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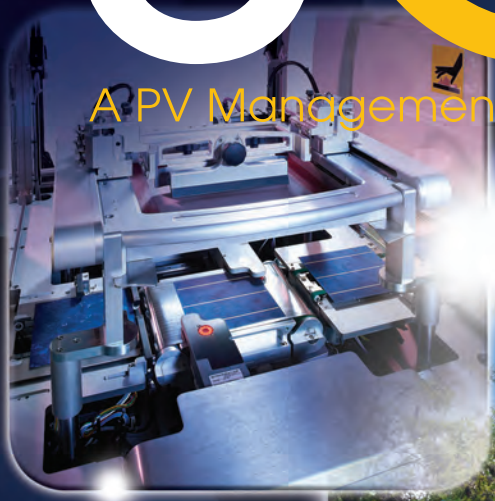
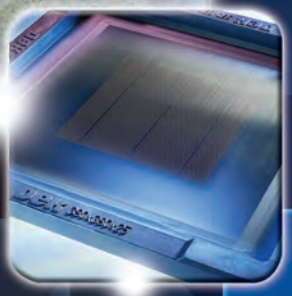
A PV Management Magazine





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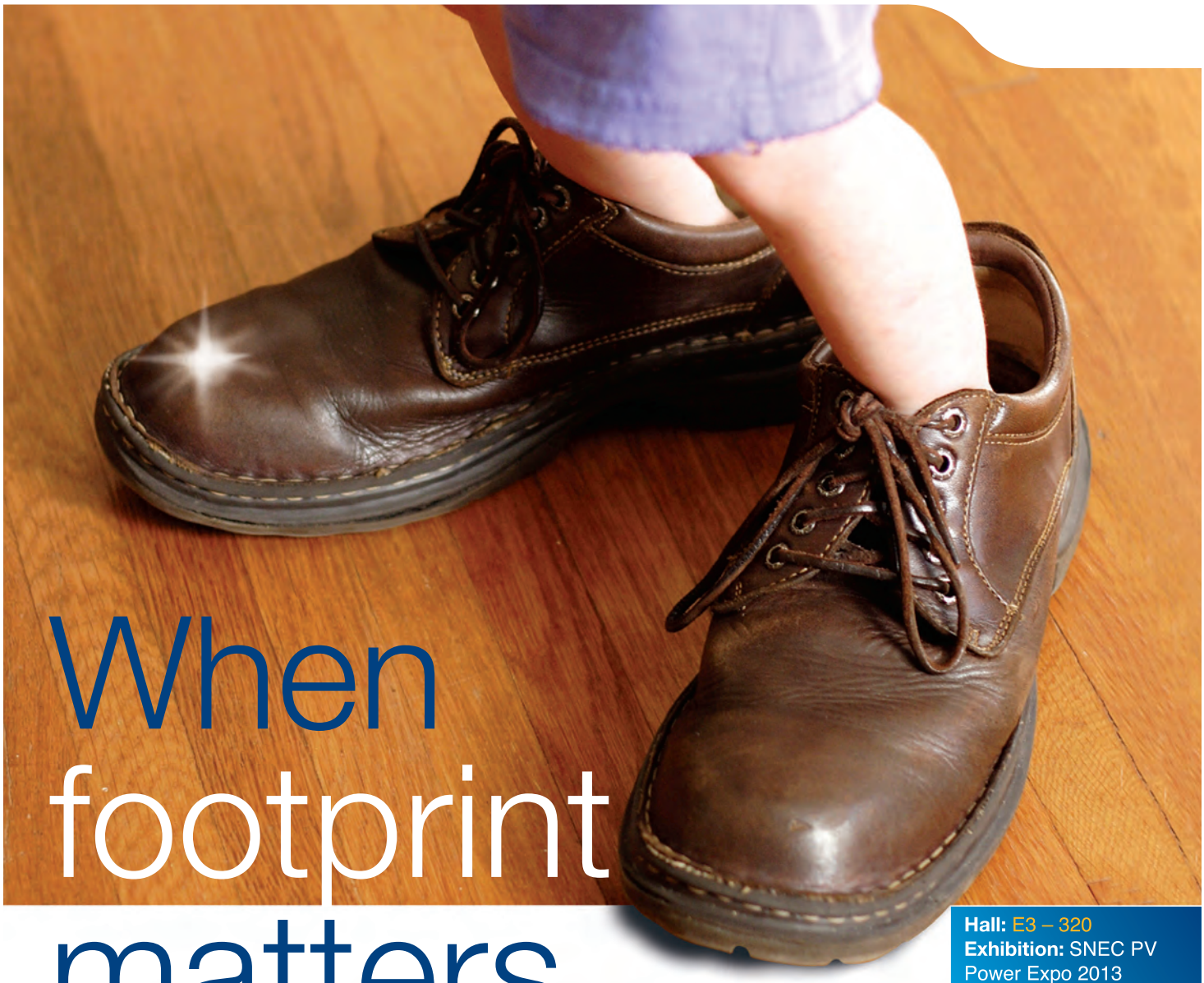

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David Ridsdale
Editor-in-Chief

The crossroads of change

The last twelve months has been very revealing for the global solar and PV industry as market places eject the less fortunate with consolidations, acquisitions and collapses featuring highly on the agenda. This process is occurring in all levels of the global market but each one is at its own point of rapid expansion or reactive contraction. What is fascinating is how each area follows the same pattern refusing to learn from other regions errors. In the long run stable markets are being formed but it is not just the poorly run companies being pushed out of growing market places. Local subsidies tend to instigate the gold rush and over subscription tend to create the reactive backlash. Despite the state of potential confusion there are some patterns that are beginning to emerge that provide some clues to future growth.

A key issue that has emerged is how the instigators of local subsidies deal with rapid growth. In general these are governments creating impetus to kick-start a local market that can assist in meeting global goals in reducing carbon emissions. Once they are announced the industry does rush forward but largely driven by short term financial desires rather than long term sustainable goals. A great deal of hot air is expended as new players try and argue their credentials. It is amazing how many regions fall for the talk of a new player rather than seek the facts that they say they can do. However it occurs every new region wanting to encourage solar expansion finds them with too much activity too fast. This drains planned expenditure and for countries and regions in an austerity mode this is the crossroad of crisis. A key factor has emerged for the more successful longer-term response. Whoever has retrospectively changed their tariff conditions has found little respect and less inclination to fund future expansions.

Some markets do not have to concern themselves with this as their markets will grow with those that are left but in newer markets at a time of global consolidation it is a higher risk. Recent times have shown that size is no obstacle to market forces and the PV industry has grown faster than financial expectations. It is still the market that determines growth and there has been a need for the market to reassert itself. To achieve this and restore the industry to a more reasonable level there must be losses and we are currently seeing this dynamic being played out. While it may look terrible there are key factors that point to a more positive longer-term position. The most obvious has been that the overall market has grown. Yes there are blips and glitches at a local level but the global figures show growth and this will continue as solar and other renewables continue to form a firm foundation for future energy needs.

Of course the other issues affecting the industry are also outside the industry's control even if they begin within. There as been a continued rash of trade concerns placed on China's doorsteps and the outcomes of these disputes will determine the course for many solar and PV companies and markets. June sees the expected decision from the European Union on anti-dumping claims against the growing might of China. Make no mistake the USA decision was only a Hors d'oeuvre compared to the potential cost of this main course. With rumours abounding that a deal will be cut to ensure there are no trade wars we can only wait and see. The industry may be at a cross roads but the way China deals with the rest of the world is also in question at this time.

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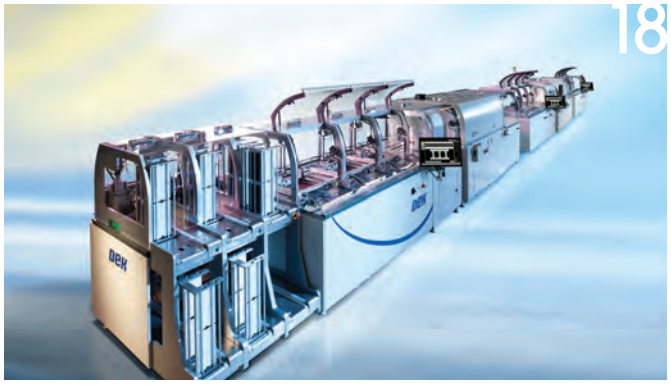

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EU launches investigation into Chinese solar glass

THE EUROPEAN COMMISSION has initiated an anti-subsidy investigation into imports of solar glass from China. The initiation is based on a complaint lodged by the association EU ProSun Glass, which claims solar glass from China is being subsidised in China and then sold in the EU at prices below market value and causing material injury to the EU solar glass industry. An anti-dumping investigation into imports of solar glass from China is currently ongoing. This proceeding was initiated on 28 February 2013.

The anti-subsidy investigation could take up to 13 months, although under trade defence rules the EU could impose provisional anti-subsidy duties within nine months if it considers these necessary. Solar glass is a special glass used mainly, but not exclusively, for the production of solar panels. It is an essential component not just of solar panels, but of many solar energy products.

This investigation has, however, no direct link with the probe related to the imports of solar panels launched by the European Commission last September (MEMO/12/647): it is a stand-alone investigation concerning a clearly distinct product. The EU solar glass market is valued at less than €200m.

Why is the European Commission opening this investigation?
The Commission is legally obliged to open an anti-subsidy investigation when it receives a duly substantiated complaint from EU producers which provides prima facie evidence that exporting producers from one or more countries outside the EU are subsidising a product which is then sold on to the EU market and causing material injury to the EU industry.

EU ProSun Glass, an ad hoc association representing European solar glass manufacturers, lodged just such an anti-subsidy complaint on 14 March 2013 in which it argues that the Chinese exporting producers of solar glass have benefited from a number of subsidies granted by the Government of China. EU ProSun Glass's collective output represents considerably more than the 25% of Union production required by law. EU ProSun Glass is not formally affiliated with EU ProSun, a separate coalition of solar equipment manufacturers which launched the solar panel complaint last year.

The Commission found that the complainant brought sufficient elements showing:
possible subsidies benefiting the exporting producers in China;
injury suffered by the Union industry; and
a possible causal link between the subsidised imports and the injury suffered by the Union industry.

The Commission concluded that there was sufficient prima facie evidence to warrant the opening of an investigation. The European Commission will send out questionnaires to various interested parties, such as exporting producers, Union producers, importers and associations. It will ask for information relating to the exports, production, sales and imports of solar glass. Once the interested parties have responded to the questionnaires, the Commission will verify the data, often by going to the premises of the companies.

On the basis of the information it has collected, the Commission will establish if subsidisation has taken place and whether the injury claimed is a result of the subsidised imports. This examination will also include consider possible other factors that might have contributed to the injury.

In addition, the Commission will carry out the so-called "Union interest test". The EU is the only WTO Member to systematically carry out such tests. The Commission will consider whether the potential imposition of measures would be more costly to the EU economy as a whole than the benefit of the measures would be to the complainants. The Commission will assess the level of duty needed to counteract the injurious effects of the subsidy. Measures, if any, will be imposed at the level of subsidy or injury whichever is the lower – the so-called 'lesser duty rule.' By systematically applying the 'lesser duty rule', the EU goes beyond its WTO obligations. Within nine months of the start of the investigation, the Commission will issue its provisional findings.

There are three possible scenarios:
impose provisional anti-subsidy duties (normally for a four months period);
continue the investigation without imposing provisional duties; or
terminate the investigation.

Throughout the investigation, all interested parties have a right to make their views and arguments heard by sending in comments to the Commission and/or taking part in hearings. The Commission takes account of the comments received and addresses these in the remainder of the investigation. The Council is legally obliged to take a final decision on the imposition of any definitive measures within 13 months of the investigation being started. In the present case, that means before 26 May 2014. The final findings will be published in the Official Journal of the European Union.

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Yingli becomes number one global supplier

YINGLI FROM CHINA became the largest global supplier of PV modules in 2012 based on annual merchant shipments, while previous leader and besieged fellow Chinese producer Suntech Power dropped to fifth place, according to IHS.

In a year that proved very challenging for the entire PV industry, Yingli managed to increase its merchant shipment volumes by 43 percent year-over-year to leapfrog Suntech as well as U.S.-based First Solar, the two largest suppliers of 2011.

First Solar managed to defend its position as the No. 2 module manufacturer, while Suntech lost significant ground and was displaced to fifth position behind Trina Solar and Canadian Solar. REC, the only Top 10 supplier headquartered in Europe, grew faster than most of its Chinese competitors in 2012. Increasing its module shipments by 31 percent year-over-year to 757 megawatts (MW), REC strengthened its position as a leading player in a highly competitive environment.

Although the PV industry is consolidating and many players have exited the business, many of the Top 10 module suppliers lost market share in 2012. While the Top 10 in 2011 had accounted for 46% of global module shipments, the group last year only achieved a combined share of 40 percent.

"Canadian Solar, as well as Jinko Solar and Hanwha SolarOne were the only Top 10 companies that managed to grow merchant module shipments at a double-digit rate in 2012—in addition to Yingli and REC, of course," explained Stefan de Haan, principal analyst for solar at IHS. "SunPower and Trina grew at a slower pace, while Suntech, First Solar and Sharp from Japan saw declining shipment volumes. Global PV end markets increased by a robust 14 % in 2012 so suppliers effectively lost some ground."

The fall of debt-burdened Suntech had become apparent by the third quarter last year, when the company closed factories and cut production significantly. On March 20, 2013, the manufacturing unit of the company announced insolvency. According to the IHS Q1 PV Integrated Market Tracker, the entities gaining share from the Top 10 companies were the large, but not leading, players who scaled up their operations during a phase of general pessimism.

"Japanese suppliers Solar Frontier and Kyocera expanded output and shipments massively in 2012, and both benefited from the current boom in Japan," de Haan added.

Strong performance was also recorded for Chinese suppliers Renesola, Astronergy, Hareon Solar, and JA Solar, increasing module shipments by more than 200 MW for each in 2012. Until 2011 it was sufficient for the leading module suppliers to focus on very few key markets in the world—above all on Germany and Italy—in order to maintain a successful business. However, this situation has changed.

Yingli generated 24 percent of its 2012 revenue in China. Jinko is another winner in this market, shipping approximately 400 MW to China alone in 2012 while also building up a strong presence in South Africa. For its part, Canadian Solar generated 26 percent of 2012 sales in the U.S. market and is also one of the strongest imported brands in Japan. Leading U.S. supplier First Solar, on the other hand, is anchoring itself to the Latin America market with the acquisition of a Chilean-based developer and its portfolio. These are a few examples highlighting the importance of timely and appropriate reaction for PV suppliers in a rapidly changing environment.

China reaction dictates market

SEASONALITY and policy incentive deadlines from the end-market in China drove global solar photovoltaic (PV) demand down to 6.2 gigawatts (GW) in 1Q'13, down 23% Q/Q. Over the next four quarters, China will account for more than 20% of global PV market demand, ranging between 0.9 and 3.6 GW, according to the NPD Solarbuzz Quarterly report, but its volatile PV demand cycles will create new supply challenges for leading PV manufacturers.

"Chinese solar PV demand was the key global driver at the end of 2012, which helped to deplete upstream inventory levels that had accumulated over previous quarters," said Michael Barker, senior analyst at NPD Solarbuzz. "However, extreme swings in PV demand from China over the next year will make capacity utilization and inventory control particularly challenging. At the same time, demand from other global PV markets is beginning to offer predictable quarterly demand levels that are essential for long-term planning."

Germany, Italy, France, and the UK will lead demand in Europe over the next four quarters, accounting for over 65% of regional PV demand. European solar PV demand will no longer be dominated by policy deadlines, so demand in that region will be relatively flat Q/Q. Over the next four quarters, demand from European end-markets is expected to range from 2.7 to 3.2 GW.

