental health and safety function.

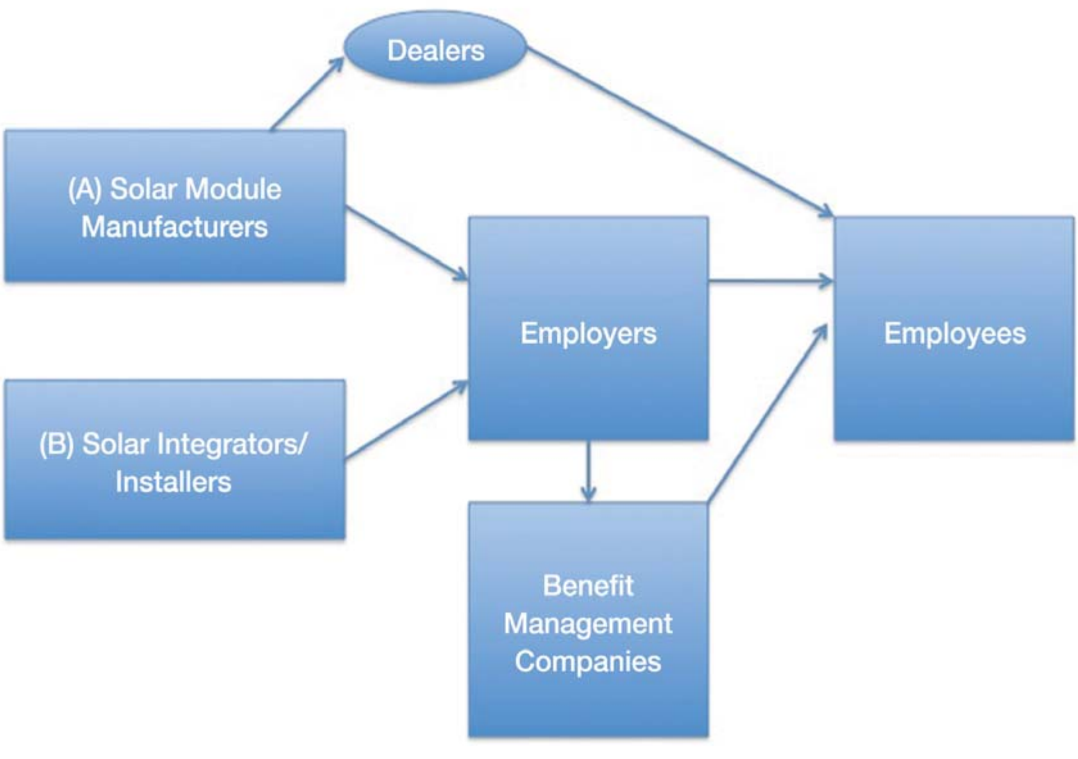

Figure 1. Solar employee purchase programs: business ecosystem (simplified).

Case study

For the purposes of this article, one solar EPP is discussed in depth, as an example of what can be expected in this space. In the full report, four additional companies are profiled, all of which are installers and each of which has experienced varying degrees of success.

SunPower Corporation

SunPower is a publicly owned company that designs, manufactures, and delivers solar electric technology for residential, commercial, and power plant applications. It is one of the most vertically integrated companies in the solar industry – from cell and module manufacturing to system design and integration. For residential installations, SunPower works with more than 400 dealers in the United States and Europe.

As of November 2008, SunPower had solar EPPs with 15 employers in the U.S. and was in talks with other prospective partners. Employer partners include Hewlett-Packard Company and other Fortune 500 companies, some of which were large-scale system customers, some of which were not.

Under SunPower's programs, an incentive, in the form of a post-installation rebate, is determined for each employer, using a standardized, tiered rebate matrix. During an initial promotional period, the amount of the rebate may be increased if a predetermined kilowatt volume threshold is met.

Programs can be run at no cost to the employer. However, SunPower encourages employer investment by offering dollar-for-dollar matching. It positions the program as a long-term benefit to its employer partners rather than as a limited-time offering.

From SunPower's perspective, its vertically integrated business structure and national dealer network position it to effectively administer solar EPPs for corporate partners.

With dealers in 29 states, SunPower is able to offer semi-national coverage in the United States and additional coverage in certain other countries. Moreover, SunPower handles all marketing, administration, and infrastructure needs for implementation of EPPs, allowing the dealers to focus on design, installation, and customer service.

Hewlett-Packard's solar EPP

Hewlett-Packard (HP) had not thought of offering a solar EPP when it began working with SunPower on a power purchase agreement for its 1.2MW commercial system in San Diego. However, when SunPower proposed an employee program, HP agreed that it would be beneficial. It was a natural extension of HP's sustainability network, which was already hosting meetings on residential solar, and Live Green, a formal employee engagement program for the environment, which has presented lectures from climate scientists, film reviews and discussions with producers, and Earth Day celebrations [4].

With no contribution from HP, SunPower was prepared to offer a rebate. With dollar-for-dollar matching, SunPower agreed to increase its rebate for a combined rebate of up to US$4,000 per employee until HP funds ran out. The program started in December 2007.

Employees reserved the money for their rebate from HP by submitting an application. They then had two weeks to enter into a contract with a SunPower dealer and would receive the rebate after the installation was complete. By April 2008, HP's matching funds had been depleted, but SunPower continues to provide a rebate.

HP outsourced administrative management of the program to the voluntary benefit management company, Beneplace. However, there is still an internal contact person at HP who receives monthly reports from SunPower and meets with one of its representatives every two weeks.

To market the program, SunPower had a booth at HP headquarters' Earth Day fair and participated in events at other locations. HP regularly distributed information through its intranet, and SunPower and HP co-hosted a series of virtual 'brown-bag' presentations.

HP has been one of SunPower's most successful solar EPPs, with enthusiastic employees providing positive feedback. High interest among employees was readily apparent to HP and SunPower when attendance at the first virtual brown-bag presentation far surpassed either company's expectations – more than 200 employees signed in to the online conference room. According to HP in September 2008, that initial interest has resulted in the installation of more than 200kW, with 54 employees and two retirees installing systems or currently under contract and 160 people engaging in the evaluation process.

Assessment and outlook

The solar EPP approach to sales and marketing in the U.S. residential market is being developed and evaluated by a small number of companies. While there is extensive EPP experience in other industries to draw on, this model has had limited experience in the solar industry.

For those solar companies that are public about their solar EPP efforts, assessments range from cautiously optimistic to highly enthusiastic. The consensus (not yet backed up with large, established programs and extensive quantitative data) is that for a small cost to the solar provider, solar EPPs provide significantly higher visibility and can generate sales volume driven by employer partners, which can reduce cost of sales and increase the rate of residential solar adoption.

It may be that solar EPPs are at their most powerful when they link residential and non-residential sales, each channel serving as a marketing communications conduit for the other. The question is: how much is that marketing communications connection worth? Or perhaps more importantly, what is the value of solar EPPs to sales and operations in particular?

