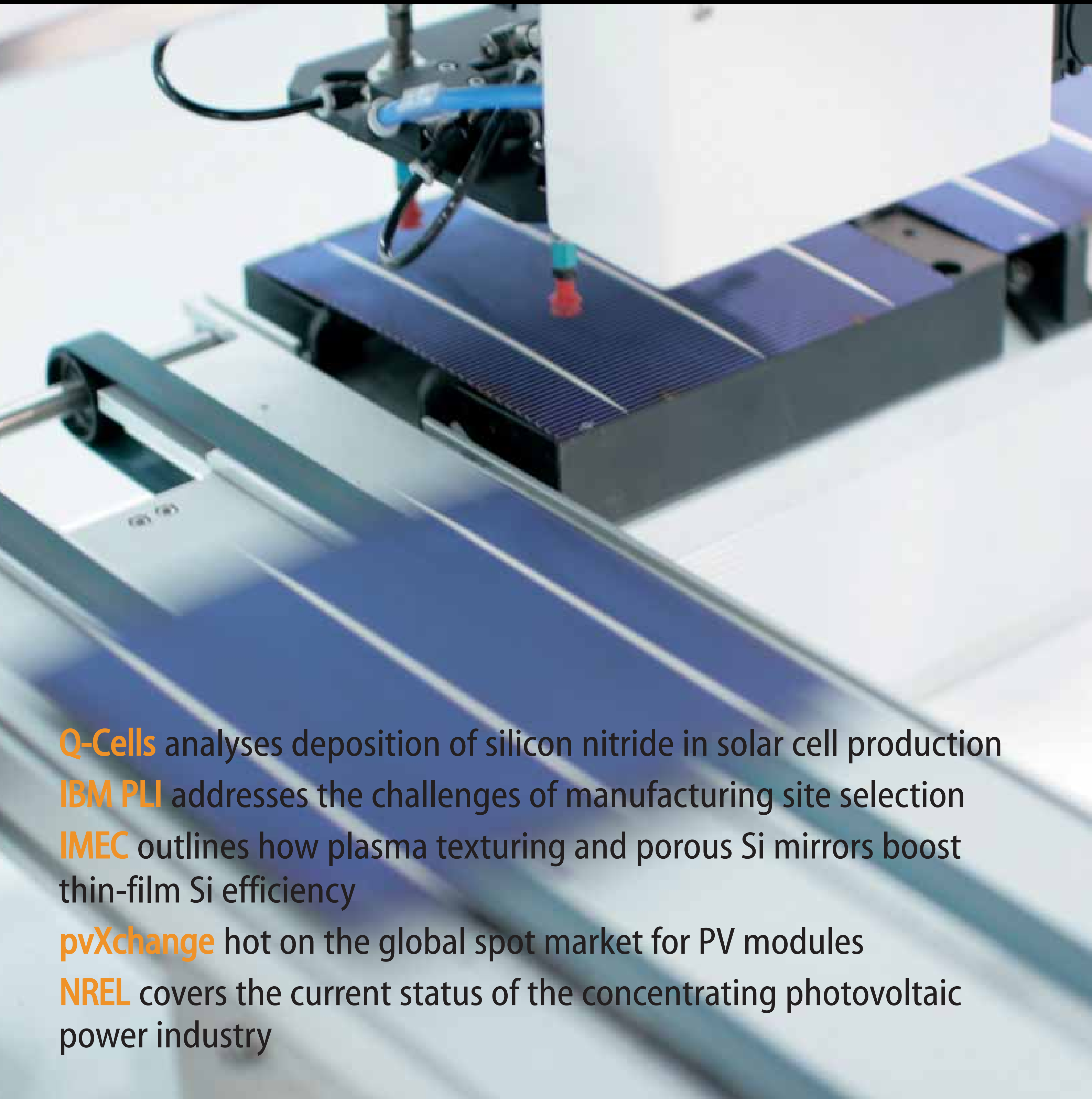
First Edition

Photovoltaics International

THE TECHNOLOGY RESOURCE FOR PV PROFESSIONALS



Q-Cells analyses deposition of silicon nitride in solar cell production

IBM PLI addresses the challenges of manufacturing site selection

IMEC outlines how plasma texturing and porous Si mirrors boost thin-film Si efficiency

pvXchange hot on the global spot market for PV modules

NREL covers the current status of the concentrating photovoltaic power industry

Third Quarter 2008

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 on the launch 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

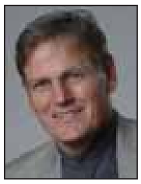
Takashi Tomita has been working at Sharp for 34 years and is widely recognised as a fore-father of the solar industry in Japan. He was responsible for setting up Sharp's solar cell manufacturing facilities in Nara and silicon production in Toyama. Takashi's passion for solar power has led him to hold 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.