PV demand outside China and Europe will be driven by the U.S. and Japan, which exhibit different phases of demand. The Japanese market is strongest during the first half of the year and the U.S. market is strongest during the second half. Combined with new demand from the emerging PV markets, such as the Middle East and Southeast Asia, this ROW group will provide stable PV demand over the next four quarters, ranging from 2.5 to 3.6 GW each quarter.

ABB and Power-One merge

ABB AND POWER-ONE have announced that their boards of directors have agreed to a transaction in which ABB will acquire Power-One for $6.35 per share in cash or $1,028 million equity value. This will create the largest inverter company for the global solar market. The transaction would position ABB as a leading global supplier of solar inverters to a market forecasted by the International Energy Agency to grow by more than 10 percent per year until 2021. This rapid growth is being driven by rising energy demand, especially in emerging markets, rising electricity prices and declining costs.

"Solar PV is becoming a major force reshaping the future energy mix because it is rapidly closing in on grid parity," said ABB's CEO, Joe Hogan. "The combination of Power-One and ABB is fully in line with our 2015 strategy and would create a global player with the scale to compete successfully and create value for customers, employees and shareholders."

Power-One has one of the market's most comprehensive offerings of solar inverters, ranging from residential to utility applications, and a broad global manufacturing footprint. It also has a power solutions portfolio that is adjacent to ABB's power conversion business. Power-One employs almost 3,300 people, mainly in China, Italy, the US and Slovakia. In 2012, it generated $120 million in earnings before interest, taxes, depreciation and amortization (EBITDA) on sales of approximately $1 billion.

"This transaction delivers significant value to our shareholders and will enable Power-One to accelerate its growth," said Richard J. Thompson, CEO of Power-One. "Together we can better address the growing worldwide demand for innovative, renewable energy solutions and strengthen our global leadership. I believe ABB is the right partner and now is the ideal time for our companies to join forces."

ABB's portfolio in power and automation, global footprint and service organization make it a natural player in solar PV. For many years ABB has brought its solutions to the solar PV industry and is on track to generate sales of more than $100 million in solar inverters in 2013.

Solar inverters are one of the fastest-developing technologies in power electronics, requiring substantial research and development (R&D) resources. In 2012, ABB invested about $1.5 billion in R&D overall.

"The combination of these two successful companies will create significant value-driven growth based on innovation – which means inverters offer opportunities for differentiation – global reach, high quality and technology leadership," said

Ulrich Spiesshofer, head of ABB's Discrete Automation and Motion division, into which Power-One will be integrated. "The acquisition supports the implementation of the division's strategy for renewable energy and the goal to build on our strength in power electronics."

The transaction is structured as a merger and is subject to the satisfaction of customary closing conditions, including approval of Power One's shareholders at a special meeting and receipt of customary regulatory approvals.

The merger agreement contains certain agreed deal protection mechanisms. Investment funds affiliated with Silver Lake Sumeru have entered into an agreement to vote in favor of the transaction. The transaction is expected to close in the second half of 2013. ABB will finance the transaction out of its own funds.

LDK secures investment

FINANCIALLY beleaguered LDK Solar has announced that it has secured an investor to help secure its future. The company announced that it has entered into a share purchase agreement dated April 25, 2013 with Fulai Investments Limited, which has agreed to purchase additional 25,000,000 newly issued ordinary shares of LDK Solar, at a purchase price of US$1.03 per share with an aggregate purchase price of US$25,750,000, subject to the terms and conditions of the share purchase agreement, including a lock-up for 180 days from the closing date of the contemplated transactions. The share purchase price reflects an 8% discount to the 5-day average share price.

Pursuant to the share purchase agreement, the parties will endeavor to fulfill the closing conditions to consummate the transactions prior to June 28, 2013.

Fulai Investments has agreed to pay LDK Solar in two installments prior to the closing: the first in May for US$15,000,000 and the second in June for US$10,750,000. Fulai Investments also has the right to designate two non-

executive directors to the LDK Solar board upon consummation of the transaction. The net proceeds will be used for general corporate purposes in LDK Solar's operations

Europe declining in growing global capacity

GLOBAL PHOTOVOLTAIC (PV) installations are forecast to exceed 35 gigawatts (GW) in 2013, equivalent to growth of 12 percent, according to recently released analysis from IHS. IHS also reaffirmed its earlier prediction that global PV installations surpassed 30 GW in 2012, with final analysis showing that installations, in fact, grew 14 percent to reach 31.4 GW last year.

These findings and the latest PV demand projections for 2013 and beyond were recently issued by the IHS solar team, which comprises analysts from the IHS acquisitions of IMS Research, iSuppli, and Emerging Energy Research. Contrary to many other more pessimistic predictions for the industry, IHS foresees the PV industry to continue along its double-digit growth path in 2013 and to exceed 35 GW for the first time.

"We often see quite pessimistic forecasts at the start of each year for PV installations, due to a seasonal slowdown and talks of major incentive cuts as Europe reassesses its PV policy typically after yet another year of record growth," said Ash Sharma, senior director of solar research at IHS. "However, our analysis of more than 60 countries around the world shows that demand outside of Europe will more than compensate for the fall in the Continent, and installations will go on at any rate to hit 35 GW this year."

Asia surged in the fourth quarter of 2012 and installed more than 4 GW during the period, an amount close to half the global total. Asia' importance to the global PV market is predicted to continue, according to IHS, and Asia in 2013 will become the largest region for PV installations for the first time in 10 years. PV installations in Asia are forecast to grow to 15 GW this year, in the process exceeding Europe, which is predicted to drop to 13 GW. For the China market, however, IHS is less optimistic than others on likely installations for that country this year:

"We predict China will install at least 6 GW of new PV capacity this year," noted Sharma. "This is some way lower than the 10 GW figure that has been widely circulated around the industry as China's target for 2013. The continued issue of grid-connecting megawatt-scale PV projects, as well as delays in developers receiving FIT payments, is likely to hold back China from installing more this year. Even so, a dwindling European market and restrictions on Chinese modules could well drive higher domestic installations."

Although IHS confirmed that global PV installations surged past 31 GW last year, its analysis showed that grid-connected PV capacity was actually lower than 30 GW.

"When analyzing PV demand, some people talk of installations while others talk of connections. This often causes confusion, and so IHS tracks both to fully understand the market dynamics," Sharma noted. "Connections were lower in 2012 than installations, owing to lengthy delays in connecting major projects in countries such as China and India. For instance, up to 2.5 GW of PV projects were completed but not connected to the grid at the end of 2012 in China".

While Europe accounted for 70 percent of PV installations in 2011, IHS found that this fell to 57 percent in 2012 and is predicted to slide further to 37 percent in 2013, especially as the region becomes outflanked by Asia. Almost all of Europe's so-called mature PV markets are predicted to decline in 2013—a development forecast to take place despite bright spots of growth in countries such as the U.K., Turkey and the Netherlands. As a result, IHS predicts that installations in Europe will fall from 18 GW in 2012 to 13 GW in 2013.

"While hopes in the past could have been pinned on Germany or Italy—which accounted for nearly two-thirds of European installations in 2012—growth here looks impossible," Sharma said. "Changes to Germany's EEG and Italy's Conto Energia are already in place, and a contraction in these two big markets is predicted in 2013. Moreover, looming antidumping measures against Chinese manufacturers are taking their toll on Europe, resulting in price increases and additional registration paperwork that will further temper solar demand this year."

Despite Europe's dramatic decline in 2013, IHS maintains that double-digit growth will occur again in global installations. Growth rates of 250%, 50% and 65% are forecast for Middle-East & Africa, Americas, and Asia respectively, supporting global growth, but continuing the industry's geographic fragmentation.

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Bosch announces complete solar withdrawal

BOSCH is to discontinue its activities in crystalline photovoltaics. Bosch's manufacture of ingots, wafers, cells, and modules will be ceased at beginning of 2014. As far as possible, individual units are to be sold quickly. All development and marketing activities are likewise to be ended. The module plant in Vénissieux, France, is to be sold. Plans to construct a manufacturing facility in Malaysia will be ended. Bosch plans to sell its shares in aleo solar AG. Bosch Solar CISTech GmbH in Brandenburg, Germany, will be continued – as before – as a development center for thin-film technology. Its future alignment will be decided at a later date.

Over the past years, Bosch Solar Energy has tried unsuccessfully to achieve a competitive position. Due to global overcapacity, which has since become huge, nearly the entire industry is sustaining heavy losses. Dr. Stefan Hartung, the chairman of the Bosch Solar Energy AG supervisory board and member of the Robert Bosch GmbH management board responsible for the Energy and Building Technology business sector, sums up the situation as follows: "Despite extensive measures to reduce manufacturing cost over the past year, we were unable to offset the drop in prices, which was as much as 40 percent." As announced in January 2013, the losses of the Solar Energy division came to some one billion euros last year. The division currently employs some 3,000 associates, roughly 850 of them at aleo solar AG and some 150 at CISTech.

"Over recent months, Bosch has comprehensively examined every aspect of its solar business. We have considered the latest technological advances, cost-reduction potential, and strategic alignment. And there have also been talks with potential partners. However, none of these possibilities resulted in a solution for the Solar Energy division that would be economically viable over the long term. We deeply regret this," said Dr. Volkmar Denner, the chairman of the Bosch board of management. Stefan Hartung added: "We know full well that associates face a difficult time. Together with the employee representatives, we will search for solutions that are as acceptable as possible. We appreciate the hard work done by our Solar Energy associates. Over the past year, our associates have fought hard for the future of their division. For this, we owe them our thanks. Nonetheless, our joint efforts to achieve long-term economic stability failed to bear fruit."

Effective April 1, 2013, the supervisory board of Bosch Solar Energy AG has appointed Dr. Steffen Haack chairman of the management board, with responsibility for sales and technology. In addition, Franc Gruber has been appointed the management board member responsible for commercial affairs. Haack has been the management board member responsible for sales since August 1, 2012. Gruber has worked for Bosch in various executive commercial functions within and outside Germany since January 1, 2000, most recently in the corporate controlling department.

The present chairman of the board of management of Bosch Solar Energy AG, Holger von Hebel, and the management board members Dr. Volker Nadenau and Jürgen Pressl will resign from the company board of management effective March 31, 2013.

Commenting on these changes, Stefan Hartung said: "In Steffen Haack and Franc Gruber, we have experienced board members who will initiate the steps that are now necessary and see them through to completion.

Sharp's triple junction success

SHARP CORPORATION has achieved the world's highest solar cell conversion efficiency of 37.9% using a triple-junction compound solar cell in which three photo-absorption layers are stacked together.

Sharp achieved this latest breakthrough as a result of a research and development initiative promoted by Japan's New Energy and Industrial Technology Development Organization (NEDO) on the theme of "R&D on Innovative Solar Cells."

Measurement of the value of 37.9%, which sets a new record for the world's highest conversion efficiency, was confirmed at the National Institute of Advanced Industrial Science and Technology (AIST).

Compound solar cells utilize photo-absorption layers made from compounds consisting of two or more elements, such as indium and gallium.

The basic structure of this latest triple-junction compound solar cell uses proprietary Sharp technology that enables efficient stacking of the three photo-absorption layers, with InGaAs (indium gallium arsenide) as the bottom layer.

By optimizing the relative proportions of indium, gallium, and arsenide, Sharp succeeded in increasing the efficiency with which the cell absorbs sunlight at its various wavelengths.

This improvement enabled Sharp to achieve the world's highest solar cell conversion efficiency of 37.9%.

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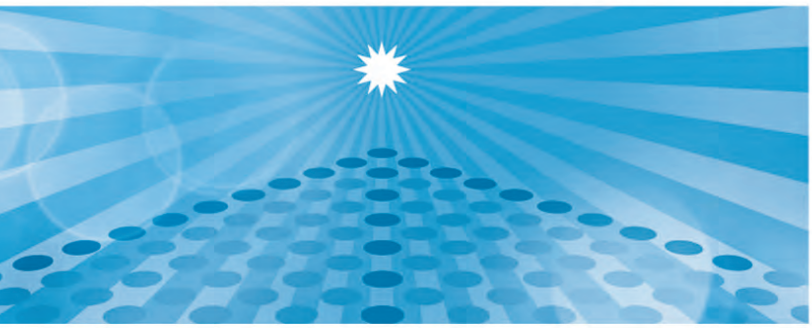

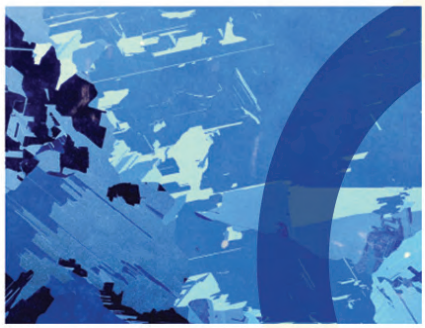

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PV Group advances PV manufacturing standards, connects PV supply chain stakeholders, and advocates our members' interests on global opportunities, shared challenges and critical manufacturing issues that impact innovation, promote investment, and growth in the solar market. Today, PV Group serves the global PV manufacturing supply chain with an international network of trade events, international standards development, public policy initiatives, research, and information that work together to expand opportunities in solar energy for our members and contribute to the overall growth of the industry.

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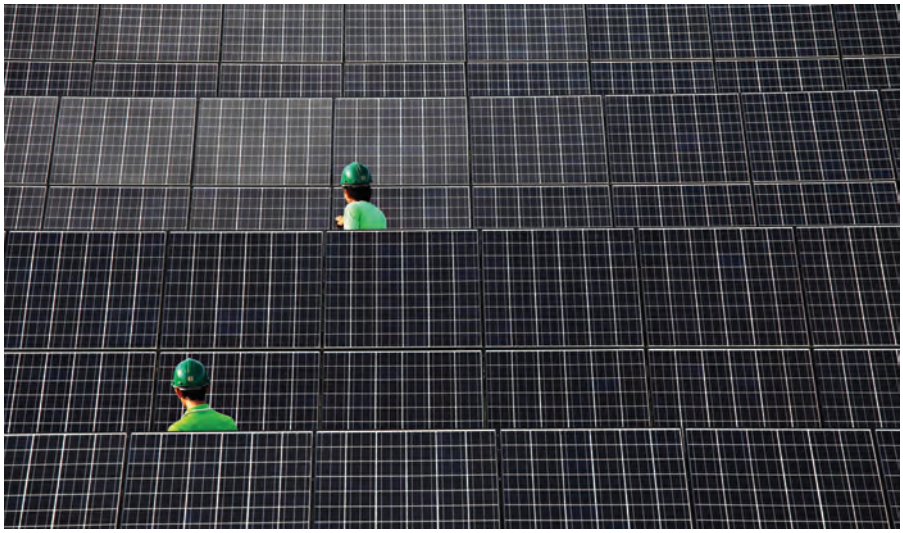
Work begins on world's largest solar farm

MIDAMERICAN SOLAR and SunPower Corp.have marked the start of major construction at the Antelope Valley Solar Projects – two projects co-located in Kern and Los Angeles counties in California – with a community celebration. The 579-megawatt development will employ approximately 650 workers during a three-year construction period; generate more than $500 million in regional economic impact, the majority of which will be generated during construction; and serve California's growing electricity demand with clean, renewable solar power.



The Antelope Valley Solar Projects make up the world's largest solar power development under construction. When complete, the projects will provide enough energy to power approximately 400,000 average California homes.

"The Antelope Valley Solar Projects are already creating needed jobs and economic opportunity in local communities, while at the same time, providing direct, long-term environmental benefits," said Paul Caudill, president of MidAmerican Solar. "We look forward to continuing our involvement in the Rosamond, Lancaster and Palmdale communities and, as we move forward, in the surrounding areas. The MidAmerican Solar team is committed to working hand-in-hand with the development's neighbors and stakeholders. We also look forward to providing a reliable source of renewable energy to our customer Southern California Edison."