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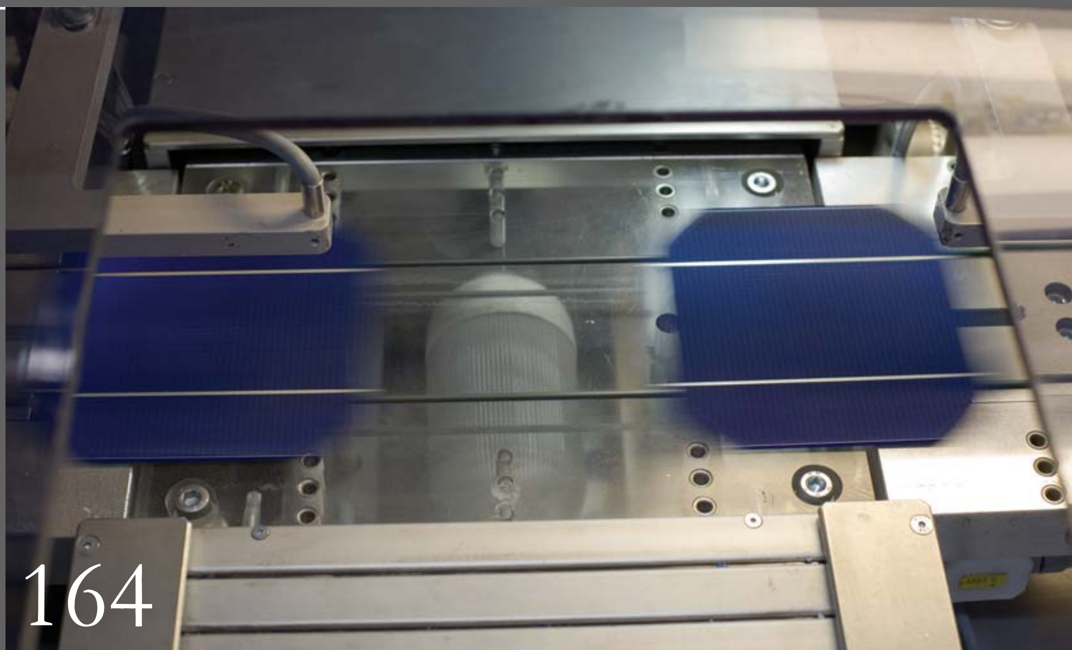
For further information on AltaTerra's Research Network of services and for answers to questions such as the following, please contact the company.

- What are the advantages and disadvantages of the solar EPP model?
- What type of company is in the best position to offer solar EPPs? What is/will be the role of benefit management companies?
- What types of employers, other than large corporations, might solar power providers target for solar EPPs?
- What makes a program successful?
- What are the steps to implementing and building out solar EPPs?

Market Watch



Report: Sizing the U.S. solar PV opportunity

By Vishal Shah, Barclays Capital Solar Energy

In our view, commercial solar projects can generate IRRs in excess of 10% (assuming refundable ITC, US$4/W system ASPs) in nine states in 2010 and IRRs between 5% and 10% in six additional states. In 2011, we expect commercial solar projects to generate competitive IRRs in five additional states (assuming US$3.50/W system ASPs). Assuming 0.5% solar energy penetration in these states, total incremental solar PV opportunity over the next three years could be as large as 4.4GW or 10x the size of current annual installations in the U.S and almost comparable to the size of the global solar market. Our analysis does not include potentially lower cost of capital resulting from the loan guarantee program. We believe the US$8 billion loan guarantee program proposed by the House has the potential to support nearly US$80 billion worth of projects and can facilitate low cost financing for the 4.4GW worth of commercial solar projects through 2011.

Utility Solar Opportunity: According to SEPA, approximately 1.5GW worth of solar PV projects were in various stages of contract cycle (announced contracts, RFPs, proposals) as of September 2008. Additionally, during the recent earnings call, SunPower management highlighted that their pipeline of opportunity in the US utility market is nearly 1GW. Assuming additional 1.5GW worth of utility contracts were being discussed in 2008 and not included by SEPA, we believe approximately 3GW of utility scale solar PV are likely in various stages of negotiation. We assume that roughly 40% of these projects are completed by 2011 timeframe resulting in incremental 1.1GW of demand.

Federal Solar Rooftop Program and Federal RPS – Potential Sources of Upside: President Obama has proposed a Federal RPS program mandating all states to generate up to 10% of electricity from renewables by 2012 and 25% by 2025. Assuming 500MW incremental demand from Federal RPS program and 1.5GW incremental demand from Federal rooftop program – we see up to 2GW of incremental upside over the next three years.

Cost to the taxpayer: We estimate the cost to the government in the 5.5GW to 7.5GW demand scenario to range between US$5 and US$7 billion (assuming 30% debt ratio in projects, loan guarantee program and 30% refundable ITC for 70% of the equity portion)

With respect to 2009 demand impact, taking SunPower's guidance (US$2B assuming financing improves, US$1.6B assuming financing does not improve) and assuming US$5/W system ASPs, we believe potential demand upside from refundable ITC could be nearly 85MW for SunPower, 80MW for First Solar and 100MW for other solar PV companies.

	Retail Sales (MWh)	MWh/MW	0.5% Solar Penetration MWh	0.5% Solar Penetration MW
2010: 10% IRR				
HI	10,731,520	1,692	53,658	32
TX	320,614,840	1,800	1,603,074	891
DC	11,414,847	1,595	57,074	36
NJ	77,593,167	1,576	387,966	246
NY	145,081,709	1,502	725,409	483
CA	252,764,015	1,889	1,263,820	669
CT	32,214,610	1,461	161,073	110
NV	31,312,306	2,032	156,562	77
RI	7,887,575	1,562	39,438	25
2010: 5%-10% IRR				
NH	10,973,309	1,559	54,867	35
DE	11,761,153	1,550	58,806	38
MA	56,142,019	1,454	280,710	193
ME	12,367,668	1,614	61,838	38
NM	19,845,735	2,117	99,229	47
NC	125,656,807	1,666	628,284	377
2011: 10% IRR				
CO	46,723,841	1,914	233,619	122
OR	45,636,448	1,726	228,182	132
AZ	66,933,251	2,074	334,666	161
2011: 5%-10% IRR				
VT	5,663,772	1,473	28,319	19
FL	218,584,494	1,705	1,092,922	641
				4,373

Source: Barclays Capital Research.

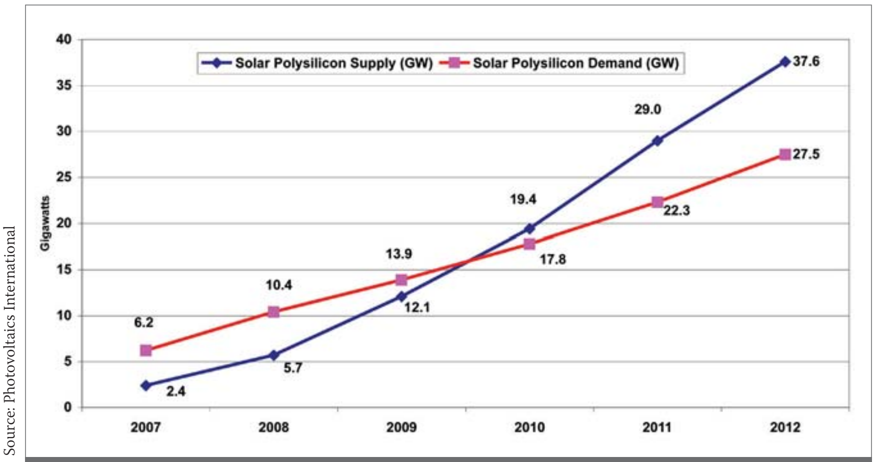
Incremental solar PV opportunity by 2011: 4.40W.

iSuppli reveals the winner and losers in the solar industry shakeout

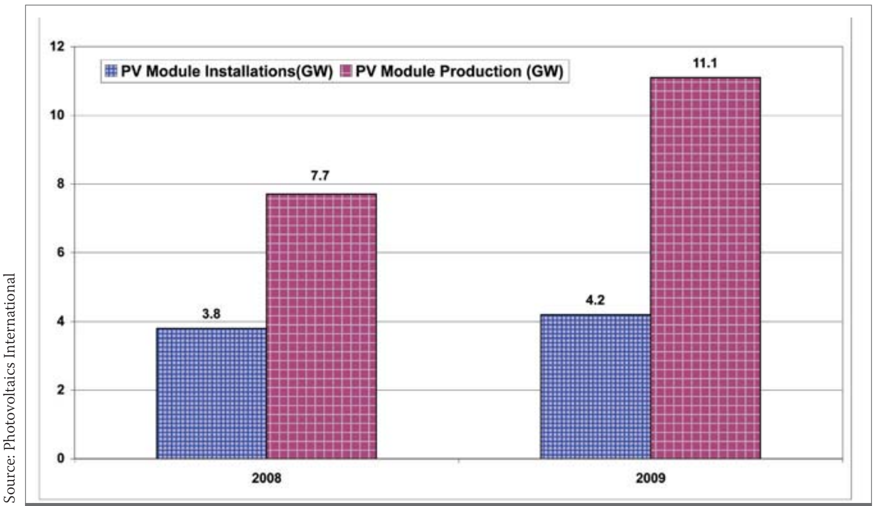
In a webinar hosted by Henning Wicht, Senior Director & Principal Analyst, Photovoltaics and MEMS Research at iSuppli Corp., it was noted that the massive increase in production of polysilicon, cells and modules will result in plunging prices across the supply chain. These price decreases will generate a divide between winners and losers in the photovoltaics industry, with those achieving a low cost-per-watt, such as First Solar, having the upper hand. The global economic downturn and restricted access to capital are projected to limit the growth in PV installations to 4.2GW in 2009, a Year-on-Year growth of only 10%. The corresponding figure for 2007 was 40%, while 2008 saw installation growth of 50%.