Contents

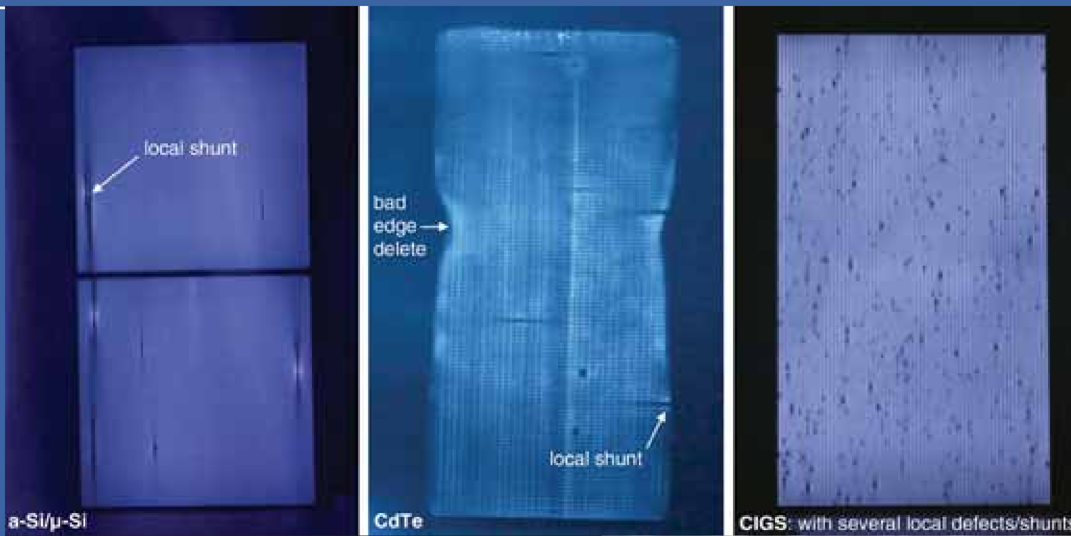
Photovoltaics International

As the CapEx for special machinery in the photovoltaic industry is quite high, subsidies and incentives often play an important role.

The maximum efficiency of light conversion for the Si/SiN/air stack is obtained at n_{633nm}~1.9 at a thickness of d~85nm, assuming zero or negligible absorption.

Contents

Cell Processing



"The maximum efficiency of light conversion for the Si/SiN/air stack is obtained at n_{633nm} ~1.9 at a thickness of d~85nm, assuming zero or negligible absorption"

53

Irish company researches "spray-on" solar cells

Science and Technology Research Partners (Strep), a Dublin-based company, is currently developing "spray-on" solar cells that can be painted onto a roof and integrated electronically to generate energy. The company, headed by University College Dublin and Cambridge University graduate Dr. Mazhar Bari, is researching the technology based on titanium dioxide, among other materials, and has recently moved the development from a wet-state chemistry to a solid-state application.

Currently, the dye-sensitised spray-on cells are operating at an efficiency rate of 40% of regular silicon-based cells, but the ease and relatively lower cost of production of the flexible thin-film cells could potentially render the technology a runner in the industry. The aim is to reach a 10 per cent conversion rate at 10 per cent of the production cost of traditional solar cells.

"The technology in its current stage is a wet state. What I am doing is working on the solid state version. It is wet chemistry basically but I have found a way to make it solid state," said Dr. Bari. "Right now, it is more screen printing but it will develop at some stage into a sprayable technology. It will be applied very much like paint."

Research and Development News Focus

Fraunhofer Institute to use AIXTRON's CRIUS epitaxy reactor for III-V-Si PV cell development

The Fraunhofer Institut für Solare Energiesysteme (Fraunhofer ISE) has placed an order with AIXTRON for its 300mm Close Coupled Showerhead CRIUS epitaxy reactor that will be used for the research and development of GaAs-based multi-junction solar cells on silicon.

"Within the scope of the BMBF project 'III-V-Si' we will receive AIXTRON's Close Coupled Showerhead system," said Dr. Frank Dimroth, head of the III-V-Epitaxy and Solar Cells group. "Fraunhofer ISE operates an AIX 2600G3 Planetary Reactor for more than 10 years and has achieved excellent results on this tool. Now we would like to start a second development pathway focussing on single large wafer processes on Si. We have been working with AIXTRON and closely monitored the evolution of growth technology for the preparation of compound semiconductor thin films on silicon wafers. This is a challenging task but we are confident that the CRIUS tool will meet our requirements of low memory effect, high uniformity and throughput with the requisite economics for solar cell production."

SVTC Technologies attracts JA Solar to new Photovoltaic Development Center

SVTC Technologies has officially launched its Silicon Valley Photovoltaic Development Center, with the aim of becoming a leading RD&E center for the global photovoltaics industry. The new centre is located in an 87,000 square foot facility in south San Jose, California, and cost between $20 and $30 million. The facility will also house a 5MW turnkey solar manufacturing line from Roth & Rau.

"SVTC Technologies has seen a surge in demand for a facility devoted exclusively to the solar industry, which is why we have established the Silicon Valley Photovoltaic Development Center," said Kurt Laetz, SVTC Solar Program Manager. "We want to serve the solar manufacturers already here and attract new ones, helping to establish Silicon Valley as North America's premier environment for solar innovation. By tapping into the enormous talent, creative energy and financial support focused in this region, we intend to do for solar energy what Silicon Valley has done for other high-tech industries."

According to SVTC, solar cell manufacturers and solar start-ups will be able to access the Roth & Rau equipment for product development purposes, while Roth & Rau will benefit from having these potential customers working on their tools. Additionally, Roth & Rau will use the Silicon Valley Photovoltaic Development Center as its North American demonstration showroom.