"The start of construction on the Antelope Valley Solar Projects underscores that solar is a reliable, cost-competitive energy source," said Howard Wenger, SunPower president, regions. "SunPower is proud to partner with MidAmerican Solar and Southern California Edison on this historic project, which is bringing critically needed jobs and economic opportunity to California today and will generate abundant clean, renewable power to the state over the long term."

The Antelope Valley Solar Projects are owned by MidAmerican Solar. SunPower designed and developed the projects and is the engineering, procurement and construction contractor. SunPower also will provide operations and maintenance services for the plants via a multiyear services agreement.

The Antelope Valley Solar Projects will provide renewable energy to Southern California Edison under two long-term power purchase contracts.

"Southern California Edison appreciates the opportunity to work with MidAmerican Solar and SunPower to meet California's renewable energy goals and recognizes the start of construction as an important step on that path," said Steven Eisenberg, Southern California Edison's vice president of energy contracts.

At the 3,230-acre site, SunPower is installing the SunPower Oasis Power Plant product, fully integrated, modular solar technology that is engineered to rapidly deploy utility-scale solar projects while minimizing land use. The Oasis product uses high-efficiency SunPower solar panels mounted on SunPower T0 Trackers, which position the panels to track the sun during the day, increasing energy capture by up to 25 percent. Construction began in January 2013 and is expected to be complete by year-end 2015.

Electricity generated by the projects will displace approximately 775,000 metric tons of carbon dioxide per year – the equivalent of taking approximately 3 million cars off the road over the next 20 years.

MidAmerican Solar and SunPower representatives hosted today's community picnic and celebration at the project site west of Rosamond.

PV storage market set to explode

THE WORLDWIDE MARKET for PV storage is forecast to grow rapidly to reach $19 billion in 2017, from less than $200 million in 2012, according to a new report entitled 'The Role of Energy Storage in the PV Industry' from IMS Research, now part of IHS Inc. Following the introduction of an energy storage subsidy in Germany, global installations of PV storage systems are forecast to grow by more than 100 percent a year on average over the next five years, to reach almost 7GW in 2017 and worth $19 billion.

Germany will account for nearly 70 percent of storage installed in residential PV systems worldwide in 2013. However, opportunities also will exist in other regions and applications in the future and Germany's share of the global market naturally will fall as a result.

Subsidy to accelerate growth in Germany

GERMANY'S long-awaited subsidy for PV storage systems is due to launch on May 1st. IHS predicts that the subsidy will promote rapid growth in the German residential sector, and result in almost 2 gigawatt-hours (GWh) of effective storage capacity being installed during the next five years.

"Because domestic electricity rates now significantly exceed residential feed-in tariff rates, there is strong interest in increasing self-consumption in residential PV systems to maximize the financial return of the system," said Sam Wilkinson, PV analyst at IHS. "As a result, 8MW of PV systems were already installed with storage in Germany in 2012, prior to the subsidy being released. The introduction of the widely anticipated subsidy will quickly accelerate uptake by making the lifetime cost of PV systems with storage cheaper compared to those without it."

Although the rates are not confirmed yet, the proposed subsidy will reduce the average 20-year cost of a PV system with storage to 10 percent less than a system without it. Previously, the high cost of batteries had more than offset the savings created by increased self-consumption, and PV systems without storage offered a more attractive return.

Will other countries follow Germany's lead again?

While Germany is forecast to remain one of the largest markets for PV storage, energy storage solutions will also be deployed in a wide range of other regions, the report found. Germany was the pioneer of the FiT for PV systems and along with Japan initially drove the PV market's development.

As the first country to introduce a subsidy for PV storage, Germany will inspire other countries to follow suit, if the scheme proves successful, IHS expects.

"We do expect that other countries will follow Germany's example and adopt similar subsidy schemes to promote the use of PV energy storage—particularly in a case promoting self-consumption and grid stability," Wilkinson said. "Even without subsidies storage can be an attractive proposition in conjunction with residential PV systems in some markets, such as the U.K., where the market is forecast to begin growing quickly in 2014, when the price of batteries is predicted to have fallen sufficiently to make PV storage financially viable."

Storage is also predicted to be used in larger systems, in order to improve the integration of PV into the grid, increase the financial return of PV systems and meet the increasingly demanding connection requirements that some countries are imposing on intermittent electricity sources like PV.

Amonix claims new record for module efficiency

CPV MANUFACTURER Amonix Inc. has announced that it has successfully converted more than 36% of direct sunlight into electricity. A module showcasing Amonix's latest-generation CPV technology has been in outdoor testing from late February to April of this year.

During this period, the Amonix module demonstrated a peak operating efficiency of 36.2% measured on March 14, 2013 with a DNI of 876 W/m2, an ambient temperature of 16°C and instantaneous wind speed of 1 m/s, breaking the previous 34.2% peak efficiency set by Amonix in May 2012.

Over the entire testing period, the Amonix module earned a National Renewable Energy Laboratory (NREL) outdoor efficiency rating of 34.9%, a new world record, under international standard

operating conditions for concentrator photovoltaics of 900 W/m2, 20°C ambient temperature and 2m/s wind speed, breaking the previous 33.5% rated efficiency record also set by Amonix in May 2012.

The module uses Boeing Spectrolab 40% high efficiency solar cells and Amonix's proprietary CPV technology to achieve world record performance.

This result continues Amonix's long history of leading the world in solar module efficiency, having been the first to convert over 1/3rd of the sun's energy in May 2012, and the first to break 30% module efficiency in 2011.

"Amonix's proprietary technology platform allows us to continue driving rapid performance improvements in our CPV system," said Vahan Garboushian, Amonix Founder and CTO. "The advances we have demonstrated over the last 2 years have all been with the same generation 40% cells, demonstrating an unprecedented cell to module conversion efficiency of greater than 90%.

With improvements that are underway in cell efficiency and additional advances in our module technology, we expect that we will continue to drive efficiency higher over the coming years."

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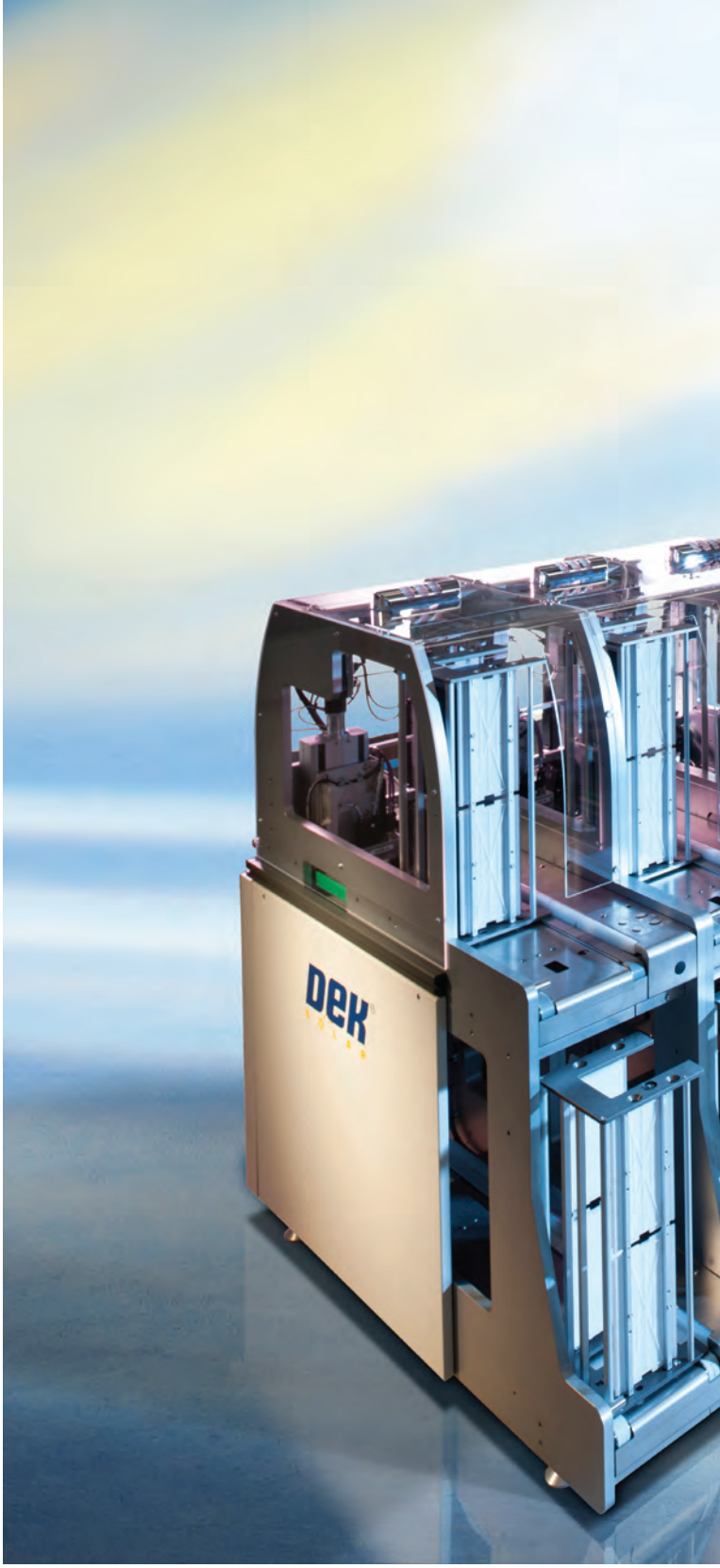
Delivering solar cost leadership:

New state-of-the art technology centre in Suzhou

On 17 May, cell manufacturers, Chinese dignitaries and media will have a first look at DEK's new, state-of-the-art technology centre for the solar industry in Suzhou, China. This research hub will be the centre of innovative process optimisation and technology developments enabling DEK customers to become cost leaders, and benefiting the wider solar industry for years to come.



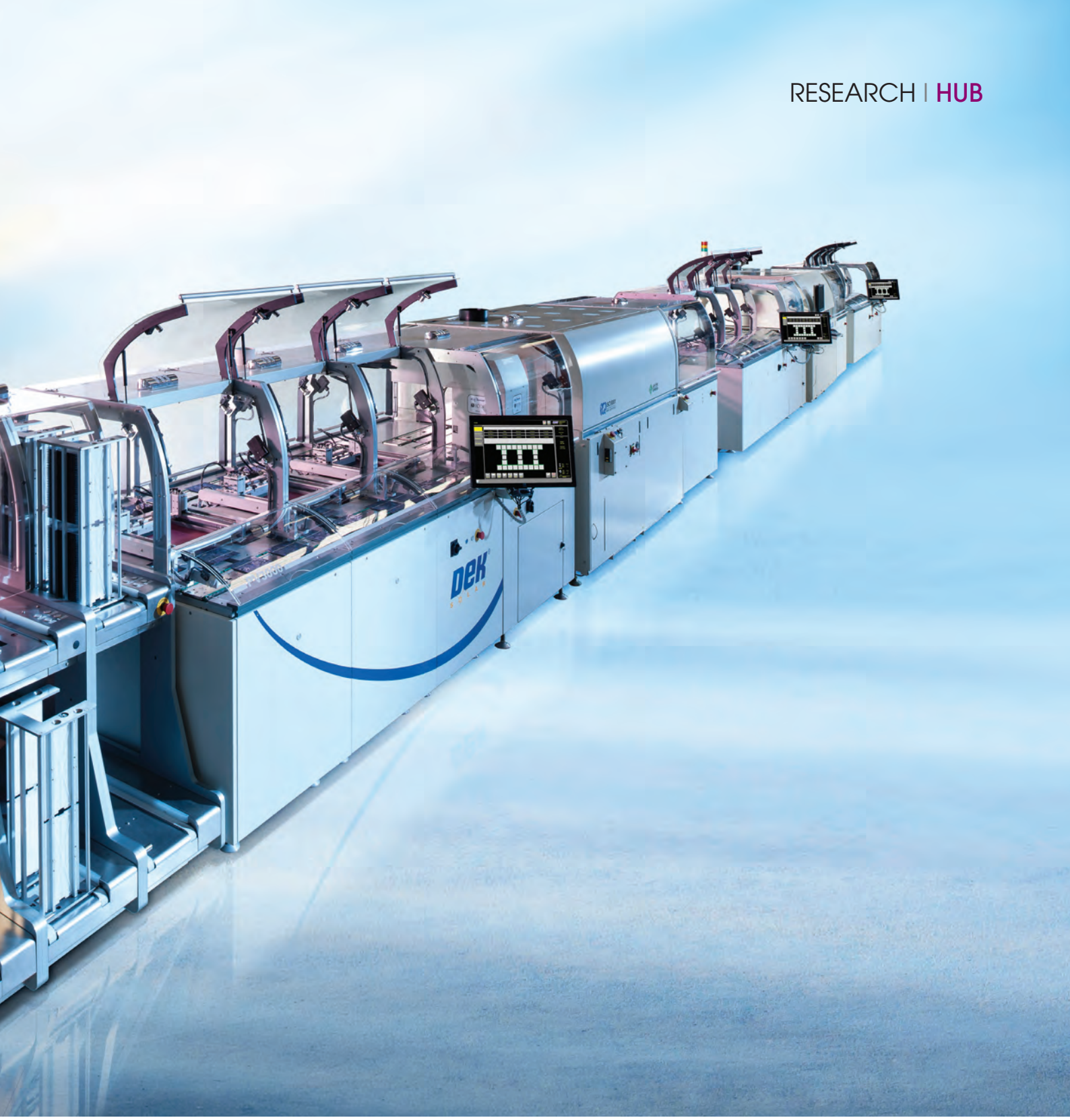
To some, now may seem like an inopportune time to be investing in such a facility. However, even in a PV market with excess capacity, cell manufacturers who are cost leaders reap the benefits. Being a cost leader does not necessitate being the lowest quality supplier; instead, it is about being the firm which is able to deliver the required quality at the lowest cost.

There are benefits to achieving such financial efficiencies no matter what the broader economic outlook. In tough times it supports price flexibility and in good times margins increase.

Furthermore, there is mounting evidence that the solar industry is poised for an upturn. Solar power is forecast to grow significantly as a percentage of overall electricity generation capacity by 2035. In the short term, total PV demand by the end of 2013 is forecast to be in the region of 33GW, representing growth of 8% on 2012. Given these long-term growth prospects and the more immediate expected resurgence in demand, the time for solar cell manufacturers to be investing in their production lines is now.

Why Suzhou

As a $1 million investment and DEK Solar's first research facility in China, the Suzhou Technology Centre marks a significant step forward for the company and reflects its commitment to the sector and region.



DEK already has sales teams of significant size located within South East Asia and China. However, with 80% of all solar cells currently being produced in China and the country expected to outpace Germany in 2013 to become the leading PV consumer worldwide, having a technology hub in the market is critical.

In 2012, the top three PV markets by installation were Germany (24%), China (13%) and Italy (13%). In 2013, demand is expected to shift to Asian markets with China (17%) and Japan (15%) leading the way and demand in Germany falling (15%).

DEK's decision to locate the centre in Suzhou is also driven by the city's close proximity to many of DEK's tier one cell manufacturing customers. The location is an ideal base from which the company can continue its long held tradition of working closely with customers to develop products which match their exact needs.

What's on offer at the Suzhou Technology Centre

Optimising solar cell manufacture and achieving cost leadership is a hugely complex job that can only be accomplished through improved printing accuracy, reductions in costs per watt, and strategic cost saving investments. The Suzhou Technology Centre has been resourced and equipped specifically to help solar cell manufacturers deliver these requirements:

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State-of-the-art technology

DEK Solar platforms deliver industry leading levels of agility and repeatable printing accuracy enabling reductions in production costs and improvements in costs per watt. These technologies will be on show within the Centre and will be available for process development.