iSuppli is now forecasting a return in 2010 of the high growth rates that the industry has come to expect, boasting over 6GW of installed capacity and showing potential for 10GW in 2012. However, overcapacity is going to become a major problem for the industry. Polysilicon production is projected to reach 100,000MT, or 12GW, in 2009. Planned polysilicon capacity expansions could see that figure climb to over 250,000MT by 2012, or approximately 38GW. While demand for polysilicon is expected to grow by 34% in 2009, it seems supply will shoot up to 112%, leading to a spectacular fall in polysilicon prices.

The 2008 polysilicon price peak saw the cost reach approximately US$400 per kg, but this figure is expected to fall to an average of US$250 per kg in 2009. Prices are forecasted to fall to below US$150 per kg in 2010, below US$100 per kg in 2011 and below US$50 per kg in 2012. At



iSuppli Corp: Polysilicon supply and demand forecast to 2012.



iSuppli Corp: PV module supply and demand forecast 2008-9

these low selling prices, it is survival of the fittest, with only the most cost-efficient polysilicon producers being able to sell above cost.

Module mayhem

Eight consecutive years of growth coupled to low barriers to entry have resulted in a significant expansion in PV module production that will see supply exceed demand by 102% in 2008 and reach a massive 168% excess in 2009. Module revenues are expected to fall nearly 20 percent in 2009 to US$12.9 billion, compared to US$15.9 billion in module revenues expected in 2008.

According to Wicht, solar module installations will reach 3.8GW in 2008 and rise to 4.2GW in 2009, a 9.6 percent rise. However, PV module production will reach 7.7GW in 2008 and 11.1GW in 2009, forcing module prices down, overall revenue decline and a significant risk of many new entrants, especially from China and Taiwan going out of business.

The pure-play module manufacturers will find it increasingly difficult to compete, with their module prices in the range of US$3.45 per watt. Integrated cell and module manufacturers, such as those with a cost-per-watt of US$2.48, could fare better, but it is expected that companies such as First Solar could be the big winners in this struggle. The thin-film leader has the lowest cost-per-watt in the industry, and the company's future profitability are secure, both from a cost point of view, but also because the fundamental attraction of grid parity goals remain in place.

During the second half of 2010, after a number of manufacturers have exited the market, Wicht expects prices and revenues to rebound. The forecast for 2010 is for revenues to reach US$17.8 billion, a 38.2% rise over 2009, followed by growth of 11.1% in 2011 and 29.1% in 2012.

The plummeting module prices in 2009 could, according to Wicht, actually fall close to production costs for c-Si panels but could spark an additional 20% growth in installations with market revenue rising by 15.7%. The limited upside growth would be due to installers being unable to meet demand.

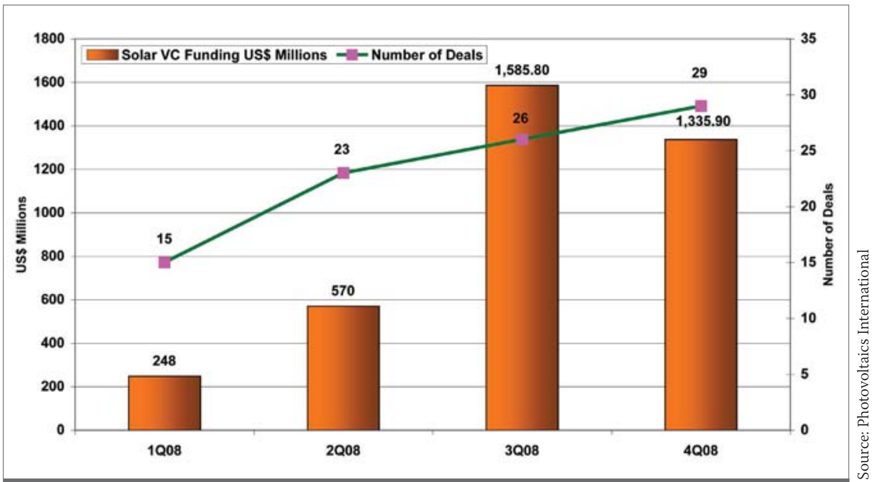
Ernst & Young presents increased cleantech investment figures for 2008

Analysts Ernst & Young have presented their figures for investment in the cleantech industry for the first three quarters of 2008. Venture capital investment in cleantech companies reached a record US$4.6 billion for the period, including data from activity in the U.S., Europe, China and Israel. Data from the U.S. and Europe showed increases in energy generation, making investment in solar energy one of the highest sectors in the region. Total investment following seven rounds of financing amounted to €139 million in the solar sector alone.

Solar start-ups garner more than half of quarterly greentech VC investments, report says

Solar start-up companies accounted for more than half of the US$2.5 billion-plus in venture capital investments made in the final quarter of 2008, according to the latest Venture Power Report issued by Greentech Media. Twenty-nine of the 115 VC rounds completed during the quarter came from the solar sector, for a total of almost US$1.336 billion, outpacing the next busiest sector – ethanol/biofuels/gasification – by a wide margin.

More solar deals closed in the fourth quarter than in the third quarter, which had 26 rounds. The solar total was heavily influenced by Solyndra's massive fund raise, but even without that figure, the solar investing landscape was still very active and perhaps overinvested, the report says.



Greentech Media: Solar VC funding US$ millions (2008).

Applied Materials expects to grow solar biz in'09, despite order push-outs


Applied Materials executives Charles Gay, Mike Splinter, and Mark Pinto

Although recently crowned the largest equipment supplier to the photovoltaics industry by a market research firm, Applied Materials isn't immune from order push-outs and cancellations as the PV manufacturing supply chain struggles with the lack of credit to finance business growth. In its FY1Q09 conference call, Applied's executives noted that its EES (Energy and Environmental Solutions) business unit, which incorporates its solar sales, saw revenue of approximately US$800 million in 2008. The expectation is that sales will exceed this figure in 2009, though specific guidance was not given.

However, Mike Splinter, President and CEO of Applied Materials, guided that the overall crystalline silicon equipment market will be down about 50% Year-on-Year in 2009. Its 'SunFab' thin-film equipment sales would also be impacted by the difficulty with some customers accessing lines of credit. Splinter noted that a gap of several quarters is now expected before 'SunFab' sales resumed.

Applied noted that it was forced to take US$210 million off its bookings backlog specifically from China-based wafering customers as order push-outs exceeded its 12-month recognition window.

"We expect at least one additional 'SunFab' sign off in Q2," remarked George Davis, CFO of Applied Materials in the conference call. "Any revenue upside in our EES segment would come from acceleration of other 'SunFab' factory acceptances as we are seeing improvement in our start-up cycle time."


Applied Materials' SunFab thin-film line.

Greentech Media sees increase in global module output to 23.7GW by 2012

A report by research firm Greentech Media and the Prometheus Institute for Sustainable Development claimed that global module capacity will grow to 27.6GW – enough to produce 23.7GW of modules – by 2012. The company sees a significant drop in manufacturing costs to below US$1.50 per watt for most technologies, while it foresees thin-film production to drop as low as 70 cents per watt.