"It is a testament to the power of our mission, and to the respect that SVTC Technologies has gained worldwide, that companies of the calibre of Roth & Rau have chosen to join our Silicon Valley Photovoltaic Development Center at its inception," said Laetz. "Being able to offer an automated solar cell manufacturing line, as well as crucial certification services, will be extremely valuable for manufacturers of new solar products."

"SVTC Solar is providing a vital piece of the solar energy puzzle in the U.S., and we immediately recognized the importance of being a partner in their venture from the beginning," said Dietmar Roth, CEO of Roth & Rau AG. "We are pleased to bring our solar cell manufacturing equipment and extensive industry expertise to this exciting new photovoltaic development center and using it as our North American demonstration showroom."

JA Solar has also signed a letter of intent to locate its North American research and development operations in the Silicon Valley Photovoltaic Development Center.

"We are very impressed with the Silicon Valley Photovoltaic Development Center's facilities, services and goals," said Dr. Kang Sun, President and COO of JA Solar. "We look forward to a long and fruitful relationship with the centre and with SVTC Solar, which we expect will result in our ability to develop exciting new products for our customers worldwide."

Magnolia and Kopin to co-develop indium nitride-based quantum dot solar cells

Magnolia Optical Technologies and Dr. Roger Welser of the Kopin Corporation have announced their co-development of indium nitride-based quantum dot solar cells for NASA and defense applications. Magnolia and Kopin have carried out successful collaborative development of GaN-based materials in the past. The aim of the current research is to develop high-performance solar cells that can withstand such conditions as can be encountered in use in situations such as NASA space exploration and other defense applications.

"Quantum effects in nanostructured materials enable new innovative device concepts that can radically enhance the operation of traditional semiconductor devices," said Dr. Ashok Sood, President of Magnolia. "For example, a larger fraction of the solar spectrum can be harnessed while maximizing the solar cell operating voltage by using quantum wells and quantum dots embedded in a higher band gap barrier material. Nanostructured devices thus provide a means to decouple the usual dependence of short circuit current on open circuit voltage that limits conventional solar cell design. Ultra-high conversion efficiencies are predicted for solar cells that collect both low and high energy photons from the solar spectrum while maintaining high voltage operation."

NexTechFAS to collaborate with Abbie Gregg, Inc. on solar technology development

The partnership between NexTech Solutions, Inc. and FAS Holdings Group, LLC, entitled NexTechFAS, has announced that it is collaborating with engineering and consulting company Abbie Gregg, Inc. (AGI) on solar technology development.

Product Briefings

SierraTherm

SierraTherm's new APCVD system offers 660mm deposition width

Product Briefing Outline: SierraTherm Production Furnaces has introduced its new 5500 Series APCVD system with a 660mm deposition width. This tool is capable of depositing a combination of up to five layers of doped (BSG, PSG) and undoped SiO_2 films in a single pass. Its throughput capacity of 1875 WPH for 156mm wafers or 2300 WPH of 125mm wafers make it compatible with today's high production cell lines. Films with thicknesses of up to 300nm can be deposited at this process speed.

Problem: Depositing doped and undoped SiO_2 films onto crystalline silicon solar cells has been problematic due to the unavailability of high throughput deposition equipment. Atmospheric pressure chemical vapor deposition (APCVD) systems transport wafers on a conveyor belt and deposit films at elevated temperatures as the wafers pass beneath chemical injector heads. The production capacity of in-line APCVD systems has only a fraction of requirements due to limitations on film deposition width across the conveyor belt used to transport the cells.

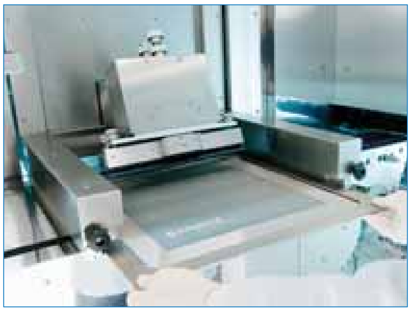
Solution: The 5500 Series APCVD conveyor furnace is well suited for continuous high volume processing of substrates requiring single as well as multi-layer thin films. SierraTherm's in-line system design assures that each substrate receives the same process treatment.

Applications: SnO_2:F. Transparent conductive oxide for sheet glass. Other conductive film applications include SiO_2, undoped; diffusion barrier or insulating layer for silicon wafers or soda-lime sheet glass; SiO_2-, boron- or phosphorous- doped (BSG or PSG) TiO_2. Antireflective layer for silicon solar cells.

Platform: Maintenance-conscious design allows chemical injectors and exhaust ducting to be cleaned in situ. Multiple injector heads can be used in series within a single furnace, maximizing process throughput, uniformity, and flexibility while minimizing cost. Modular chemical vapour injector head assemblies allow quick and easy installation and removal from the coating chamber.

Availability: July 2008 onwards.

MANZ



MANZ complete back-end line offers throughput of 2400 cells per hour

Product Briefing Outline: The MANZ I-series back-end line has a throughput of 2400 cells per hour, and is claimed to be the fastest backend system available in the market today. One single system includes printing, firing, laser edge isolation, cell testing and sorting for crystalline solar cells.

Problem: To manufacture crystalline solar cells, electrical contacts must be created on the front and back side of the solar cell. The three metal layers (one on the front and two on the rear side) are created using a screen printing process. Metal particles dissolved in a solvent are transferred to the solar cell through a textured screen. The wet paste must then be then dried in an oven after each printing step. Existing suppliers of screen printing machine have a maximum throughput of 1500 cells per hour.