DEK's revolutionary screen and stencil technology makes accurate, fine line printing possible, reducing the amount of silver paste deposited. In addition, DEK's printing platforms, make these reductions in paste consumption possible at scale while also minimising wafer breakage rates.

Visitors to the Centre will be able to view DEK's printing platforms such as Apollo, Eclipse and PV1200+. DEK's Apollo platform is able to deliver ± 10 micron accuracy @ 2 Cpk capability; enabling high performance print-on-print, dual print and selective emitter processes with all the associated cost and cell efficiency benefits.

DEK's Eclipse offers similar levels of accuracy and repeatability to Apollo but adds the flexibility of modular design. However, by offering both double and triple head platforms, Eclipse also helps manufacturers scale production quickly.

Finally, PV1200+, DEK's cost effective metallisation platform helps deliver lower capital investment, another factor which has an impact on production costs. With fully incorporated drying, handling and inspection equipment, this technology provides a compact solution to meet standard cell production requirements.

Combining platform with process

Another aspect of the Suzhou Technology Centre will be its capability to process all potential metallisation options for its customers. Previously, Chinese customers had to travel internationally to receive this level of process development. Now, with the opening of the Centre in Suzhou, the service can be provided locally in China. Such a service is especially beneficial as a printing platform alone cannot deliver higher cell efficiency. For this, solar cell manufacturers must combine equipment with expertise. With the launch of the Suzhou Technology Centre, DEK will now be able to provide Chinese customers with process development capability in close proximity, delivering the tools to assure print process optimisation and higher first past yield.

Examples of the printing processes made achievable by these tools include print-on-print and dual printing. Dual printing isolates the busbar and finger printing processes. Doing so allows for more effective control of the volume of silver deposited, resulting in less silver being consumed. This two-step process achieves thinner, taller conductors that can increase cell efficiency.

Working in partnership

The Centre will also enable DEK to work closely with customers to develop long-standing strategic partnerships, with the ultimate goal being cost optimisation and increased cell efficiency. Additionally, DEK partners with best in class suppliers of materials, dryers, furnaces, and test and measurement equipment to provide end-to-end cell metallisation processing and validation.

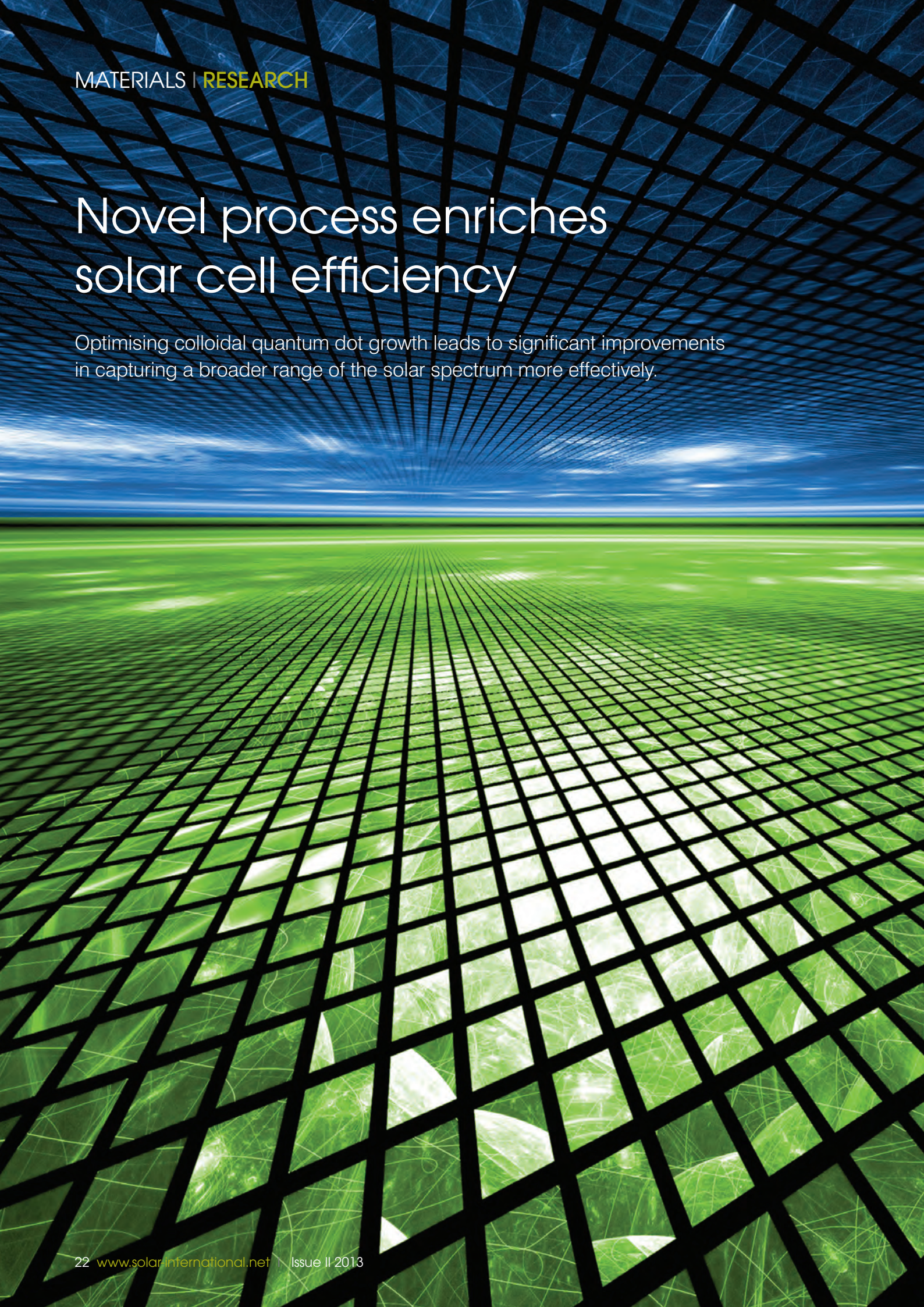
In the short term, the 20 Centre staff will work with customers on the following research priorities: higher efficiency cells; lower material costs; a reduction in the shadow effect; and dual printing which allow different materials to be used.

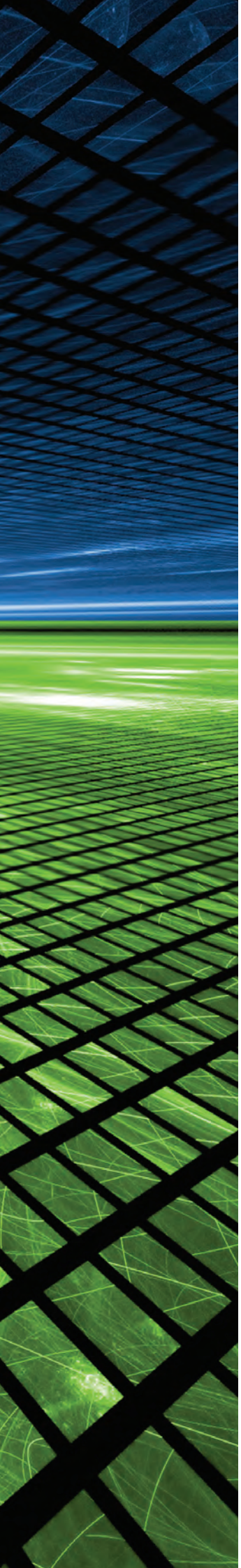
In the mid-term, staff will aim to pursue improved manufacturing efficiency and higher throughput lines, and longer term the focus will be on researching new cell technologies.

The benefits of this research and the new technologies which result will not only be felt in China. Within DEK, the new processes developed in Suzhou will require integration with new equipment and features designed and manufactured at DEK's other research hubs worldwide. And, perhaps, with its collaborative research approach and broad scope of industry-leading initiatives, the Suzhou Technology Centre may also help expedite the upturn in the fortunes of the solar industry.

Novel process enriches solar cell efficiency

Optimising colloidal quantum dot growth leads to significant improvements in capturing a broader range of the solar spectrum more effectively.





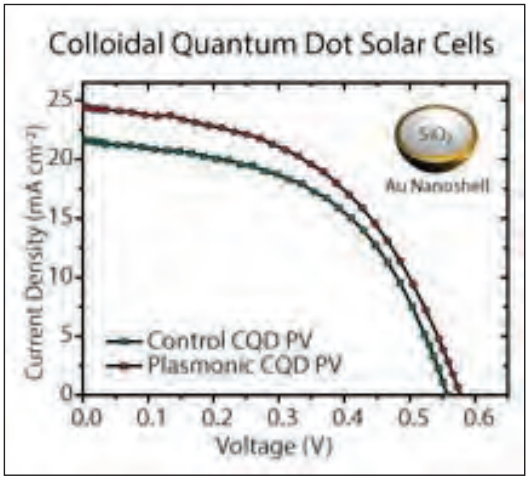
In a paper published in the journal Nano Letters, a group of researchers from the University of Toronto describes a new technique to improve efficiency in what are called colloidal quantum dot photovoltaics. It's a technology that already promises inexpensive and more efficient solar cell technology. But researchers, led by Ted Sargent, say such devices could be even more effective if they could better harness the infrared portion of the sun's spectrum, which is responsible for half of the sun's power that reaches the Earth.

The solution has an unwieldy name: spectrally tuned, solution-processed plasmonic nanoparticles. These particles, researchers say, provide unprecedented control over light's propagation and absorption. The new technique developed by Sargent's group shows a possible 35 percent increase in the technology's efficiency in the near-infrared spectral region, says co-author Susanna Thon.

Overall, this could translate to an 11 percent solar power conversion efficiency increase, she says, making quantum dot photovoltaics even more attractive as an alternative to current solar cell technologies.

"There are two advantages to colloidal quantum dots," Thon says. "First, they're much cheaper, so they reduce the cost of electricity generation measured in cost per watt of power. But the main advantage is that by simply changing the size of the quantum dot, you can change its light-absorption spectrum. Changing the size is very easy, and this size-tunability is a property shared by plasmonic materials: by changing the size of the plasmonic particles, we were able to overlap the absorption and scattering spectra of these two key classes of nanomaterials."

Sargent's group achieved the increased efficiency by embedding gold nanoshells directly into the quantum dot absorber film. Gold is not usually thought of as an economical material but researchers say lower-cost metals can be used to implement the same concept proved by Thon and her co-workers. The current research provides a proof of principle, says Thon.



"People have tried to do similar work but the problem has always been that the metal they use also absorbs some light and doesn't contribute to the photocurrent - so it's just lost light." More work needs to be done. We want to achieve more optimisation, and we're also interested in looking at cheaper metals to build a better cell. We'd also like to better target where photons are absorbed in the cell - this is important photovoltaics because you want to absorb as many photons as you can as close to the charge collecting electrode as you possibly can."

The research is also important because it shows the potential of tuning nanomaterial properties to achieve a certain goal, says Paul Weiss, Director of the California NanoSystems Institute at the University of California, Los Angeles. "This work is a great example of fulfilling the promise of nanoscience and nanotechnology," Weiss says. "By developing the means to tune the properties of nanomaterials, Sargent and his co-workers have been able to make significant improvements in an important device function, namely capturing a broader range of the solar spectrum more effectively."

Further details of this study have been published in the paper " Jointly Tuned Plasmonic–Excitonic Photovoltaics Using Nanoshells," by Daniel Paz-Soldan et al in Nano Letters (2013).

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SIC infiltrates inverter markets

As photovoltaic inverter manufacturers adopt SiC MOSFETs, when will other industries move towards wide bandgap devices, asks Solar International.

As the power electronics market embraces a buoyant decade, the future for wide bandgap devices looks bright. SiC diodes have stormed into the photovoltaic inverter market, and the same flavour of MOSFET is now penetrating this high-end segment. This trend looks likely to continue.

Earlier this month, France-based analysis business, Yole Developpement, predicted the entire inverter market will swell from $45 billion, in 2012, to $71 billion by 2020.

As expected, the market segment of the moment for the solar industry is PV inverters, but as Yole analyst Alexandre Avron highlights, unexpected opportunities have surfaced.

"Yes, we are seeing PV inverters first but what is a little surprising is the use of SiC [devices] in light rail traction applications," he says. "There has been a real interest for the SiC MOSFET and several companies are already carrying out field tests."

As Avron highlights, Alstom is testing SiC MOSFETs in its auxiliary inverters for trains. "Many more small research and development teams in major businesses, especially in Asia, are pushing for new materials," he adds. "This is a traditional, conservative market. You just don't expect rail traction to be attracted to SiC MOSFETs."

More predictably, Avron expects the equally conservative hybrid and electric car manufacturers to show a greater interest in SiC devices. These components can operate at much higher temperatures than silicon counterparts, removing the need for liquid cooling loops and cutting the size, weight and volume of the overall inverter system. This is quite a bonus for the performance-driven but space-

But what about GaN - many power device manufacturers have touted progress in high power GaN diodes and transistors - yet how many products have reached the market? The long-awaited arrival of the SiC MOSFET only came after a long fanfare of announcements

constrained car manufacturer. But still these players will first scrutinise how SiC performs in the solar industry, which as Avron puts it, is providing the "field test".

"We've looked at these photovoltaic inverters and right now the architecture hasn't changed much," he says. "Manufacturers have taken out the 1200V silicon IGBTs and put in either a SiC MOSFET or JFET, and changed the input boost converter a little bit. They will now see how the [device] reacts in real-life conditions at higher volumes of production."

But change is afoot. According to Avron, new inverter architectures - that make the most of the advantages that SiC MOSFETs and JFETs can bring - are under development.

"These have, for example, higher switching frequencies, and if you compare the [designs] to today's architectures, you really see how much room for improvement there is," he says.

Avron doesn't expect the new, improved inverter architectures will surface for two to three years yet.

"We know [other industries] will go for these inverters, but first inverter manufacturers need to see exactly how SiC reacts." he adds.

"The MOSFET is really the heart of the inverter and if your heart isn't strong then you've wasted your money... but in two to three years, manufacturers will no longer be afraid to base a real product on the SiC MOSFET."

But what about GaN?

Many power device manufacturers have touted progress in high power GaN diodes and transistors - yet how many products have reached the market?

The long-awaited arrival of the SiC MOSFET only came after a long fanfare of announcements, and Avron is concerned GaN transistors are following the same path.

"We've seen lots of marketing about what companies are doing in-house, but still we don't have a 600V device available," he says. "I expect there are non-disclosure agreements and the players are getting the first production batches from GaN manufacturers, but it's a little late."

Still, progress is underway. For example, California-based Transphorm qualified its 600V HEMT last year and recently revealed a 600V GaN module for GaN-based high power PV converters. And Avron reckons industry will adopt these and future GaN devices.

"We think it will take a little bit of time... but SiC should be used in very high voltages and we could then see GaN used where SiC is now, PV inverters, electric cars and so on," he says. "We are seeing different positioning for GaN and SiC, and more people are accepting that there is no full competition between the two [technologies]."

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InP Nanowires propel solar cells

An indium phosphide nanowire solar cell can produce an effect per active surface unit several times greater than today's silicon cells.

Researchers from Lund University in Sweden have shown how InP nanowires could pave the way for more efficient and cheaper solar cells.

"Our findings are the first to show that it really is possible to use nanowires to manufacture solar cells," says Magnus Borgström, a researcher in semiconductor physics.

Research on solar cell nanowires is on the rise globally. Until now the unattained dream figure was ten per cent efficiency - but now Borgström and his colleagues are able to report an efficiency of 13.8 percent.