The report, 'PV Technology, Production and Cost, 2009 Forecast,' provides an analysis of global manufacturing capacity, production and costs, encompassing all technologies in the industry. Greentech Media analysed the current marketplace and created supply and demand forecasts for the future of the industry, coming up with a list of companies that they suspect will find the next few years of the economic downturn particularly difficult.

It also sees high-efficiency monocrystalline and low-cost thin-film technologies as the sturdiest and most likely to weather the stormy times ahead, with an amount of uncertainty for the durability of the multicrystalline manufacturers.

Solar spot market pvXchange reports successful 2008 and announces company expansion

Berlin-based pvXchange, the photovoltaic spot market trading company, provided positive reports of its sales for 2008 and as a result has decided to open a public limited company. pvXchange international N.V., with offices in Maastricht, Netherlands, will be involved with all business dealings of the company, leaving the parent company (pvXchange GmbH) to continue operation of the international solar trading platform.

The company saw a trading volume of approximately €300 million in 2008, a more than 100% increase on 2007's trade figures. Martin Schachinger, company CEO, puts this increase down to the current economic crisis and people's need to avoid risk and high prices. pvXchange has seen a significant increase in its customer base, which now numbers close to 3,000, and it expects this number to increase further over the next few years.

HELAPCO outlines change in Greek feed-in tariff laws

According to the Hellenic Association of Photovoltaic Companies (HELAPCO), the Greek Parliament has altered the feed-in tariff laws, resulting in a regression of the tariff levels from August 2010 and an abolishment of the unofficial 800MW cap. Tariff levels will remain unchanged until that date, although grid connection agreements can be signed prior to this deadline, with a subsequent 18-month timeframe within which to finalise the installation.

The new laws state that any applications over 3GW that have been submitted must be either approved or rejected by the end of 2009, while installations costing more than €100,000 will be eligible for a 40% grant. Rooftop PV projects will receive a different set of criteria that are expected to include an extra 750MWp allowance, scheduled for introduction later in the year, but it is said that these types of system will not be eligible for a grant. PV systems greater than 10MWp have been granted a new tender process, according to the announcement, with details also expected later in the year.

	Government's Proposal (Aug. 08) New Feed-in-tariffs (€/kWh)		
	Mainland Grid		Autonomous island grids
	≤100 KWp	>100 KWp	≤100 KWp
2008	0.457	0.407	0.507
2009	0.460	0.410	0.510
2010	0.450	0.400	0.500
2011	0.399	0.354	0.443
2012	0.354	0.314	0.393
2013	0.313	0.279	0.348
2014	0.279	0.248	0.310
FIT regression for newcomers			
1% per month in 2010-2013, 0.5% per month in 2014			
FIT guaranteed for 20 years			
Annual adjustment of FIT for inflation (25% of last year's inflation)			
Plus 40% grant			

New Greek feed-in tariff laws.

Newport's solar equipment orders up 150% in 2008

Newport Corporation has continued to expand rapidly into the photovoltaics equipment market, now offering c-Si and thin film products that tap into its core technologies of lasers, motion control and optical systems. The company noted in a conference call with financial analysts to discuss fourth quarter and full-year results that orders to PV manufacturers had grown more than 150% in 2008, to reach US$33.6 million compared with orders of US$13.3 million in 2007.

Solar equipment sales totalled US$21.0 million in 2008, compared with US$9.3 million in 2007. Fourth quarter sales to PV manufacturers reached US$5.9 million, while orders received totalled US$3.2 million.

Robert Phillippy, President and CEO of Newport noted in the call that access to capital for some customers was proving harder to obtain and expected a pause in production expansions until the capital markets improved. However, he said that the underlying demand for solar energy remained strong, despite financial market conditions.

SolarWorld in no need of cash after sales grow 30% in 2008

German solar panels manufacturer SolarWorld sees no need to refinance before 2013, and even then expects issues to be limited. SolarWorld AG has posted 2008 fiscal revenue of €900 million, a 30% increase over 2007. Operating result before taxes and interest (EBIT) also grew by more than 30% to €260 million. SolarWorld said that the current results were exactly inline with its previous guidance. The company also noted that January, 2009 sales had exceeded those of January, 2008, despite poor weather conditions for installations in key European markets.

"We carried out a private placement at the end of 2006 of about €300 million (US$397.1 million) in the United States that runs over 7 to 12 years," said SolarWorld CFO Philipp Koecke. "If the financial markets return to normal I do not expect that we will come into a situation where we will actually have to refinance."

The company's 2008 sales have grown more than 30%, and it expects its 2009 sales to be in excess of €1 billion. The company has fared better than peers Chinese LDK Solar Co. and Solon, who both cut their sales forecasts as a result of the global financial crisis. SolarWorld grabbed media attention last November when it announced its plans to bid on General Motors' Opel unit in Germany, stating that it hoped to turn the company into Europe's first "green" car company.

Applied also noted that it has five further 'SunFab' lines to be qualified in order to realise revenue, intimating that a few of these would be qualified in 2009.

Splinter reiterated in the Q&A session of the conference call that some of its existing 'SunFab' customers are planning further expansions and that Applied was working closely with them on scheduling, though did not provide further details.

Aleo Solar's CFO foresees sunny outlook for 2009

Uwe Bögershausen (pictured), CFO for module manufacturer Aleo Solar, has said in an interview with Reuters that it expects 2009 to hold promising profit levels for the company. The company has secured short- and long-term financing for the year ahead, and expects a hike of €380 million in sales this year as compared to 2008.

The optimistic outlook does come with a warning, however: Mr. Boegershausen expects the first quarter of this year to be weaker revenue-wise than the same period last year, but overall, the prognosis is good.

"Regarding short-term financing, we have extended our credit lines and feel well positioned in the current economic environment," commented Mr. Boegershausen in the interview with Reuters. "The first quarter may be weaker compared to last year, but that holds true for everyone. But we will remain on track in a difficult market environment."

Solar Power International 2009 shifts to larger Anaheim venue, pushes dates back

Organizers of the Solar Power International trade show have decided to move the 2009 event to a larger venue and change the dates. Originally scheduled to be held in San Jose on October 19-22, the show will now take place at the Anaheim Convention Center, October 27-29. The change was made to accommodate the event's rapid growth.

Attendance at SPI jumped from 12,500 in 2007 to 23,200 in 2008, according to the Solar Electric Power Association (SEPA) and Solar Energy Industries Association (SEIA), the show organizers.

The U.S. stimulus bill primer: implications for the solar industry

David Owen, *Photovoltaics International*

The American Recovery and Reinvestment Act has now been passed, and there is much talk about what this will actually mean for the solar industry. The final version of the stimulus bill amounts to US$789, which will be the government's most expansive economic rescue package since The Great Depression, even after the cuts. Will it really stimulate the solar market in the US and how can you benefit from this? *Photovoltaics International* has been following the headlines closely and has provided this round-up so that you are completely up-to-date.

When did it happen?

28th January – House passes US$819 billion version of the bill

10th February – Senate passes a US$838billion version of the bill

11th February – the House and Senate renegotiate the bill

13th February – the House and Senate agree a US$789 billion version of the bill

16th February – President Obama signs the bill into law in Denver, Colorado

What does the bill include for solar?

In order to stimulate the economy and create jobs, the bill includes over US$6 billion in loan guarantees for renewable energy projects, solar in particular. Industry representatives have estimated that the bill will create 67,000 jobs in the solar power sector this year and a total of 119,000 jobs over the next two years.