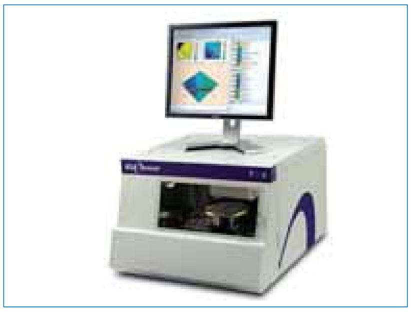
Solution: The MANZ Back-end line prints two cells at once and integrates additional process steps such as firing, laser edge isolation or cell testing and sorting. The system is able to replace two traditional screen-printing systems and saves investment, space, consumable and labour costs. Additional features include: printer; micro crack control system before the first printing step to lower the breakage rate in the system; automatic screen cleaning system; closed-loop print control after each individual printing step using MANZ vision systems; automatic paste dispenser; tester and sorter; electrical measurement using H.A.L.M; front- and rear-side measurement using MANZ vision systems' 3D contamination measurement and electroluminescence measurement.

Applications: Printing, firing, laser edge isolation and testing and sorting of crystalline solar cells.

Platform: Standardized modules from MANZ I-series: IML 2400 – Inline Metallization Loader; IPC 2400 – Inline Print Contact; IDF 2400 – Inline Drying furnace; IWB 2400 – Inline Wafer Buffer; IFF 2400 – Inline Firing Furnace; ILE 2400 – Inline Laser Edge Isolation and the ICT 2400 – Inline Cell Tester and Sorter.

Availability: September 2008 onwards

KLA-Tencor



KLA-Tencor's new P-6 surface profiler handles 2D and 3D surface analysis

Product Briefing Outline: KLA-Tencor has unveiled its latest stylus surface profiling system, the 'P-6,' offering a unique set of advanced features for scientific research and production environments, such as photovoltaic solar cell manufacturing. The P-6 system benefits from measurement technologies developed on advanced semiconductor profiler systems, but in a smaller, more economical bench top design for samples up to 150mm. The P-6 profiler has been qualified at BP Solar, a major photovoltaic manufacturer

Problem: For the solar market, the P-6 has the resolution, scan quality and automation needed to improve solar cell efficiencies in the development stage, as well as monitor process quality in production.

Solution: The P-6 offers complete high resolution 2D and 3D analysis of surface topography in a versatile platform, which is claimed to have the best price-to-performance capabilities available from any manufacturer. The system's three different measurement head configurations offer flexibility for a wide range of vertical topographies, and the P-6's 'point-and-click' user interface makes it easy to operate. New features include: low noise floor improves measurement sensitivity to characterize small topography; less than 6Å step height repeatability ensures stringent process control; 150mm X-Y sample stage enables single measurement to cover full substrate and 2D stress measurement and analysis minimises defects and improves yield.

Applications: The P-6 Stylus profiler is capable of addressing a wide range of measurements and applications such as thin-film and thick-film step heights; photoresist/soft films; etched trench depth; materials characterisation for surface roughness and waviness; surface curvature and form and 2D stress of thin films, amongst others.

Platform: Standard 2μm radius stylus, with options from sub-micron to 25μm radii available. Extensive list of standard measurement parameters, Apex report generating software and advanced 3D imaging.

Availability: July 2008 onwards.

Silicon nitride thin films in µc silicon solar cell production

Hubert-Joachim Frenck, Q-Cells AG, Bitterfeld-Wolfen, Germany

ABSTRACT

Ever since the introduction of attractive feed-in tariffs for photovoltaic electricity generation, there has been a huge surge in all kinds of photovoltaic applications. Products based on multicrystalline wafers still have the largest market share with thin-film products picking up in recent times. In the course of this process, production technology for wafer-based solar cells has been improved. With the second generation of tools, a trend towards standardization is apparent.

Deposition of silicon nitride is one of the key processes of solar cell production. While its technological significance is often underestimated, it is the only process step that serves a multitude of purposes. In this contribution we will present aspects of the deposition of silicon nitride thin films and discuss open questions with respect to the physics of the deposition process and its implication on machine technology.

Introduction

The deposition of thin films is a key technology for a large variety of technical and scientific applications. Among them is the deposition of silicon nitride (SiNx) to passivate the surface of silicon solar cells. The SiN film serves several purposes. It is a broadband anti-reflection layer, it serves to saturate dangling bonds and/or other surface states of the silicon, and last but not least, it is a protection layer to prevent alkali ions and other impurities from diffusing into the silicon causing perturbations of the performance of the solar cell. This multitude of properties to be fulfilled at the same time often causes difficulties in assessing the effect of a single process parameter, let alone the task of optimizing the SiN film in all required aspects at the same time. The aforementioned technical features of the SiN film provide the very property that largely determines the aesthetically pleasing appearance of a cell, and hence a PV module, as the colour of the module is determined by the cell composition. In order to complicate things further, there are numerous deposition techniques being applied both on a scientific level as well as in production environments.