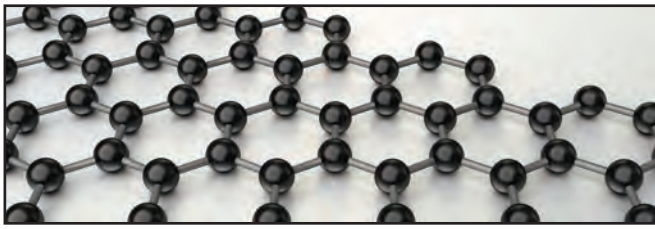
The nanowires are made of InP and work like antennae that absorb sunlight and generate power. The nanowires are assembled on surfaces of one square millimetre that each house four million nanowires. A nanowire solar cell can produce an effect per active surface unit several times greater than today's silicon cells.

Nanowire solar cells have not yet made it beyond the laboratory, but the plan is that the technology could be used in large solar power plants in sunny regions such as the south-west of thr USA, southern Spain and Africa. The Lund researchers have now managed to identify the ideal diameter of the nanowires and how to synthesise them.

"The right size is essential for the nanowires to absorb as many photons as possible. If they are just a few tenths of a nanometre too small their function is significantly impaired," explains Magnus Borgström. The silicon solar cells that are used to supply electricity for domestic use are relatively cheap, but inefficient because they are only able to utilise a limited part of the effect of the sunlight. The reason is that one single material can only absorb part of the spectrum of the light.

Research carried out alongside that on nanowire technology therefore aims to combine different types of semiconductor material to make efficient use of a broader part of the solar spectrum. The disadvantage of this is that they become extremely expensive and can therefore only be used in niche contexts, such as on satellites and military planes.

However, this is not the case with nanowires Because of their small dimensions, the same sort of material combinations can be created with much less effort, which offers higher efficiency at a low cost.

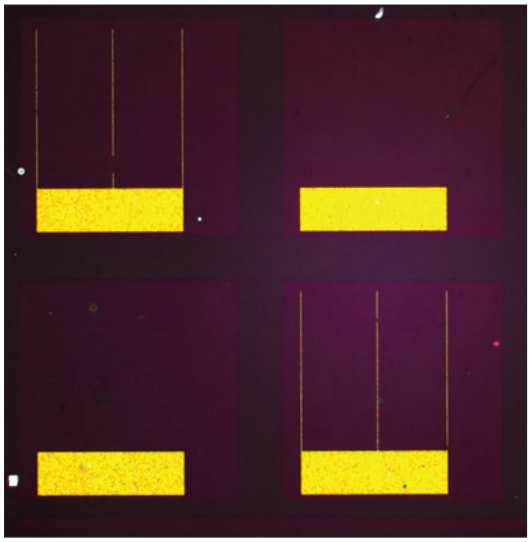


Characterisation of NW-array solar cells: 0° (left) and 30° (right) tilt scanning electron microscopy (SEM) images of as-grown InP NWs with a surface coverage of 12 percent

The process is also less complicated. The researchers have shown that the nanowires can generate power at the same level as a thin film of the same material, even if they only cover around 10 per cent of the surface rather than 100 percent. The research was carried out as part of an EU-funded project, AMON-RA, coordinated by Knut Deppert, Professor of Physics at Lund University.

"As the coordinator of the project, I am very proud of such a great result - it has well exceeded our expectations. We will of course continue the research on nanowire solar cells and hope to achieve an even higher level of efficiency than the 13.8 per cent that we have now reported," concludes Knut Deppert.

Further details of this work have been published in the paper, " InP Nanowire Array Solar Cells Achieving 13.8% Efficiency by Exceeding the Ray Optics Limit," by M. Borgström et alinScience1230969. DOI:10.1126/science.1230969



Optical microscope image of NW solar cells

Link solar-cells with dots and wires

MIT researchers have improved the efficiency of a quantum-dot photovoltaic system by adding a forest of nanowires.

Using quantum dots as the basis for a photovoltaic cell is not a new idea, but attempts to make such devices have not yet achieved sufficiently high efficiency in converting sunlight to power. Now a new wrinkle added by a team of researchers at MIT - embedding the quantum dots within a forest of nanowires - promises to provide a significant boost.

Photovoltaics (PVs) based on tiny colloidal quantum dots have several potential advantages over other approaches to making solar cells.

For one, they can be manufactured in a room-temperature process, saving energy and avoiding complications associated with high-temperature processing of silicon and other PV materials. They can be made from abundant, inexpensive materials that do not require extensive purification, as silicon does. And they can be applied to a variety of inexpensive and even flexible substrate materials, such as lightweight plastics. But there's a trade-off in designing such devices, because of two contradictory needs for an effective PV.

Firstly, a solar cell's absorbing layer needs to be thin to allow charges to pass readily from the sites where solar energy is absorbed to the wires that carry current away - but it also needs to be thick enough to absorb light efficiently. Improved performance in one of these areas tends to worsen the other, says Joel Jean, a doctoral student in MIT's Department of Electrical Engineering and Computer Science (EECS).

"You want a thick film to absorb the light, and you want it thin to get the charges out," he adds. "So there's a huge discrepancy."

That's where the addition of zinc oxide nanowires can play a useful role, says Jean, who is the lead author of a paper to be

published in the journal Advanced Materials. These nanowires are conductive enough to extract charges easily, but long enough to provide the depth needed for light absorption, Jean says.

Using a bottom-up growth process to grow these nanowires and infiltrating them with lead-sulphide quantum dots produces a 50 percent boost in the current generated by the solar cell, and a 35 percent increase in overall efficiency, Jean says. The process produces a vertical array of these nanowires, which are transparent to visible light, interspersed with quantum dots.

"If you shine light along the length of the nanowires, you get the advantage of depth," he says. But also, "you decouple light absorption and charge carrier extraction, since the electrons can hop sideways onto a nearby nanowire and be collected."

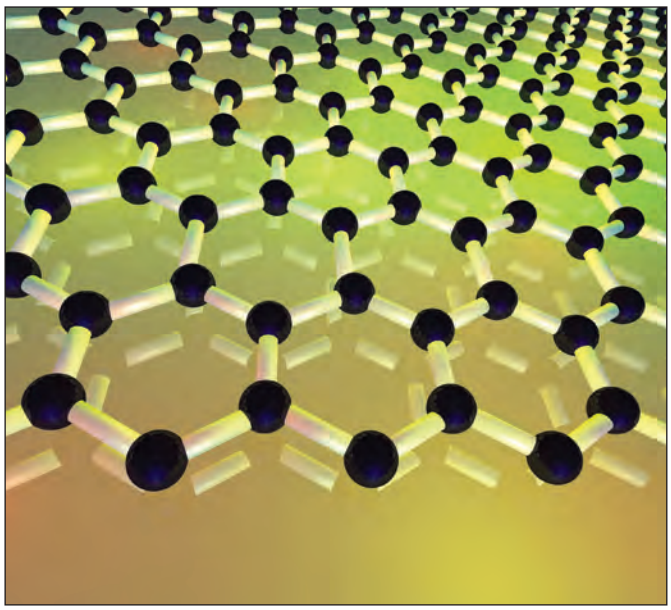
One advantage of quantum dot-based PVs is that they can be tuned to absorb light over a much wider range of wavelengths than conventional devices, Jean says. This is an early demonstration of a principle that, through further optimization and improved physical understanding, might lead to practical, inexpensive new kinds of photovoltaic devices, he says.

Already, the test devices have produced efficiencies of almost 5 percent, among the highest ever reported for a quantum-dot PV based on zinc oxide, he says. With further development, Jean says, it may be possible to improve the devices' overall efficiency beyond 10 percent, which is widely accepted as the minimum efficiency for a commercially viable solar cell.

Further research will explore using longer nanowires to make thicker films, and also work on better controlling the spacing of the nanowires to improve the infiltration of quantum dots between them.

This research has been described in depth in the paper, "ZnO Nanowire Arrays for Enhanced Photocurrent in PbS Quantum Dot Solar Cells" by Joel Jean et al in Advanced Materials. DOI: 10.1002/adma.201204192

The team was supported by the National Science Foundation; the MIT Centre for Materials Science and Engineering; the Samsung Group; the MIT/Masdar Institute Cooperative Program; the MIT Energy Initiative; the Hertz Foundation; and the Agency for Science, Technology and Research of Singapore.



Scanning Electron Microscope images show an array of zinc-oxide nanowires (top) and a cross-section of a photovoltaic cell made from the nanowires, interspersed with quantum dots made of lead sulphide (dark areas). A layer of gold at the top (light band) and a layer of indium-tin-oxide at the bottom (lighter area) form the two electrodes of the solar cell. (Images courtesy of Jean, et al/Advanced Materials)

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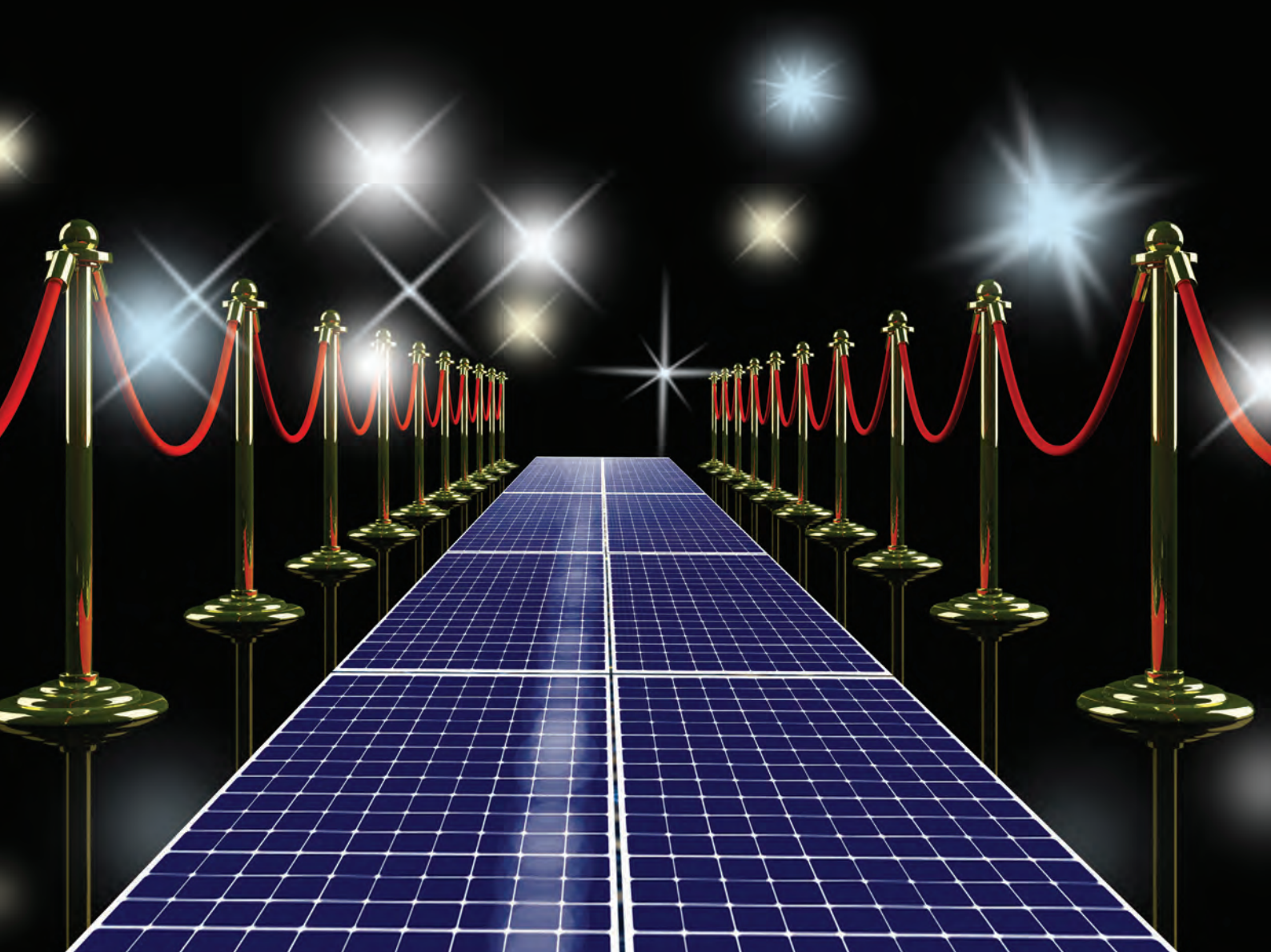

Tandem solar cells are set to benefit from surface activated bonding

Surface activated bonding of GaAs and silicon substrates can yield high-quality heterojunctions, according to electrical characterization and microscopy.

A Japanese partnership between Osaka City University and NTT Photonics Laboratories has shown that surface-activated bonding is a promising approach for fabricating novel heterojunctions. This can be used in several devices, including tandem solar cells built from GaAs and silicon.

Surface activated bonding, which begins by the firing of fast beams of argon atoms onto surfaces, has a significant advantage over conventional wafer bonding: It does not require a heating step to form high-quality electrical junctions. Studies by researchers at UCLA have revealed that the electrical properties of a conventionally bonded GaAs/GaAs interface are strongly influenced by pre-bonding surface treatments and post-bonding annealing. “They claimed that annealing in the range of 400°C to 600 °C was essential for realising excellent characteristics,” explains Naoteru Shigewaka from Osaka City University. According to him, this annealing step has its downsides: It takes time; it may drive the diffusion of impurities through interfaces; and it can create mechanical defects, due to differences in substrate thermal expansion coefficients.

Shigewaka and his co-workers have used surface activated bonding to form a GaAs-silicon heterojunction. This has been probed by current-voltage and capacitance-voltage measurements and scrutinized by field emission scanning electron microscopy and energy dispersive X-ray spectroscopy. Devices were formed by taking a boron-doped silicon substrate and a silicon-doped GaAs substrate (resistivities of 0.1 Ωm and 0.002 Ωm, respectively, and carrier concentrations and 2.4 x 1017cm^{-3}and 1.1 x 1018cm^{-3}, respectively) and cleaning them

The surface-activated bonding tool involves the bombardment of substrates by a beam of fast argon atoms

with acetone and ethanol in an ultrasonic bath for 5 minutes. After drying under nitrogen, substrates were loaded into a surface-activated bonding tool and their surfaces were activated by an argon fast atom beam. After this step, pressing the substrates together for 60 s united them, and then Al/Ni/Au and AuGe/Ni/Ti/Au stacks were evaporated on the silicon and GaAs substrates, respectively. Rapid thermal annealing at 400 °C formed ohmic contacts. Imaging with a field-emission scanning electron microscope showed that no structural defects, such as cracks, were present at the interface. What's more, the level of oxygen found in the interface is similar to that in the GaAs substrate, according to energy dispersive spectroscopy. Plots of current as a function of voltage showed that the device had rectifying properties similar to those in conventional p-n junctions. For this heterojunction, the onset for the forward bias voltage was 0.38 V.

Capacitance-voltage measurements enabled calculations for the depletion layers. They are estimated to be 84 nm in silicon, and 18 nm in GaAs. Two other features found in the current-voltage characteristics are an increase in current at higher values of reverse bias, and a gradient in these plots that shows very little variation with temperature. The researchers say that this behaviour can be explained with a trap-assisted tunnelling model, which incorporates a trap energy of 0.1 eV.

Thanks to the lack of any signs of oxygen at the interface, the team is arguing that its surface-activated bonding promises to enable the fabrication of high-quality, novel devices. They are now processing tandem cell structures formed by surface-activated bonding.

Reference
J. Liang et al. Appl. Phys. Express 6 021801 (2013)

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Trade wars dominate global thinking

Investors and manufacturers are cautiously wondering how 2013 will pan out for the global solar industry and have their eyes on a number of situations not just regions. Raj Prabhu, CEO and Co-Founder of Mercom Capital Group provides a global solar forecast and predicts steady growth in unsteady times.