- US$6.3 billion funding to increase energy efficiency in federal buildings – specifically, projects such as integrated solar roofs and lighting systems.
- A new 30% tax credit for equipment and facilities that manufacture renewable energy-generating materials, such as solar panels.
- US$6 billion loan guarantee program. This should support US$60 billion of renewables projects. Assuming 50% of the US$60 billion loans are for renewables generation (remainder for transmission) and wind/solar receive 80% of the renewable generation investments, we estimate ~2GW solar PV capacity buying power.
- US$11 billion for the development of "smart grid" projects, which use new technologies to create a more efficient and cost-effective energy grid.
- US$3.5 billion state/local government grants for energy efficiency and conservation. Funds are expected to be used for a wide range of renewable projects, which also include onsite renewable energy generation projects.
- US$3.4 billion to fund renewable energy projects of state energy offices (the solar procurement program could be included in this portion of the bill).
- US$2.5 billion will fund energy efficiency and renewable energy research, among other energy efficiency and research projects and incentives.
- US$500 million loan guarantees estimated to support US$5 billion loans to implement sustainable energy infrastructure projects.

U.S. President Barack Obama signs the American Recovery and Reinvestment Act, in Denver, Colorado.

What they said:

"Because we know we can't power America's future on energy that's controlled by foreign dictators, we are taking a big step down the road to energy independence and laying the groundwork for a new green energy economy that can create countless well-paying jobs."

U.S. President Barack Obama, after signing the American Recovery and Reinvestment Act.

"The solar provisions in the bill will allow us to begin hiring, create growth opportunities for small businesses throughout the country and keep the economic engine going."

Rhone Resch, President, Solar Energy Industries Association.

"The manufacturing credit is a huge step forward to put Americans to work making solar panels so we all can benefit from clean, affordable renewable energy."

Mike Splinter, President and CEO of Applied Materials.

"In particular, the manufacturing tax credit is an excellent first step to help generate some of the five million new green jobs President Obama has cited in his commitment to help transform our energy infrastructure from fossil fuels imported from abroad to clean energy manufactured and produced in America."

Jeannine Sargent, CEO, Oerlikon Solar.

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

PV cell and module manufacturing equipment: the likely winners start to emerge

John West, VLSI Research Europe Ltd., Bedford, UK

ABSTRACT

In the few years since the PV cell and module manufacturing industry first hit the radar, the identities of the winners and losers in the race to supply equipment have started to emerge. While some companies can genuinely claim to have been involved in the solar industry for some time, the majority are relatively new on the scene. This is hardly surprising, as the explosive growth in demand spurred any company with matching competences into action. In fact, over 300 equipment companies have been attracted to the industry since 2003 by the prospect of a share in a market valued at US$4.4 billion in 2008. For the first time, a detailed analysis of the PV equipment suppliers has been compiled by VLSI Research. The Top 10 in this list are presented here and discussed in relation to their achievements in the industry and their outlook for 2009 and beyond.

The Top 10

Applied Materials made it to the No. 1 position despite only entering the market in 2006. This rapid advancement has been achieved through an aggressive acquisition strategy, starting with Applied Films. Baccini S.p.a. was another major acquisition at the beginning of 2008 and there have been others that have helped to give Applied a broad coverage of PV manufacturing technology. Baccini brought Applied Materials a significant position in silicon wafer cell manufacturing with their screen printing and test lines, while Applied Films provided the platform for the 'Sunfab' silicon thin-film panel factories. Sunfab will have a major impact on Applied's revenues in 2009.

"The extra deposition steps required for tandem cells will help to drive strong equipment growth in this market going forward."

Oerlikon's 'Fab 1200' turnkey silicon thin-film solution continues to gain momentum and the company recognised revenue on several lines in 2008. Ulvac is the third major supplier of turnkey silicon thin-film lines and also performed well in 2008. All three companies are introducing tandem cell technology, which allows a 50% increase in cell efficiency over the current single amorphous layer cells. The extra deposition steps required for tandem cells will help to drive strong equipment growth in this market going forward.

Centrotherm and Roth & Rau continued their dominance of the PECVD market for silicon wafer-based cells. In 2008, it became clear that Roth & Rau will focus on offering more steps in the value chain for this market while Centrotherm is looking at the realm outside silicon wafer cells with equipment for polysilicon material production and non-silicon thin-film cells. Two automation companies made the Top 10 this year: Schmid Gruppe and Manz Automation, highlighting the increasing importance in cell manufacturing of inline processing and factory automation. Von Ardenne Anlagentechnik supplies PVD systems primarily for thin-film on glass applications and boasts extensive experience from the world of architectural glass. Rena Sondermaschinen is the top-rated supplier of wet etch equipment while 3S Swiss makes a range of equipment including laminators, tabbers and stringers for the manufacture of modules.

Equipment trends for 2008

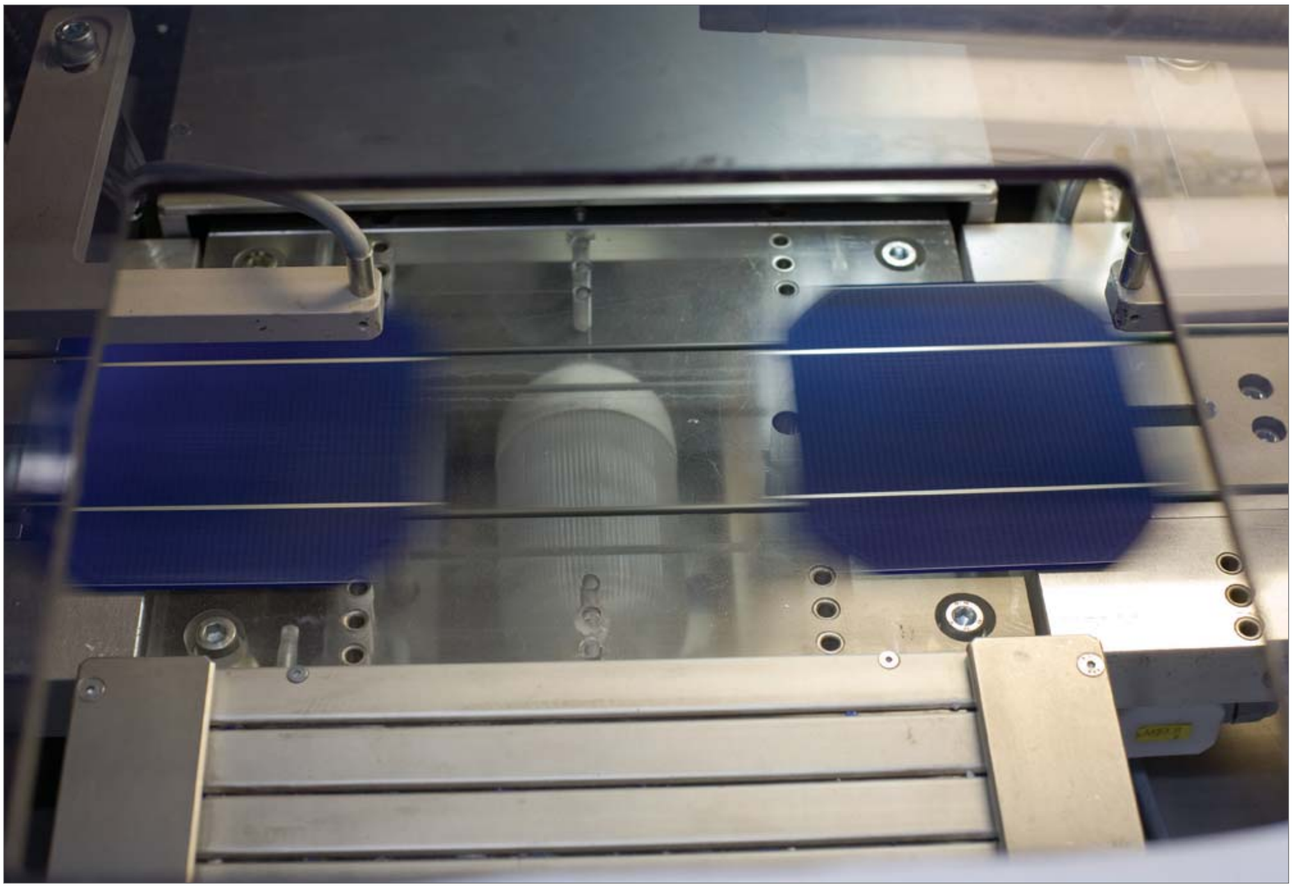
The key trend in 2008 was the explosive growth of the thin-film equipment companies, which explains the emergence of Applied, Oerlikon and Ulvac in the top half of the equipment suppliers ranking. While Ulvac has been involved in the PV industry for decades, Applied Materials and Oerlikon are relative newcomers and their fast ascent to the top of the table is indicative of the influence the semiconductor industry is having on the PV industry.