Silicon nitride has been investigated intensively for a long time for a variety of purposes like passivation of InP (indium phosphide) [1], while its application to MIS solar cells has been known for quite some time [2]. It is therefore beyond the scope of this paper to discuss all aspects of various features of the SiN deposition, nor is it the goal of this article to discuss the machinery used and its implications on film properties. While to the best of our knowledge there is no comprehensive review article in existence, major aspects of the process have been covered elsewhere

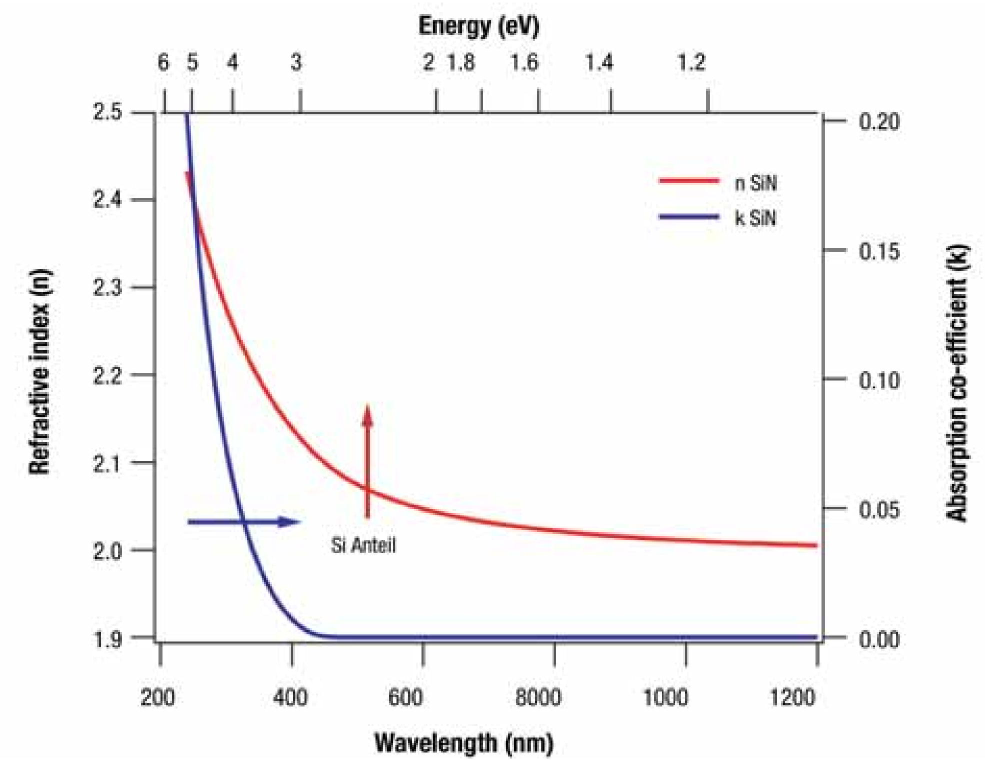


Figure 1. Calculated refractive index and absorption coefficient of a SiN_x film as a function of incident wavelength. The effect of a change in stoichiometry of the SiN_x film is indicated with red and blue arrows, respectively.

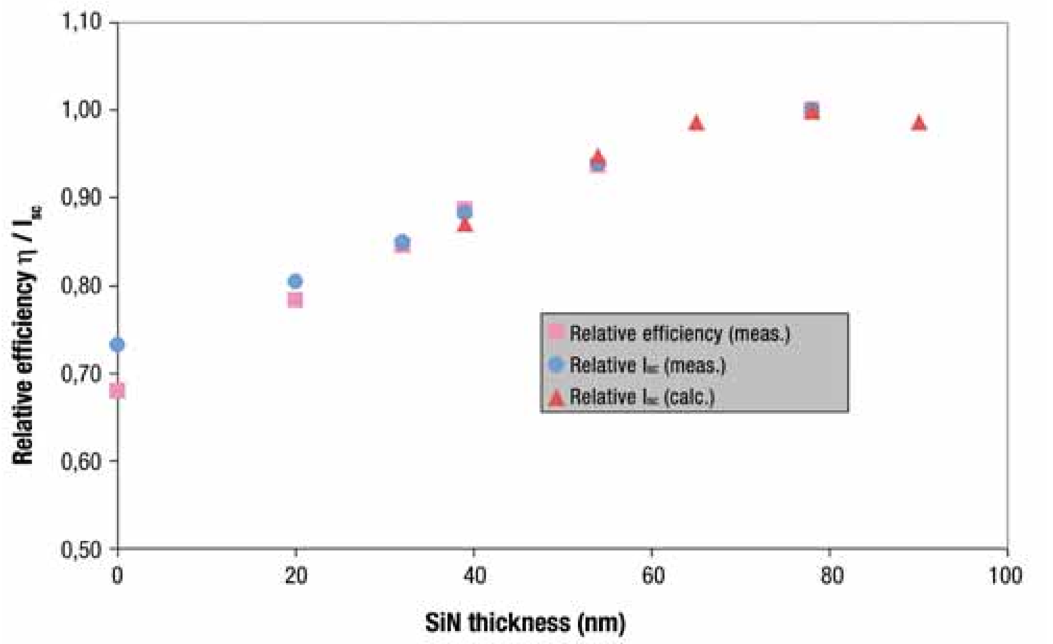


Figure 2. Relative efficiency and short circuit current as a function of SiN thickness. Data are presented in comparison with calculations using PC1D.

[3,4,5]. In this contribution, we will focus on assorted, globally measurable bulk properties of the SiN film and their impact on solar cell performance. We will concentrate mainly on the effect of a change in film thickness – at first glance a very simple parameter that appears to be easily controlled. Its effect can easily be demonstrated; nevertheless the underlying physics are a little more complicated.