Despite all the struggles experienced by the industry over the past few years, global solar installations still managed to grow, mainly due to Germany defying expectations and installing 7.6 GW in 2012. Final installation numbers are still trickling in and it looks like the global installations for 2012 will be in the 30-32 GW range. We are forecasting 2013 installations at 34.5 GW. While 2012 was a year dominated by overcapacity and bankruptcies. The other major topic that consumed the industry, and will continue to do so in 2013, are the trade wars.

Anti-dumping cases and protectionist measures became all too common all over the world as countries tried to rescue their own manufacturers in the face of massive over supply and ever-falling prices. So far, we have seen the United States announce final anti-dumping tariffs against Chinese manufacturers followed by the European Union filing a similar case also against China.

Meanwhile, China announced its own anti-dumping case against polysilicon suppliers from the United States, EU and South Korea

while India recently initiated an anti-dumping investigation on the imports of solar cells against Malaysia, China, Taiwan and the United States, further escalating the solar trade wars. The latest to join the list was the EU initiating an anti-dumping investigation in late February 2013, into the imports of solar glass from China. Low module prices (overall c-Si module prices dropped by roughly 30 percent in 2012) have continued to drive installations, though prices began to stabilize around November 2012, with Tier-1 spot c-Si module prices increasing from around 0.65/W to 0.67/W currently.

Along with Germany, some of the markets that drove installation growth last year were Italy, China, France, Japan, United States, India, and the UK. Greece, Bulgaria, Belgium and Australia were also major contributors.

Based on current forecasts it looks like the significant share of installations in 2013 will come from emerging solar markets like China, Japan and India. Though the 2013 forecast points to another year of growth, the effects of the growth might not be felt in the same way as before. Eight GW installed in Germany is not the same as eight GW installed in China. Penetrating these markets will be much more challenging for foreign suppliers and service providers.

Germany

PV installations in Germany totalled 7,603 MW for 2012 making it another year of record growth, despite the German Federal Network Agency (Bundesnetzagentur) efforts to slow the market. Germany has had a remarkable stretch of record installations over the last three years installing 7,400 MW in 2010, 7,500 MW in 2011 and 7,600 MW in 2012.

In an effort to slow down installations, Bundesnetzagentur announced a reduction in feed-in tariffs (FiT) for PV installations between November 1, 2012, and January 31, 2013, where FiTs decreased by 2.5 percent per month. The reduction seems to be working as installations slowed to 435 MW in November, 300 MW in December and just 275 MW in January 2013.

Having seen the success in slowing installations by monthly reductions of 2.5 percent, the Bundesnetzagentur announced in February 2013, that it will continue the monthly tariff reductions between February and April 2013 at a slightly lower rate of 2.2 percent. Cumulative PV installations in Germany stood at 32.7 GW as of January 2013. Germany's goal is to subsidize its solar program up to 52 GW.

Italy

Italy replaced its solar policy, Conto Energia IV, with Conto Energia V, which calls for a €700 million (~$900 million) subsidy cap and also provides a FiT premium for solar panels made in Europe to the tune of ~€20 (~$25)/MWh. According to Gestore dei Servizi Energetici (GSE), the annual cost of PV incentives paid out so far has reached €6.57B (~$8.55 billion) as of February 2013. The Conto Energia V program will come to an end once the annual costs of incentives reach €6.7 billion ($8.7 billion). After that cap is reached, Italy will no longer offer incentives for new PV installations. Italian PV incentives will end after the remaining 130 million (~$169 million) is used up for PV incentives. Preliminary PV installation numbers for 2012 from GSE indicate that Italy installed about 3,577 MW. With the Conto Energia cap almost reached, Italian PV installations will further slowdown, but the positive for Italy is that most parts of the country have already reached grid parity due to a combination of excellent solar insolation and high electricity costs. Italian projects have one of the higher ROIs among developed markets.

United States

The United States continues its strong installation growth and is expected to have installed in the 3,000-3,500 MW range in 2012 compared to about 1,850 MW in 2011. The continued growth in installations comes with the help of utility-scale projects; third party financed residential and commercial installations and state Renewable Portfolio Standards. Solar lease programs, where consumers lease systems instead of making the upfront investment, are extremely popular, especially in California, and are largely driving the residential markets there.

The United States is also still involved in several trade disputes even with the uncertainty surrounding the anti-dumping case against Chinese manufacturers complete – the final ruling was released in November. So far, the impact from the anti-dumping ruling seems to have had minimal impact on installations and panel prices. Other ongoing trade cases include the anti-dumping case filed by China against the U.S. polysilicon makers, and an anti-dumping case filed by India against the United States in regards to solar panels. Though the outcomes of these trade disputes may not be bad, there nevertheless will be a level of uncertainty until these cases are settled.

The United States does not have a central, cohesive solar incentive policy. Instead, the market is driven by state Renewable Portfolio Standards (RPS), state and municipal rebate programs and the 30 percent federal investment tax credit (ITC). California, the largest solar market in the country, is fueled by an aggressive RPS of 33 percent by 2020. Almost 30 states have some sort of RPS in place, and about half of them have a solar carve-out.

Japan

Japan has set a goal of achieving 28 GW of cumulative PV installations by 2020. The Ministry of Economy, Trade, and Industry (METI) announced a FiT program in June 2012, valid for 20 years, which is one of the most attractive in the world right now, with PV systems below 10 kW receiving ¥42/kWh (~$0.53) and systems above 10 kW receiving ¥40/kWh (~$0.51). For systems less than 10 kW, the government will purchase only the excess power produced for a 10 year period. For systems larger than 10 kW, the government will purchase all of the power produced. The new FiT program is designed to stimulate new large-scale power projects, as there was no FiT available for projects 500 kW or higher previously.

The generous FiTs and high rate of returns have helped spur growth, and final PV installation numbers in 2012 are expected to be in the 2,500 MW range. In tune with installations, domestic PV shipments have continued to rise as well. METI approved about 3.25 GW of solar projects just in the seven months between

April to November 2012. However, METI is now recommending lower FiTs for PV projects in Japan, though it doesn't specify new rates. As we predicted in our third quarter forecast update, the FiTs were too generous and can lead to a boom-bust cycle.

China

In our forecast from the fourth quarter we noted that the National Energy Administration (NEA) of China had set a solar power capacity target of 21 GW by 2015. The original goal for solar installations was five GW by 2015, and continued to be revised to 10 GW, 21 GW and now the latest target set is a very aggressive 40 GW by 2015; the installation target set for 2013 is 10 GW. There is also a push for stronger policy support to distributed PV, partly in response to grid issues.

China's solar industry still faces multiple challenges including economic slowdown, tightening credit by the state owned banks, significant debt exposure to solar manufacturers, bankability issues, low tariffs, bureaucracy, cumbersome permitting processes, and transmission bottlenecks (a big hurdle also facing the wind sector), along with trade disputes.

Initial solar installation goals in China were modest, aimed at some environmental benefits and the need for renewable sources of generation. Billions in credit were provided on the supply side to manufacturers to ramp-up capacity, which had the unintended result of creating massive overcapacity and a steep fall in prices, which put most manufacturers on life support.

Continued government support in the form of loans and credit were not enough to rectify the situation and stronger domestic installation goals had to be set to absorb some of the excess supply. The goals have gotten increasingly more aggressive in tune with the problems faced by domestic manufacturers. The government has gotten more serious with its solar goals as solar is now seen as a solution to the serious air pollution problems in China. The Chinese Ministry of Environmental Protection has called for more stringent air quality standards and has targeted active monitoring and forecasting PM2.5 (particulate matter) data. The ministry has also identified coal consumption and automobiles as the major source of these environmental problems.

The Chinese government announced that it allocated about $2 billion for the second round of projects for its Golden Sun Program in 2012, and a direct subsidy of $0.40/W. There is allowance for regional adjustments to the FiTs based on local resource conditions and preferential VAT policies. The BIPV subsidies for 2013 are in the $1.20/W to $1.40/W range for approved projects. It has to be noted that unlike other markets, most forecasts for China are basically government goals.

France

PV installations in France for 2012 were about 1.1 GW. France has been all over the place when it comes to solar policies, cutting its FiTs several times in 2012, followed by a shift from a FiT system to a bidding system for large-scale projects above 100 kW. However, there was some good news in the form of fresh policy support from the new Hollande administration. The current FiT is very generous compared to Germany and includes support for rooftop projects; there is also a "Made in EU" bonus of 5 -10 percent on top of the FiT.

India

Indian solar installations have been driven by the Jawaharlal Nehru National Solar Mission (JNNSM) with a goal to install 20 GW of solar power by 2022, and various state policies and state RPOs.

India installed 980 MW in 2012, slightly lower than our forecast of 1,090 MW. The difference was largely due to delays in Gujarat to commission 144.5 MW of PV projects; most states missed their renewable portfolio obligations (RPO) goals as enforcement is almost non-existent. Cumulative installations to date in India now stand at over 1.2 GW.

In addition, there are 340 MW of PV projects due to be connected to the grid in March 2013 under the JNNSM Phase I, Batch 2 policy. We are forecasting India to install another 1.3 to 1.4 GW in 2013.

The Ministry of New and Renewable Energy (MNRE) recently proposed a draft Phase II policy and opened it up for comments. Phase II would have a target of achieving 3,000-9,000 MW of solar power through various batches as previously seen in Phase I.

This consensus forecast is based on Mercom's views and methodology with data compiled from: Barclays Capital, BNEF, Bundesnetzagentur, Citi, Collins Stewart, Credit Suisse, Daiwa, Deutsche Bank, Enerplan, EPIA, EUPD, GTM Research, GSE, Hyundai, ICBC, IHS iSuppli, Jefferies, JP Morgan, JPEA, Kaufman Bros, KGI, Macquarie Capital, Maxim Group, Mercom Capital Group, METI, NEA, Piper Jaffray, R.W. Baird, Solarbuzz, Stifel Nicolaus, UBS, and other government, public and private sources.

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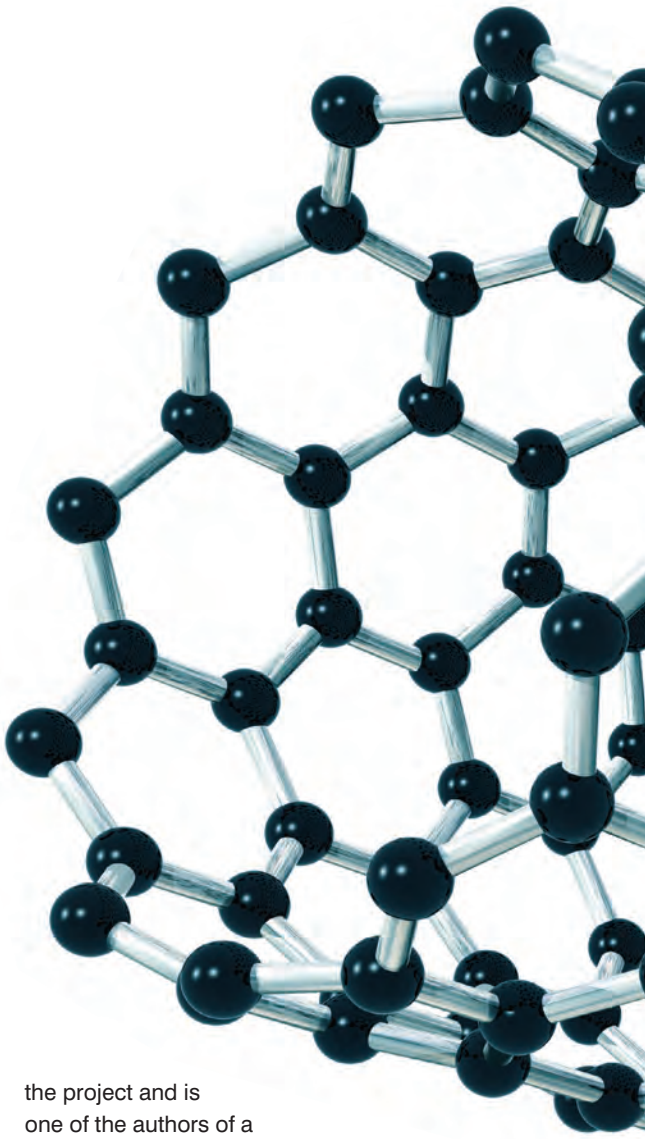
GaAs nanowire solar cells have massive potential

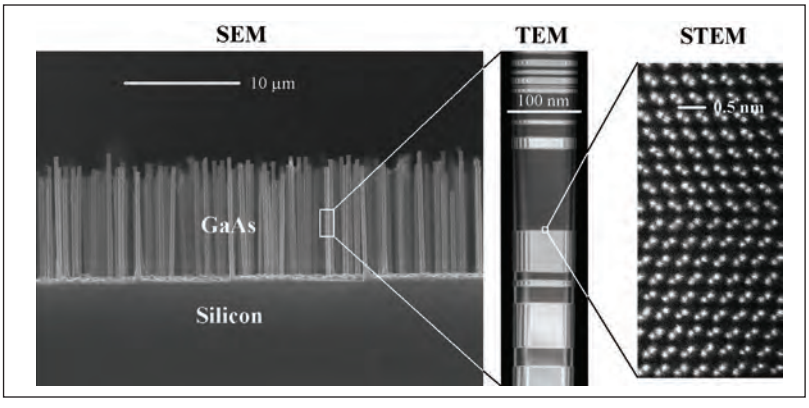


Cylindrical III-V nanowire structures are predicted to have potential in the development of solar cells, quantum computers and other electronic products.

Scientists have shown that a single nanowire can concentrate the sunlight by up to 15 times of normal sunlight intensity. The researchers who made the discovery come from the Nano-Science Centre at the Niels Bohr Institut, Denmark and the Ecole Polytechnique Fédérale de Lausanne, Switzerland.

Surprised with the results, the team believe their latest data shows the potential for developing a new type of highly efficient solar cell.

Due to some unique physical light absorption properties of nanowires, the limit of how much energy can be utilised from the sun's rays is higher than previously believed, say the researchers. These results demonstrate the great potential of development of nanowire-based solar cells says Peter Krogstrup, a Ph.D. scientist who worked on the project and is one of the authors of a paper published in Nature Photonics.



Various microscope images of the GaAs nanowire structure

In the past few years, the project researchers have developed and improved the quality of the nanowire crystals. These crystals have a cylindrical structure with a diameter of about 10,000 part of a human hair.

The team members believe their nanowire technology could have great potential in the development of not only solar cells, but also next generation quantum computers and other electronic products. It turns out that the nanowires naturally concentrate the sun's rays into a very small area in the crystal by up to a factor 15.

And because the diameter of a nanowire crystal is smaller than the wavelength of the light coming from the sun, it can cause resonances in the intensity of light in and around nanowires. Peter Krogstrup points out the resonances concentrate the sunlight, leading to a higher conversion efficiency of the sun's energy.

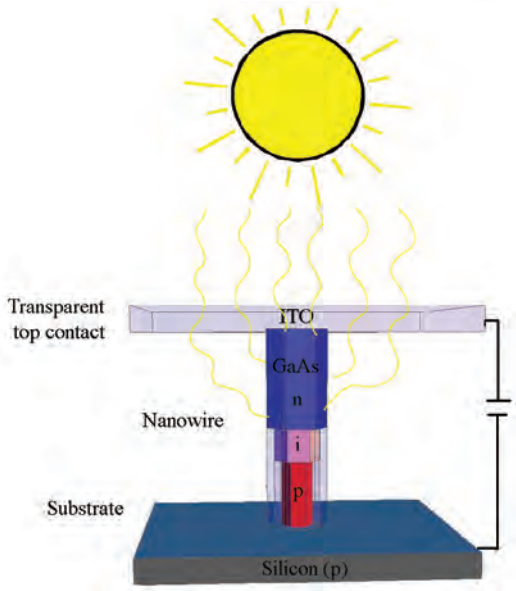
New efficiency limit

The typical efficiency limit - the so-called "Shockley-Queisser Limit," has for many years been a landmark for solar cell efficiency among researchers, but now it seems that it may be increased. The scientists point out that their

exciting discovery could move the theoretical limits. And moving the limit by only a few percent should have a major impact on the development of solar cells, exploitation of nanowire solar rays and perhaps the extraction of energy at international level.