Overall, about a quarter of all equipment suppliers to the PV industry have a long pedigree in semiconductors, yet they account for over half the PV industry's revenues. This is because they have been invaluable in bringing key technologies and expertise to bear on manufacturing problems, particularly those associated with thin-film cell technologies.

2008 Rank	Company	2008 US$M
1	Applied Materials	455
2	Roth & Rau AG	275
3	Centrotherm GmbH + Co. KG	270
4	OC Oerlikon Balzers AG	250
5	Ulvac, Inc.	240
6	Manz Automation AG	140
7	Schmid Gruppe Technology Systems GmbH	125
8	Von Ardenne Anglagentechnik	120
9	RENA Sondermaschinen GmbH	85
10	3S Swiss Solar Systems	70

Source: VLSI Research Inc.

Preliminary ranking of top 10 suppliers of PV cell and module manufacturing equipment, 2008.



Courtesy of Deutsche Solar.

Outlook for 2009

While 2008 was a spectacular year in terms of growth, the outlook for 2009 is less certain. The solar cell manufacturing industry is losing its immunity to the credit crisis as demand for cells starts to cool while existing fabs are ramping up to full capacity. As a result, weaker companies are struggling to find the finance to fund the next round of expansion. The impact on the equipment industry has seen some order delays and push-outs, but so far there are no reports of cancellations. The real worry is the lack of new contracts for delivery of equipment through to the end of 2009 and early 2010. This trend is unsettling as it is likely to result in the shaking out of some of the less well-resourced equipment companies as they too struggle to finance their activities.

As a result of the deteriorating order situation, the outlook for the PV cell and module manufacturing industry is for growth in sales to slow to 8% average in 2009 across all technologies. Given the current economic climate, this is still a very attractive market, but compared to the huge growth rates experienced in recent years this feels like a serious downturn for the industry. Equipment companies that have been ramping up to meet the strong growth in demand are now finding they have overshot the market and are having to pull back from some of their earlier expansion plans.

> "The outlook for the PV cell and module manufacturing industry is for growth in sales to slow to 8% average in 2009 across all technologies."

The indications are that the larger, well-resourced equipment companies are best placed to weather the next few years, and that many of the smaller companies that do not have good product and service differentiation will fall by the wayside.

About the Author

John West is the managing director of VLSI Research Europe and has been analysing the PV equipment market since 2006. He was awarded an M.B.A. from Cranfield University and has a degree in medical physics from the University of London.

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Downstream is up, upstream is down – what does the credit crisis mean for the PV industry?

Daniel Pohl, EuPD Research | 360Consult, Bonn, Germany

ABSTRACT

News of credit crunch woes filtering down the lines over the past few months has instilled a sense of frugality in all industry sectors. While the credit crisis has indeed affected the PV industry, German banks, investors and creditors have claimed that the financing of small PV systems in the private sector seems not to be endangered. Downstream players are still optimistic, but the upstream sector is anticipating severe damage as a result of the economic situation. An interactive workshop-style discussion, hosted by market researcher EuPD Research and the CleanTech consultancy 360Consult, invited top-level executives to contribute their experiences of the current financial situation, as discussed in this paper.

The effects of the international financial crisis clearly affect all industrial sectors around the globe, including greentech companies and the photovoltaics sector. Whereas the segment of small systems for the private end-customer seems not to have been affected by the credit crunch, the cost-intensive segment of large-scale PV plants is expecting stormy weather.

"Due to a very comfortable situation in the German banking sector, financing of small systems for private end-customers should not be affected by these global turbulences in the first place. Besides the KfW (Kreditanstalt für Wiederaufbau), comparable to a state bank who [sic] is granting private loans for reconstruction and modernization in the housing sector, the Umweltbank as well as the cooperative banks have not withdrawn funds to finance these projects", explained Markus Wackerbeck, Senior Consultant at the German cleantech consultancy 360Consult, part of Hoehner Research & Consulting Group. This comment leads one to the assumption that it is mainly the upstream players – the manufacturers – that are going to be affected by the current situation, whereas the downstream players – such as installers or wholesalers – might get off cheaply. "According to our clients, investors and planning companies in particular in the league of megawatt plants are expecting difficulties when it comes to financing", Wackerbeck states, adding that the same applies for all photovoltaic companies with ambitious expansion plans in 2009, and, as a result, high cash needs.

Where might the crisis lead?

Within the framework of a recently held workshop in Germany's finance metropolis of Frankfurt on the Main, more than 80 top-level executives from the photovoltaics sector exchanged their thoughts on the issue of the outlook for the future of the industry. One main concern of the delegates from various nations was the potential for difficulties emerging in taking up dept capital in the forefront of project planning. Due to the current financial situation, venture capital is becoming more and more expensive. But on the other hand, the crisis may even lead to desperately needed market consolidation, which might turn out to be very healthy for the PV industry as a whole. Other factors that need consideration in this discussion are the market stimulation packages that are being adopted by governments all across the globe. "These enormous financial aids granted by most international administrations will clearly show a positive effect on the whole cleantech industry, including the PV sector", Markus Wackerbeck points out.

In addition to these ad hoc measures, the solar industry benefits from long-term promotion schemes such as feed-in-tariffs (FIT), which should keep the demand from plummeting in the short term. "Nevertheless, our consultants presume that the recession at hand clearly has a negative impact on purchase power and investment abilities as well as the energy demand in general. In the scope of an international downturn, the overall energy demand is going to decrease and the whole climate debate could partly become a luxury problem compared to accumulated insolvencies, unemployment and political instability", warns Wackerbeck.

'Downstream is up, upstream is down'

Based on recent surveys conducted by market researcher EuPD Research, 360Consult concludes that downstream players such as wholesalers and installers will profit slightly from the upcoming changes in the market. While in the past photovoltaic products and PV components have practically sold themselves due to robust subsidies and incentives as well as a level of demand far

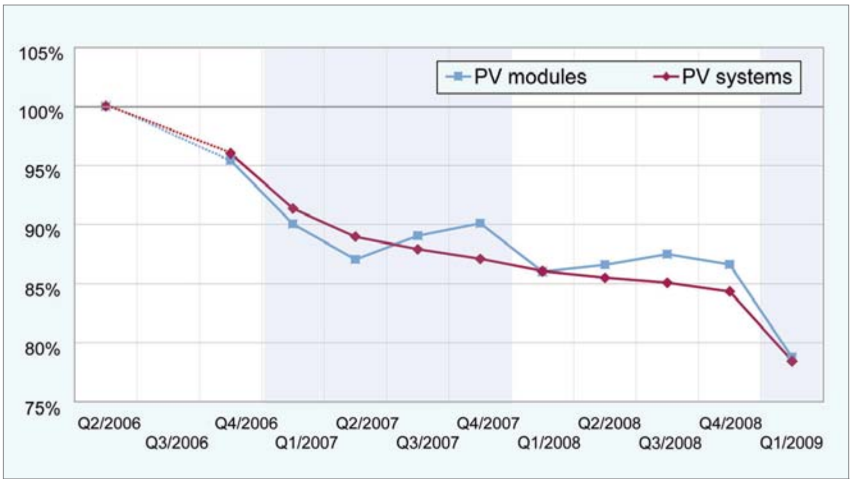

Figure 1. German module and system prices point downward.