Optical properties of thin SiN_x films

It has both been calculated [6] and shown experimentally [7] that for a single layer of antireflection coating, the maximum efficiency of light conversion for the Si/SiN/air stack is obtained at n_{633nm}~1.9 at a thickness of d~85nm, assuming zero or negligible absorption. Currently, most ARC coatings on solar cells are deposited using a slightly higher refractive index accounting for the encapsulation in a module. In most cases, a refractive index of n_{633nm}~2.05 [7] is used today. Considering the low refractive indices of glass and EVA, the optimum refractive index is even higher, which would also be desirable from a point of view of electrical passivation [8]. From Figure 1 it can be noted that the refractive index of an SiN layer is easily adjustable by changing the silicon content of the film, which in turn is achieved by changing the gas ratio between the Si-containing precursor (SiH_4) and the nitrogen-containing precursor (N_2 or NH_3).

> The maximum efficiency of light conversion for the Si/SiN/air stack is obtained at n_{633nm}~1.9 at a thickness of d~85nm, assuming zero or negligible absorption.

In Figure 1, the spectral behaviour of the absorption value k is also given. Films

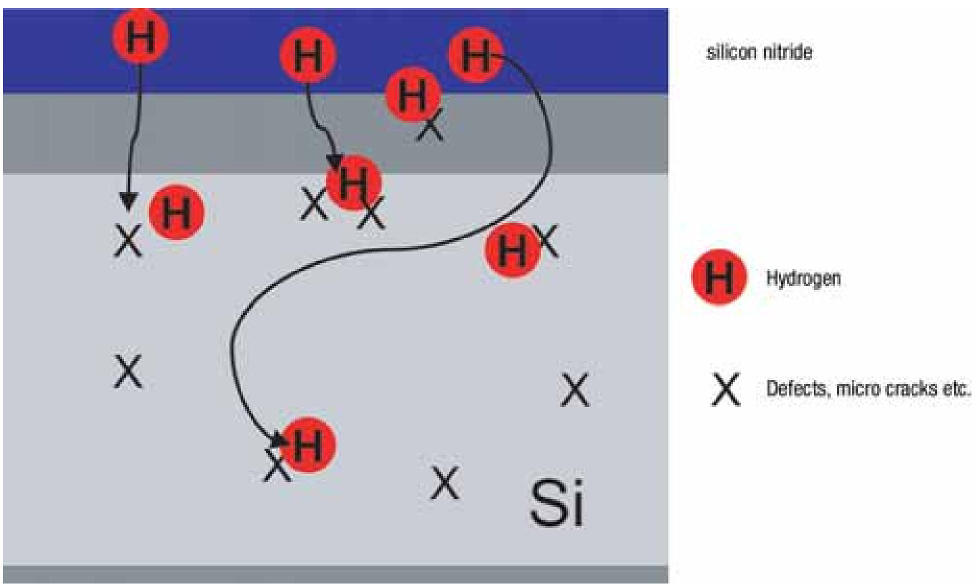


Figure 3. Model showing the effect of hydrogen diffusing to the interface of silicon to SiN and into the bulk of the silicon substrate.

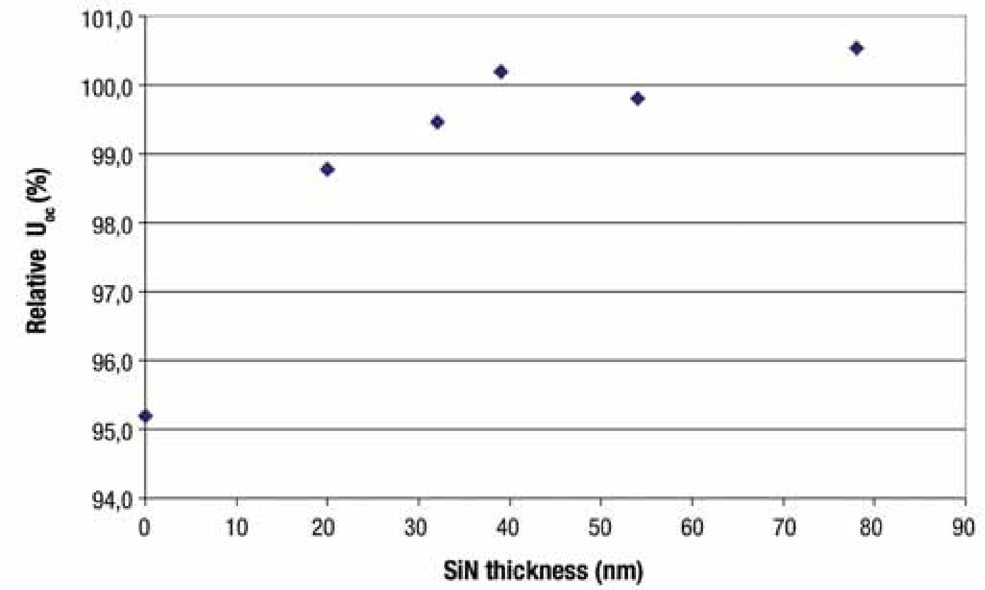


Figure 4. Relative open circuit voltage as a function of SiN thickness.

with low Si content (i.e. low refractive index) can be correctly assumed to exhibit zero or negligible absorption. On increasing the silicon content in the SiN film, the absorption of the film is also increased.