However, it will take some years before production of solar cells consisting of nanowires becomes a reality, acknowledges Krogstrup. This research was conducted in collaboration with the Laboratory des Matériaux Semiconducteurs, Ecole Polytechnique Fédérale de Lausanne, the Foundation and the company SunFlake A / S.

The scientific findings reported here support results published in the journal Science in January. Here, a group of researchers from Lund, showed that the sun's rays was sucked into the nanowires due to the high amount of power that their solar cell produced.



Above, the sun's rays are drawn into a nanowire, which stands on a silicon substrate. At a given wavelength the sunlight is concentrated by up to 15 times (Credit: Niels Bohr Institute)

Strategies for enhancing photovoltaic performance

There are many options for improving the performance of III-V solar cells, including inserting quantum wells and dots to extend spectral coverage and adding nanoparticles and diffraction gratings to boost light trapping. Insights into all these approaches are outlined by Sudha Mokkapati, Samuel Turner, Haofeng Lu, Lan Fu, Hark Hoe Tan and Chennupati Jagadish from The Australian National University.

Efficiency is the key metric for solar cells. Increasing this ups the energy produced by the cell, and in turn cuts generation costs and trims the footprint of the cell required to deliver a given output.

One option for enhancing the performance of a conventional solar cell is to modify its design by inserting structures that stretch the spectral absorption to longer wavelengths. Adding quantum wells and dots can realize this, with greater spectral absorption increasing short-circuit current densities that could ultimately boost the overall efficiency of the solar cell. Gains in current resulting from the incorporation of wells or dots also open up new opportunities for bandgap engineering, allowing better current matching between different sub-cells of a tandem solar cell. For example, in a Ge-InGaAs-InGaP tandem solar cell, inserting InGaAs quantum wells or quantum dots into the InGaAs middle sub-cell transfers current from the current-overproducing bottom sub-cell to the current-limiting middle sub-cell.

A handful of research groups have pursued these approaches to improving solar cell performance. For example, Keith Barnham's group at Imperial College, London, have increased the spectral response of an AlGaAs reference cell by turning to an GaAs-AlGaAs quantum well solar cells, while our team at The Australian National University have enjoyed similar success by replacing a GaAs reference cell with

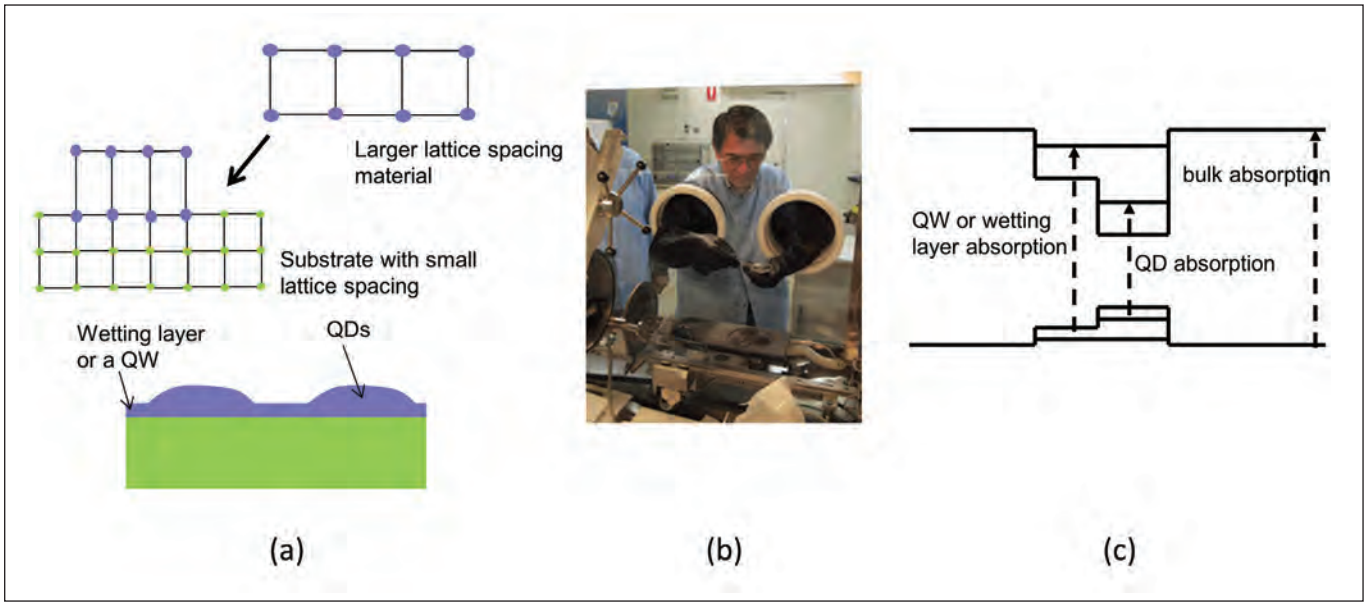


Figure 1: The formation of quantum dots in the Stranski-Krastanov growth mode (a) and the MOCVD reactor used for growing QWs/QDs (b). The relative bandgap energies of $In_xGa_{1-x}As$ quantum dot and quantum well (or wetting layer) with respect to bulk GaAs (c)

a InGaAs-GaAs quantum dot solar cell (see Figure 1 for details of the bandstructure of these novel cells).

Quantum wells and dots provide confinement of electron and holes in one and three dimensions, respectively. Both are grown epitaxially by techniques such as MBE and MOCVD. The growth of wells is very well established in academia and industry, while the formation of dots is predominantly carried out in university labs.

Dots are produced by depositing a material with a larger lattice constant on a substrate with a smaller one – in our case we grow an $In_xGa_{1-x}As$ film on GaAs using a MOCVD reactor (see figure 1). Initially, the material with a larger lattice constant material tries to grow in a layer-by-layer fashion, adjusting its lattice spacing to match that of the substrate (see Figure 1). This leads to a build up of strain in the structure, which creates defects when it exceeds a certain value. To prevent this from happening, the thickness of the deposited film must be kept below a certain value, which is governed by lattice mismatch.

When growth of the deposited film continues beyond this limit, strain in the system increases and beyond a certain threshold three-dimensional islands or quantum dots begin to form. That's because for this configuration, the total surface energy is lower than the strain energy for two-dimensional growth. Beneath the quantum dots, a thin two-dimensional layer, known as a wetting layer, still exists. This is essentially a thin quantum well. Formation of quantum dot heterostructures by this approach is said to employ the Stranski-Krastanov growth mode.

A severe limitation associated with both quantum wells and dots is the very small absorption volume. For example, the absorption fraction of a single 7 nm $In_{0.21}Ga_{0.79}As$ quantum well is only of the order of 1 percent beyond the bandgap of GaAs. So, to absorb a significant fraction of light beyond the band edge of GaAs, there needs to be a substantial increase in the absorption efficiency of the quantum wells and quantum dots.

One way to do this is to stack layers of quantum wells/dots on top of one another. However, the high level of strain in these quantum-confined absorbers means that when several of these layers are stacked together, excess overall strain can spawn the formation of dislocations, which act as non-radiative recombination centres that degrade device performance. What's more, stacking too many quantum well/dot layers together may make it very challenging to extract carriers from the middle layers. Consequently, alternative approaches are needed to increase the absorption efficiency of long-wavelength light for efficient quantum well/dot solar cells.

A hike in the absorption probability is possible via a process known as light trapping - the 'folding' of light into a thin absorber layer to increase light-matter interaction times. Folding or trapping light in the absorber layer increases the optical thickness of the absorber layer to values far beyond its physical thickness. In an absorber layer that supports only a few waveguide modes, light is trapped by coupling it to the waveguide modes. This switches its propagation direction from perpendicular to the absorber to parallel to it. For relatively thick absorbers that support a continuum of optical modes, light is

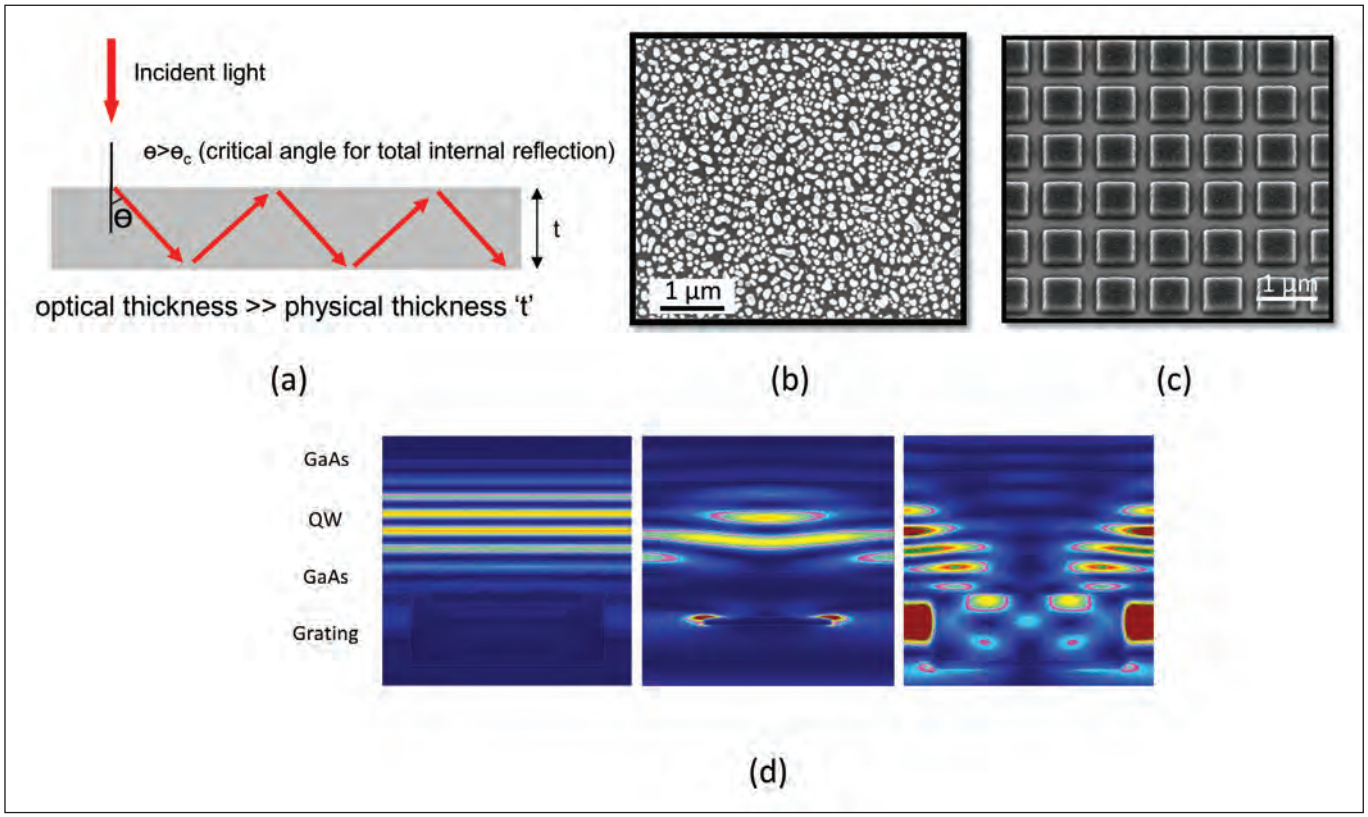


Figure 2 : Light trapping in thick solar cells by total internal reflection of weakly absorbed light (a). Scanning electron microscope images of a plasmonic nanoparticle array (b) and a diffraction grating (c) that are both fabricated on a solar cell. (d) shows how a plane wave front incident on a solar cell (left) is modified by the presence of a plasmonic nanoparticle (center) and a dielectric gratig (right) on the rear surface of the solar cell

trapped by exploiting total internal reflection (see Figure 2). The strength of this approach is that light is coupled into the absorber outside of the escape cone (or at angles larger than the critical angle for total internal reflection at the absorber-air interface). We work with substrate-based structures that support a continuum of optical modes and feature either quantum well or dot absorber layers.

We employ two light trapping approaches to enhance the absorption efficiency of long wavelength light in our quantum well/dot solar cells: plasmonic light trapping and the addition of a diffraction grating on the surface of the solar cell.

Powerful plasmonics

Light trapping is possible using plasmonic nanoparticles – tiny metallic structures that interact with the incoming light and exhibit local oscillations in the density of their free electron gas. One consequence of this phenomenon is that incoming radiation is scatterred into the solar cell at angles outside the escape cone.

Good light trapping with plasmonic structures is possible by exceling in two areas: maximizing the scattering cross-section of the plasmonic nanoparticles, and realising a high efficiency for the coupling of scattered light into the substrate. It is vital to maximise the scattering cross-section, because this ensures that the nanoparticles interact with most of the light incident on the solar cell and randomise its direction. Meanwhile, it is critical to achieve a high coupling efficiency of scattered light into the substrate of the solar cell, because this minimises reflection or transmission losses at each encounter between the weakly absorbed light and the plasmonic particles. It is also important to address parasitic losses, which are inherent to the resonant metallic nanostructures.

We form our plasmonic nanoparticles by depositing a thin silver film on the surface of a finished solar cell and annealing it in a nitrogen atmosphere. Nanoparticle arrays result from the difference in thermal expansion between the metallic layer and the substrate (see Figure 2). The fabrication process is relatively easy, since it does not require modification of the solar cell fabrication process and is scalable to large areas.

Last year we reported an 8 percent enhancement in the efficiency of a quantum dot solar cell through the addition of plasmonic light trapping. The improvement in power predominantly came from an increase in short-circuit current density (J_{sc}) by 5.6% – the open-circuit voltage (V_{oc}) also went up, but just by 0.9 percent.

A good indicator of the effectiveness of a light trapping strategy is the enhancement in path length. This is defined as the ratio between the average distance travelled by weakly absorbed light in a solar cell featuring light trapping, to the distance travelled in a planar solar cell. Based on experimental results from our plasmonic quantum dot solar cell, we calculate that this path length enhancement is approximately 2 at a wavelength of

1000 nm. We can explain why this value is much smaller than expected from a good light trapping structure: Our solar cells are fabricated on n^+ substrates, so free carrier absorption (parasitic losses) in this platform limits the benefits of this light trapping structure. We expect that parasitic losses in the device can be cut, leading to an increase in the short circuit current density and the efficiency of the solar cell, by fabricating solar cells on semi-insulating substrates.

Dielectric grating gains

Another way to couple incoming light into diffraction orders outside of the escape cone in the solar cell with wavelength-scale diffraction gratings. These periodic structures are difficult to fabricate and require a lot more process optimisation, but they do not have the parasitic losses inherent to metallic structures. The latter strength indicates that they should be better for light trapping applications in solar cells, where every available photon is valuable.

When gratings are fabricated on the surface of a solar cell, they restrict the number of optical modes in the device to which the incident light can couple. The number of diffraction modes in a material depends on the periodicity of the grating and the refractive index of the cell. Employ a very small period grating, and only the principal diffraction mode in the solar cell that lies within the escape cone is supported. Turn to a very large period grating, and a continuum of modes can then be present in the solar cell and in air. However, a large fraction of the diffraction modes supported in the solar cell are within the escape cone and do not effectively trap light.