Source: BSW 02/2009" "BSW-Solar-Index, conducted by EuPD Research commissioned by BSW.

above the available supply, the future will bring more challenges and competition. "The oversupply scenario has come true", states market expert Markus A.W. Hoehner, CEO of Hoehner Research & Consulting Group, which has been actively surveying the global energy markets for nearly a decade now. "The industry finds itself in the considerable shadow of the global financial crisis, and a worldwide recession is hindering the investment plans of some upstream companies. According to our analysts from 360Consult, the industry is facing a time of thorough upheaval unlike anything it has faced in the past," said Mr. Hoehner.

Such a hindrance for the producers may come in handy for the installers and wholesalers and, last but not least, for the end customer. Within the 'Price Index for PV Modules', conducted by EuPD Research on behalf of the German solar industry association BSW-Solar, the market experts from Bonn are clearly spotting a significant decline in prices, illustrated in Figure 2. Compared to the previous quarter, prices for solar modules in Germany, one of the leading PV markets worldwide, showed a near-double-digit fall. Consequently, investment in PV installations has become increasingly attractive for private investors – the end of the year might even see the surviving downstream players stronger than they were before this global issue.

"Such an economic turndown as this we are currently facing also provides the opportunity to boost the transformation process from a seller's into a buyer's market – in the long-term, a really positive development."

Point of view: different perceptions of the crisis

The perception of the PV manufacturers of the crisis differs from the perception of the installers and wholesalers (see Figure 3). While producers and equipment vendors in the field of crystalline and thin-film modules can expect mostly negative capital procurement outcomes from the financial crisis, the downstream players – German installers in particular – tend to lean more towards a neutral or positive assessment – a tendency Markus Wackerbeck strongly supports. "Such an economic turndown as this we are currently facing also provides the opportunity to boost the transformation process from a seller's into a buyer's market – in the long-term, a really positive development."

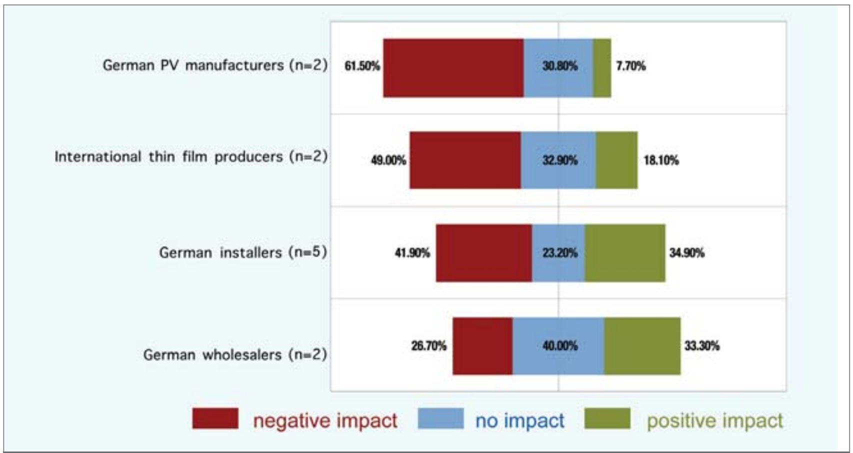

Figure 2. Different perceptions of the crisis.

Source: EuPD Research 01/2009.

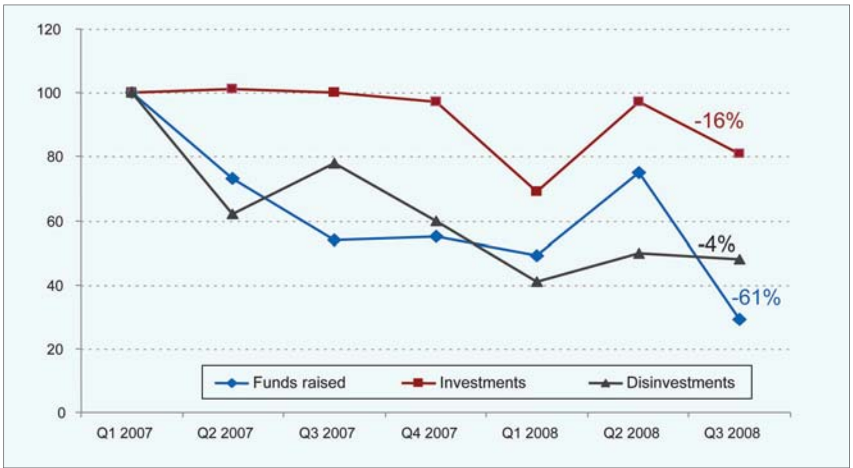

Figure 3. Financing from venture capital – indicators point downward.

Source: PEREP Analytics.

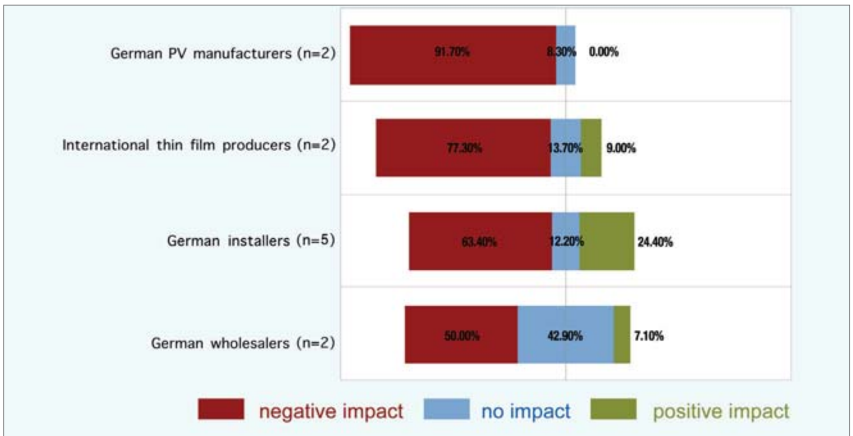

Figure 4. Responses to capital procurement concerns, gathered from various sectors of the PV industry.t from bank

Source: EuPD Research 01/2009.

About the Author

Daniel Pohl graduated with an M.A. in North American studies, literature and political science from the University of Bonn and the University Paris-Sorbonne. He has been working as an editor and media consultant in the field of economics and renewable energies and is now heading the corporate communications department at EuPD Research and 360Consult in Bonn. Throughout his career, he has published numerous articles on diverse energy topics in national and international special-interest magazines. He has also worked for national newspapers, broadcasting stations and a TV production company.

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Going Places

IBC Solar

Norbert Hahn climbs IBC Solar's ladder to join executive board

IBC Solar has promoted head of sales and marketing Norbert Hahn to the Executive Board. Mr. Hahn, who has been in the sales and marketing leader role since 2002, will continue in his current capacity while taking on management responsibilities. His contributions to the expansion of IBC's three-step sales model made him the company's choice for promotion to the board.

Wilson Sonsini Goodrich & Rosati

John F. Mizroch appointed Of Counsel to Wilson Sonsini Goodrich & Rosati

Wilson Sonsini Goodrich & Rosati, a legal services provider for technology, life sciences, and growth enterprises worldwide, has announced that John F. Mizroch has been appointed Of Counsel to the firm. In this position he will provide strategic regulatory counsel to clients regarding energy and environmental technology.

Diamond Wire Technology

Diamond Wire Technology appoints Barry Capoot as CFO

Barry Capoot has been named chief financial officer at Diamond Wire Technology (DWT), a manufacturer of diamond wire and diamond wire saws. Mr. Capoot will be trusted to lead financial management, strategic planning and contracts administration. Mr. Capoot joins DWT with 15 years of finance and administration experience already under his belt.

SunPower

Power industry vet Tom McDaniel appointed to SunPower board

SunPower Corp. has appointed electric power industry veteran Thomas R. McDaniel (pictured) to its board of directors. McDaniel recently retired from Edison International after 37 years of service. In his most recent role, McDaniel served as Edison International's executive VP, CFO, and treasurer. He was responsible for the company's financial, risk management, controller, internal audit, and IT functions.