Figure 2 shows the relative efficiency of solar cells and their respective short circuit currents. The data given in Figure 2 has been obtained by preparing solar cells using different metallization procedures taking into account varying sintering properties of the films yielding well-contacted cells. Care was also taken in comparing films with the same refractive indices. Both the relative efficiency and the I_{sc} increase with increasing SiN film thickness to reach a maximum at the desired film thickness. The data obtained by experiments correlate well to calculations using PC1D, the solar cell modelling program.

In order to capture as many photons from the solar spectrum as possible, it is necessary to coat the silicon substrate with a broadband antireflection layer. The basic data for this AR coating can be derived from first principles. For economic reasons, it needs to be a single layer, thus exhibiting a single, broad minimum. Since photovoltaic devices are essentially photon counting systems, it is desirable for the AR coating to have a minimum in the spectral reflectivity at an optical thickness of approximately 650nm. Once the refractive index of the coating is known, the necessary geometrical thickness can be calculated. Assuming no absorption and a refractive index of n~2.05, it is concluded that a geometrical thickness of d~80nm should be deposited. The case is somewhat different in case of a layer exhibiting a gradient of the refractive index with layer thickness, although basic data can be derived in the same way.

Bearing these thoughts in mind, it is clear that the main effect given in Figure 2 stems from increasingly perfect matching of the optical film thickness to the optimum required to yield a broadband antireflection layer. Thus, it is also clear that from a standpoint of a cell manufacturer, utmost care needs to be taken to achieve and control good reproduction of data on a day-to-day basis in both the homogeneity of deposition on a cell as well as in run-to-run. Fortunately, this matches with the need to produce cells and modules with an aesthetically pleasing appearance.

Thus, it is also clear that from a standpoint of a cell manufacturer, utmost care needs to be taken to achieve and control good reproduction of data on a day-to-day basis in both the homogeneity of deposition on a cell as well as in run-to-run.

Silicon nitride is also supposed to be a source of hydrogen to saturate defects and micro fissures in the bulk of the silicon wafer. This process is schematically shown in Figure 3. The silicon nitride deposited on the wafer typically contains approximately 10-15 at. % hydrogen. It is shown by FT-IR that this hydrogen is both bonded to the silicon as Si-H as well as to the nitrogen as N-H.

In order to confirm correlations between the bulk hydrogen content of silicon nitride and the properties of the interface between silicon and nitride, we performed NRRA measurements [9,10] to evaluate a hydrogen depth profile on different parts of a wafer. It was expected that the depth profile of the samples in question would reveal differences in the depth distribution of the hydrogen. Interestingly, there was no clear correlation, a fact that was also observed by Hofmann et al [10]. This result indicates that the bulk properties of the passivating film may not correlate as clearly to properties of the silicon solar cells. On the other hand, this does not rule out a contribution of bulk SiN properties on the passivation of silicon surfaces. More investigation is needed to clarify the role of the SiN layer in passivating silicon solar cells.

The quality of a surface passivation is usually assessed by determining the emitter saturation current j_{oe}. The lower the j_{oe}, the lower the recombination rate of electrons. Assuming that the recombination of electrons is evenly distributed in the solar cell, so the recombination rate is by and large determined by the surface properties. The j_{oe} gives a good estimation of the quality of a surface passivation, which in turn has a direct impact on the open circuit voltage V_{oc}. As it is more difficult to correctly determine j_{oe} than V_{oc}, which is routinely measured together as part of the electrical characteristics of a solar cell, we took this value as associated with the quality of a surface passivation [11]. This assumption is especially justified in experiments in which all other factors (e.g. sheet resistance) determining V_{oc} are kept constant.

In an attempt to assess the influence of the SiN thickness on the passivation quality of the interface between SiN and Si, the V_{oc} data from the same set already discussed in reference to Figure 2 was analyzed. The data shown in Figure 4 indicates that while a minimum thickness of around 25-35nm is required for surface passivation, little or no changes in V_{oc} are noted with increasing film thickness as required by the demands of optical light coupling as discussed previously.

While it appears to be necessary to supply a minimum amount of thickness passivation, there is no clear-cut correlation to solar cell properties with increasing film thickness other than optical optimization.

The data in Figure 4 also explains in a straightforward way the difference between the relative efficiency and the I_{sc} with decreasing film thickness as noted in Figure 2. Thus, we conclude that while it appears to be necessary to supply a minimum amount of thickness passivation, there is no clear-cut correlation to solar cell properties with increasing film thickness other than optical optimization. Hence, the passivating role of hydrogen stemming from the bulk of the SiN film needs to be investigated more closely. Moreover, there is no clear correlation of the amount of hydrogen in the SiN film to the minority carrier lifetimes as measured by µ-PCD. Our data suggests that the properties of the SiN/Si interface with respect to density of surface states' impurities imposed by dangling bonds or crystal mismatch and their saturation by the passivating layer may play a more important role than is commonly assumed. We realize, however, that much more and detailed work needs to be done to clarify the physical principles underlying the interface properties and their respective correlation to solar cell functions.

Summary

Silicon nitride thin films of the stoichiometry $Si_xN_yH_z$ (SiN) are widely used in µc silicon solar cell production. As with most other thin-film applications in any industry, the SiN films serve multiple purposes:

1. They serve as an antireflection layer in order to increase light absorption in the wavelength range where a silicon solar cell can convert light to electricity.
2. The colour of the layer determines the 'look and feel' of the solar cell
3. They serve as a diffusion barrier to impurities like alkali ions and other ambient defects.
4. The hydrogen in the SiN films is assumed to serve as a means of saturating dangling bonds at the surface of the silicon, and also to passivate defect states stemming from microfissures and other mechanical faults deep in the substrate itself.
5. SiN films must allow for sufficient sintering through of the metallic pastes to ensure a reasonable ohmic contact.

We showed in this contribution that with all of the above properties, it is vital for the overall quality of the solar cell that the geometrical and optical film thickness is controlled within strict limits. Any deviation has direct impact on the efficiency of light conversion of the cell. While this may not be a problem on laboratory scale, the sheer volume of production puts forward high demands on the achievable reproducibility of the deposition machines, a feature that is very often underestimated. It is the firm belief of the author that any potentially successful machine concept needs to take reproducibility into account as a key parameter.

The data given in this article further affirms that while application of SiN in µc silicon solar cell production is used very successfully, a lot more work needs to be conducted to clarify the role of the Si/SiN interface, which to a large extent determines the efficiency of the solar cell. In particular, the role of the hydrogen from the SiN film and its effect on the Si surface remains to be investigated in detail.

Acknowledgements

Any work relies on the contribution of several co-workers. To this end, the author is extremely grateful for the work of Martin Hanke and Carsten Swiatkowski of Q-Cells, as well as Dieter Grambole from FZ Rossendorf for the NRRA measurements.

References

[1] Meiners, L. G. 1981, *Journal of Vacuum Science & Technology*, **19** (3), 373.

[2] Hezel, R. & Schörner, R. 1981, *Journal of Applied Physics*, **52** (4), 3076.

[3] Bragnolo, J. A. et al, 12th NREL Workshop on crystalline solar cells, August 2002.

[4] Dekkers, H. F. W. et al, Crystal Clear Workshop, IMEC, November 2005.

[5] Duerinckx, F. & Szlufcik, J. 2002, *Solar Energy Materials and Solar Cells*, 231-246.

[6] Nagel, H. et al, 2nd World conference on photovoltaics, Vienna, 1998.

[7] Schmidt, J. et al, 17th European PV Solar conference, Munich, 2001.

[8] Schmidt, J. et al, 19th European PV Solar conference, Paris, 2004.

[9] Chow, R. et al 1982, *Journal of Applied Physics*, **53** (8), 5630.

[10] Hofmann, M. et al, 22nd European PV Solar conference, Milan, 2007.

[11] Britnar, B., Ph.D. thesis, Konstanz, July 1998.

About the Author

Dr. Hubert-Joachim Frenck studied physics at the University of Münster and took the chair of Prof. Kassing at Kassel to conclude his Ph.D. on 'Molecular engineering in PE-MOCVD thin film deposition' in 1988. The work included the tailoring of silicon nitride precursor molecules to best match the needs of a PECVD process. He has been working in thin-film technology ever since, albeit in various specialist fields. In 1999 he joined Ikarus Solar, where he was responsible for the division fabricating solar selective films for thermal collectors and for developing a range of solar thermal products. He continued this work at Viessmann SA from 2005-07. Dr. Frenck has been with Q-Cells since February 2007 and currently leads the vacuum division of the process development department. Dr. Frenck is married and has two children.

Enquiries

Hubert-Joachim Frenck
Q-Cells AG
Sonnenallee 9-21
D-06766
Bitterfeld-Wolfen
Germany

Email: j.frenck@q-cells.com

Photovoltaics International

The Technology Resource for PV Professionals

The time is now! The economic, technological and political forces are converging to make photovoltaic manufacturing one of the fastest growing and dynamic industries in the world. As fuels for traditional energy supplies dwindle and end consumers become increasingly conscious of their impact on climate change and the environment, the time is now for PV to gain a strong share of the renewable energies marketplace.

Focussing on technology, Photovoltaics International is the only journal specifically designed for the PV supply chain, including materials, components equipment, manufacturing and large-scale utility installation. It is a business-to-business publication that will influence the purchasing decisions of professional PV manufacturers and integrators through independent editorial and high-quality technical articles.

Articles presented in Photovoltaics International are independent and depict actual data and findings for the education of facilities managers, executives and engineers. We will provide coverage of the best and latest developments in the PV manufacturing industry, and present these in a clear, easily navigable format.

Photovoltaics International is free to manufacturers of wafers, cells and modules as well as professionals responsible for creating and installing large-scale solar power plants. Fill in the form below and we will process your request.

Editorial Contributions

Prospective writers are welcome to provide content for technical papers covering the most pertinent issues in the PV industry. All submissions will be reviewed by our experienced editorial team.

Highlights of the next issue:

"Cleaning solutions for efficiency improvement in inline solar cell manufacturing"
by Dr. Jan Bultman from the Energy Research Centre of the Netherlands (ECN), writing with Mallinckrodt Baker.

"Concentrating Photovoltaic Module production developments"
by Pedro Banda, Director General of ISFOC.

"Fab and facility ramp figures for PV manufacturers"
by John Cassell, WTC / iSuppli.

Emerging PV manufacturing markets report