Solar Energy Initiatives, Inc.

David W. Fann, Gregory N. Bakemann promoted at Solar Energy Initiatives

Solar Energy Initiatives, Inc., which markets solar thermal and photovoltaic technologies, have appointed David W. Fann as CEO and Gregory N. Bakemann as President, who will also continue to serve as Chief Financial Officer. Michael J. Dodak has resigned from his position in the company but will remain on the Board of Directors.

Entech Solar

Kent J. Van Houten appointed as CFO at Entech Solar

Entech Solar has appointed Kent J. Van Houten (pictured) as CFO, in which role he will manage the company's financial strategy, corporate planning, treasury functions, internal controls, and SEC reporting. Mr. Van Houten, a Certified Public Accountant, holds a Bachelor's in Business Administration degree in accounting from Howard Payne University and has held multiple finance-related positions throughout the past 30 years. He most recently served as VP of Finance & Accounts at Aegis Communications.

Tigo Energy

Tigo Energy appoints Takashi Tomita, Yair Cohen and Nathan Zommer to board of advisors

Tigo Energy has announced that Professor Takashi Tomita, Mr. Yair Cohen and Dr. Nathan Zommer will join the company's board of advisors.

Takashi Tomita (pictured) is an industry veteran, having served in leadership roles for 34 years at SHARP Corporation, most notably as an Executive Director of Sharp and head of the Solar Business Group.

Dr. Nathan Zommer founded IXYS in 1983. He served as director since 1983 and has been chairman of the board, president and CEO since March 1993.

Yair Cohen joined the IDB Group in 2005, and currently holds executive leadership roles within Clal Energy and Elron. He also serves as a Director at several other IDB Group companies.

Yingli Green Energy

Yingli Green Energy appoints Dr. Dengyuan Song as Chief Technology Officer

Yingli Green Energy, a photovoltaic product manufacturer, has appointed Dr. Dengyuan Song as Chief Technology Officer, replacing Dr. Guoxiao Yao, who resigned to pursue other interests. Dr. Song will lead Yingli Green Energy's research and development initiatives. Dr. Song has worked for the research and development of solar cells, silicon materials, and semiconductor PV devices in Australia and China for more than 27 years.

MEMC

Cypress's Ahmad Chatila takes the helm at MEMC

Following a 15-year tenure with Cypress, former Memory division EVP Ahmad Chatila has departed the company to serve as CEO and take a seat on the board of directors for MEMC Electronic Materials, Inc. Mr. Chatila (pictured) replaces Marshall Turner, who has served as Interim CEO since November 2008 and will remain on the board. The CEO appointment is effective from March 2nd, 2009.

REC Group

Tore Torvund appointed as Executive Vice President of REC Group Management

Tore Torvund (pictured) has been appointed as Executive Vice President of the REC Group to lead REC Silicon's operations, and will also serve as a member of the REC Group Management Team. Mr. Torvund replaces Gøran Bye, who left the company in February. Mr. Bye served as CFO of REC Silicon beginning in 2002 until his promotion to President in 2005.

Mr. Torvund received a M.Sc. degree from the Norwegian University of Science and Technology and has held senior executive positions in the oil and gas industry for more than 20 years.

GT Solar

GT Solar adds David Gray to oversee strategic development as Vice President

Solar equipment supplier GT Solar International, Inc. has named David Gray, Ph.D. as its first Vice President of strategic development. In this new role, Dr. Gray will steer the company's acquisition of products and technology, as well as overseeing all business development strategy. He joins the company from Canaccord Adams, an investment banking company, where he was head of technology mergers and acquisitions.

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Don't believe what you read: Solar installers offer counterpoint to NYT's green pessimism

If you were to take the Feb. 4 *New York Times*' "**Dark Days for Green Energy**" news story at face value, you might think the solar and other renewables businesses are completely tanking. Here's how the article leads off:

> *Wind and solar power have been growing at a blistering pace in recent years, and that growth seemed likely to accelerate under the green-minded Obama administration. But because of the credit crisis and the broader economic downturn, the opposite is happening: installation of wind and solar power is plummeting.*
>
> *Factories building parts for these industries have announced a wave of layoffs in recent weeks, and trade groups are projecting 30 to 50 percent declines this year in installation of new equipment, barring more help from the government.*
>
> *Prices for turbines and solar panels, which soared when the boom began a few years ago, are falling...*

There's little disagreement that the global recession is having a big impact up and down the solar PV value chain. But is the sky really falling as fast and hard as the article in the creaky ol' Grey Lady suggests? Not according to some of the grassroots solar-biz folks I spoke with at the **GoGreen Expo** held in Los Angeles a couple of weeks ago.

Photo: Tom Cheyney

The event was another one of those "all things green" shows, targeted at both the B2B and consumer markets. Organic food merchants, nature-friendly beauty product providers, and hemp clothiers hawked their wares alongside eco-construction materials outfits, electric car salesmen, and solar, wind, and water-power purveyors. While the positive vibes were palpable (dude!), the focus was diffuse.

Among the dozen or so solar exhibitors, I sought out the front-line foot soldiers in the photovoltaic revolution: the system designer/integrator/installers. According to several of them, business is still good, and they've seen only a minor downtick in their residential and commercial job flow. Although money is tight, local and state rebates as well as federal tax incentives are helping maintain some systems installation momentum.

"People are loaning money for solar," said Herb Mendelsohn, sales director for **PermaCity Solar** (shown on the right in accompanying photo, along with colleague Graham Blackman, at their GoGreen Expo booth). "We're doing three or four residential jobs plus a commercial project per week. We have about 8MW so far in the pipeline for this year."

PermaCity installed 9MW in 2008, according to Herb, about 8MW of it commercial and 1MW residential. The company hopes to double that total in 2009. "We spend as much time developing a US$20,000 system as we do a US$20 million one."

One of PermaCity's megawatt-scale clients, Costco, loves the Schott ASE panels: "They tell us, as many ASEs as you can get, we'll put 'em on our stores," Herb exclaimed. The company is also a premier dealer for SunPower, a favorite module choice among the residential customers, although he told me about a recent commercial bid to install solar systems across several campuses of a local school district which specified SunPower products.

Herb said he recently had a potential client in Beverly Hills ask specifically for First Solar panels – the first such residential request for the CdTe TFPV units. While I stood at the booth, an attendee/potential customer asked about the cost of putting solar on a large greenhouse rooftop – another first request-of-its-kind for the salesman.

Tom Folan of **SolarCity** said that in the last quarter of 2008, "we sold more than in the previous year combined. We met or exceeded our goals for last year. We're still busy and haven't seen a real downslope. December was really good, although January has been a little light."

The company's SolarLease program has become very popular, according to Tom, spurring much of the recent activity, with installation jobs in Southern California surging. Given First Solar's investment of US$25 million in SolarCity last year, it's no surprise that the firm offers the world-famous CdTe panels to customers, allthough he said that the Evergreen Solar ES-A 205-watt models are even more popular.

Daniel Burtt of **REC Solar** echoed the popularity of Evergreen's String Ribbon modules: "We can't get them fast enough." His company offers six different panel manufacturers' panels, the others being Sanyo, Sharp, Kyocera, REC (of course), and Mitsubishi. "They are the most consistent with deliveries," he said of Mitsubishi. "We have had no complaints – they are a high-quality product."

He said REC, which claims to "install more solar power systems than any solar provider in the U.S.," did about 12MW of turnkey residential and commercial installations in 2008, although business has tapered off a bit over the past few months. Still, he noted that the company believes it will continue to grow this year. Underscoring this, some 25 jobs are currently offered on the company's Website.

While these conversations may be anecdotal, don't represent a truly scientific sample, and were limited to systems companies benefiting from the more upbeat California solar climate, the recent experience of the PV system front-line contingent offers quite a different perspective from the pessimistic tone pervading the Times' article.

Tom Cheyney is Senior Contributing Editor (U.S.) for the Photovoltaics International journal and writes blogs for PV-Tech.org.