The sweet spot is to use wavelength-scale diffraction gratings (such as the ones shown in Figure 2), which support the principal diffraction mode in air, plus a few higher order diffraction modes that lie outside the escape cone. Good light trapping is then possible, thanks to efficient coupling of incident light to these higher order modes (see figure 2).

The key to efficient light trapping is two-fold: It involves maximising the relative number of diffraction modes outside the escape cone in the solar cell, with respect to the number of modes supported in air; and realising efficient coupling of incident light to these modes. The most efficient structures for light trapping are bi-periodic gratings with asymmetry introduced into the grating structure to satisfy these criteria. According to our calculations, the addition of an optimised asymmetric TiO_2 grating structure at the rear of the solar cell can increase the short circuit current density of a ten-stack $In_{0.21}Ga_{0.79}As$-GaAs quantum well solar cell from 1.03 to 3.30 mA/cm^2.

A common benchmark for assessing the performance of a light trapping strategy is the theoretical concept of Lambertian light trapping or the isotropic limit. This has been developed in the context of wafer-based silicon solar cells. The best that one can do is a path length enhancement of $4n^2$, (where n is the refractive index of the solar cell material), which is achieved using a Lambertian scatterer at the solar cell surface. It is possible to mimic a Lambertian surface by texturing the solar cell surface with random pyramids with feature sizes of the order of few tens of microns.

To gauge the effectiveness of the plasmonic structures and the dielectric gratings – and compare with Lambertian light trapping – we investigate the relative short-circuit current-density enhancements (ratio of J_{sc} enhancement from a given light trapping structure to the maximum possible enhancement in J_{sc} assuming all of the incident light is absorbed in the quantum wells) from the quantum well region of a ten-stack $In_{0.21}Ga_{0.79}As$-GaAs quantum well solar cell. At the optimum geometry, a TiO_2 dielectric grating can deliver a relative J_{sc} enhancement of 82 percent. This increase in current is much larger than the 28 percent that we obtained using plasmonic light trapping, and comparable to that of a Lambertian scatterer (95 percent). As mentioned earlier, the inferior result for the plasmonic light trapping structures is partly due to the absorption in the metal itself, which leads to very low short circuit current density enhancements compared to the dielectric structures that do not absorb the incident light.

We are now working on fabricating plasmonic solar cells on semi-insulating substrates, because this will minimize the free carrier absorption in the substrate. In addition, we are optimising the fabrication processes for wavelength-scale TiO_2 diffraction gratings, so that these light trapping strategies can then be used in thin film III-V semiconductor solar cells, where epitaxially grown thin film absorbers can be lifted-off from the substrate and supported on an inexpensive substrate with light trapping strategies. This approach will allow the expensive substrates to be re-used, thereby reducing material cost in solar cell manufacturing.

We acknowledge the Australian Research Council (ARC) for financial support, Australian National Fabrication Facility (ANFF), A.C.T. node for access to equipment and the National Computational Initiative (NCI) for computational resources used for this work.

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III-V solar cell pushes efficiency boundaries

NREL researchers offer insights into the progress of record-breaking multi-junction cells. It takes out-of-the-box thinking to outsmart the solar spectrum and set a world record for solar cell efficiency.

The solar spectrum has boundaries and unalterable rules. And no matter how much solar cell manufacturers want to bend those rules, they can't. So how can we make a solar cell that has a higher efficiency than the rules allow?

That's the question scientists in the III-V Multi-junction Photovoltaics Group at the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) faced 15 years ago. They were searching for materials they could grow easily that also have the ideal combinations of band gaps for converting photons from the sun into electricity with unprecedented efficiency.

A band gap is an energy that characterises how a semiconductor material absorbs photons, and how efficiently a solar cell made from that material can extract the useful energy from those photons.

"The ideal band gaps for a solar cell are determined by the solar spectrum," notes Daniel Friedman, manager of the NREL III-V Multi-junction Photovoltaics Group. "There's no way around that."

But this year, Friedman's team succeeded in bending the rules of the solar spectrum and NREL and its industry partner, Solar Junction, won an R&D 100 award from R&D Magazine for a world-record multi-junction solar cell. The three-layered cell, SJ3, converted 43.5 percent of the energy in sunlight into electrical energy - a rate that has stimulated demand for the cell to be used in concentrator photovoltaic (CPV) arrays for utility-scale energy production. The record of 43.5 percent efficiency at 415 suns was eclipsed with a 44 percent efficiency at 947 suns. Both records were verified by NREL. This is NREL's third R&D 100 award for advances in ultra-high-efficiency multi-junction cells.

CPV technology gains efficiency by using low-cost lenses to multiply the sun's intensity, which scientists refer to as numbers of suns. Friedman says earlier success with multi-junction cells - layered semiconductors each optimised to capture different wavelengths of light at their junctions - gave NREL a head start. The SJ3 cells fit into the market for utility-scale CPV projects. They're designed for application under sunlight concentrated to 1,000 times its normal intensity by low-cost lenses that gather the light and direct it at each cell.

In regions of clear atmosphere and intense sunlight, such as the U.S. desert Southwest, CPV has outstanding potential for lowest-cost solar electricity. There is enough available sunlight in these areas to supply the electrical energy needs of the entire United States many times over.

Bending material to the band gaps on the solar spectrum

Sunlight is made up of photons of a wide range of energies from roughly zero to four electron volts (eV). This broad range of energies presents a fundamental challenge to conventional solar cells, which have a single photovoltaic junction with a single characteristic band gap energy. Conventional cells most efficiently convert those photons that very nearly match the band gap of the semiconductors in the cell. Higher-energy photons give up their excess energy to the solar cell as waste heat, while lower-energy photons are not collected by the solar cell, and their energy is completely lost. This behaviour sets a fundamental limit

on the efficiency of a conventional solar cell. Scientists overcome this limitation by using multi-junction solar cells. Using multiple layers of materials in the cells, they create multiple junctions, each with different band gap energies. Each converts a different energy range of the solar spectrum.

An invention in the mid-1980s by NREL's Jerry Olson and Sarah Kurtz led to the first practical, commercial multi-junction solar cell, a GaInP/GaAs two-junction cell with 1.85-eV and 1.4-eV bandgaps that was recognised with an R&D 100 award in 1990, and later to the three-junction commercial cell based on GaInP/GaAs/Ge that won an R&D 100 award in 2001.

The researchers at NREL knew that if they could replace the 0.67-eV third junction with one better tuned to the solar spectrum, the resulting cell would capture more of the sun's light throughout the day. But they needed a material that had an atomic structure that matched the lattice of the layer above it - and that also had the ideal band gap.

"We knew from the shape of the solar spectrum and modelling solar cells that what we wanted was a third junction that has a band gap of about 1.0 electron volt, lattice-matched to gallium arsenide," Friedman comments. "The lattice match makes materials easier to grow."

They concentrated on materials from the third and fifth columns of the periodic table because these III-V semiconductors have similar crystal structures and ideal diffusion, absorption, and mobility properties for solar cells. But there was seemingly no way to capture the benefits of the GaAs material while matching the lattice of the layer below, because no known III-V material compatible with GaAs growth had both the desired 1-eV band gap and the lattice-constant match to GaAs.

That changed in the early 1990s, when a research group at NTT Laboratories in Tokyo working on an unrelated problem made an unexpected discovery. Even though GaN has a higher band gap than GaAs, when you add a bit of nitrogen to GaAs, the band gap shrinks - exactly the opposite of what was expected to happen.

"That was very surprising, and it stimulated a great deal of work all over the world, including here at NREL," Friedman says. "It helped push us to start making solar cells with this new dilute nitride material."

Good band gaps, but not so good solar material

The new solar cells NREL developed had two things going for them - and one big issue.

"The good things were that we could make the material very easily, and we did get the band gap and the lattice match that we wanted," Friedman says. "The bad thing was that it wasn't a good solar cell material. It wasn't very good at converting absorbed photons into electrical energy. Materials quality is critical for high-performance solar cells, so this was a big problem."

Still, NREL continued to search for a solution.

"We worked on it for quite a while, and we got to a point where we realized we had to choose between two ways of collecting current from a solar cell," Friedman says. "One way is to let the electrical carriers just diffuse along without the aid of an electric field. That's what you do if you have good material."

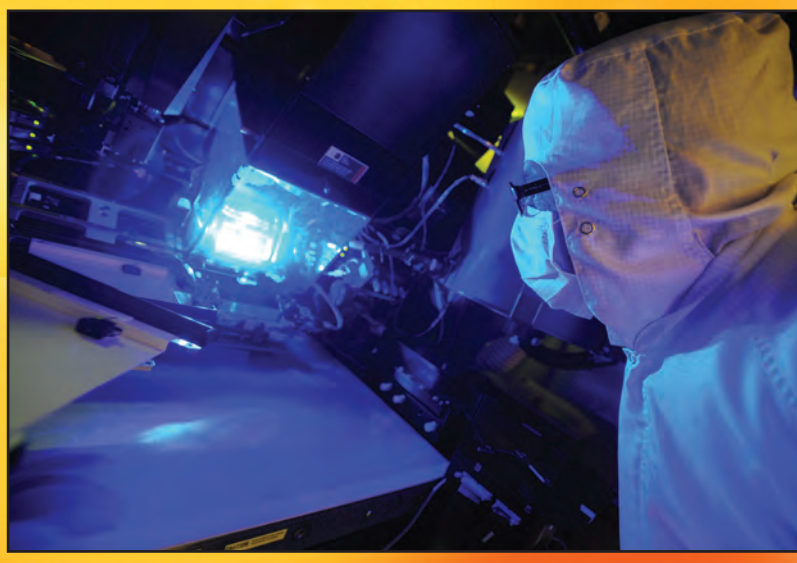
If the material isn't good, though, "you have to introduce an electric field to sweep the carriers out before they recombine and are lost," Friedman adds. But to do that, virtually all impurities would have to be removed. And the only way to remove the impurities would be to use a different growth technique.

Using molecular beam epitaxy to virtually eliminate impurities

Solar cells are typically grown using MOVPE.

"It works great, except you always get a certain level of impurities in the material. That's usually not a problem, but it would be an issue for this novel material, with the gallium arsenide diluted with nitrogen," Friedman points out.

However, a different growth technique, MBE, used in an ultra-high vacuum, (10-13 atmospheres), can lower the impurities to the point where an electric field can be created in the resulting photovoltaic junction. And that would make the otherwise promising gallium-arsenide-dilute-nitride



An operator inspects a photolithography tool used to manufacture high-efficiency Solar Junction concentrator solar cells. NREL's pioneering multi-junction work led to the Solar Junction SJ3 solar cell with tuneable bandgaps, lattice-matched architecture, and ultra-concentrated tunnel junctions. (Credit: Daniel Derkacs/Solar Junction)

NREL Principal Scientist Jerry Olson holds examples of the first multi-junction cells that were developed in the 1980s based on his scientific breakthrough

material work as a solar cell.

"The only problem was that there was no one in the entire world manufacturing solar cells by MBE," Friedman says.

But that was soon to change.

Partnering with Stanford University startup, solar junction

A Stanford University research group with expertise in the use of MBE for other electronic devices saw an opportunity. In around 2007, they spun out a startup company they named Solar Junction. Because Solar Junction was a mix of enthusiastic recent Ph.D.s and experienced hands from outside the established solar cell field, "they weren't tied to the constraints of thinking this couldn't be done, that the only economically viable way to make solar cells was with MOVPE," Friedman says.

The federal lab and the startup got together. Solar Junction won a $3 million DOE/NREL Photovoltaic Technology Incubator contract to develop a commercial multi-junction cell using dilute nitrides, and also received more than $30 million of venture-capital funding for this commercialisation effort. To see more about NREL's Incubator projects, see the NREL news release.

"So Solar Junction had this good idea. But now they had to prove that you could actually make a high-efficiency solar cell with this," Friedman continues. "Otherwise, who cares? People can make a lot of claims, but it's very simple to know whether you have a good solar cell or not - you just measure it."
It didn't take that long, Friedman points out.

By 2011, NREL had certified a new efficiency record for Solar Junction's SJ3 cell. The cell achieved an efficiency of 43.5 percent under concentrated sunlight, a significant step beyond the previous multi-junction efficiency record of 41.6 percent, and far beyond the maximum theoretical efficiency of 34 percent for traditional one-sun single-junction cells.

Dilute-nitride junction eliminates need for heavy germanium layer

With the new dilute-nitride junction, the germanium layer, which constitutes about 90 percent of the weight of the cell, is no longer needed. That may not be a big deal when it's part of a huge fixed utility-scale array. But when solar cells are used to power satellites, reduction in weight means a smaller rocket is needed to launch into space, potentially reducing costs significantly. The lighter weight is also essential for the military, which is increasingly asking soldiers to carry backpacks that include solar devices to power electronics.

Serendipitously, if the germanium substrate is retained, it has essentially the ideal band gap of 0.7 eV for a fourth junction, perfect for capturing longer wavelengths of the solar spectrum. That paves the way for a 50 percent-efficient solar cell in the not so distant future. The cost to manufacture the SJ3 cell is competitive with that of the industry-standard GaInP/GaAs/Ge cell, according to Solar Junction. Its greater efficiency translates to significant cost-of-energy savings.

According to a report released this fall from IMS Research, the CPV market is forecast to double in 2012 and reach almost 90 megawatts. The World Market for Concentrated PV (CPV) - 2012 predicts installations of CPV will grow rapidly over the next five years to reach 1.2 gigawatts by 2016.

Because of its design and size, SJ3 is an instant plug-in replacement for the standard cell now used by the space and CPV industries. So, for example, if a 40 percent-efficient cell were replaced with a 44 percent-efficient cell, this would instantly increase the entire system power output by close to 10 percent.

"This is really a classic example of NREL developing something and then industry picking it up and running with it and making it a great commercial success," Friedman mentions. "We started with some very basic materials research. We took it to the point where it made sense for industry to take over and take it to the marketplace."

"We conceived the cell, demonstrated the individual parts, and let the world know about it," Friedman comtinues. "But Solar Junction put all the parts together with record-breaking results, made it work with MBE, and commercialised it at a time when no one else seemed to be interested in or able to do it."

And now, utilities are ordering the SJ3 cells so fast that Solar Junction has depleted its pilot-scale stock and gone into partnership with manufacturer IQE to ramp up to full manufacturing scale.

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Solar growth patterns

The solar market has had exceptional growth in the last few years and continues to grow but the dynamics and regions for that growth are changing drastically. Gaëtan Masson, Head of Business Intelligence at the European Photovoltaic Industry Association (EPIA) provides a snapshot of the global PV market through 2012.

After several years of the PV market's rapid growth, 2012 was a year of market consolidation. In total, about 28.4 GW of PV capacity were installed in 2012 in countries belonging to the IEA Photovoltaic Power Systems Programme (IEA PVPS see box out) as well as other major markets. This compares to 28.9 GW in2011 and 16.7GW in 2010. This raised the total installed capacity in IEA PVPS countries close to 89.5 GW with another estimated 7 GW of capacity installed in other major countries where PV developed in the last years (India, Czech Republic, Bulgaria, Greece, Slovakia, Ukraine and Thailand).

Due to data still being collected some additional GW could have been installed in the rest of the world pushing the total installed PV capacity close to or even past 100 GW. After several years of rapid growth, the total PV market stabilized in 2012, around the 30 GW mark, with 25.2 GW coming from IEA PVPS countries and at least 3.2 GW installed in the other PV markets. The year 2012 saw the rapid growth of the Asia Pacific region and the Americas challenging Europe's prime position that has been held for a number of years. The Middle East and Africa remains a region in development for the PV market and the figures are still comparatively low.

While the three regions or countries where grid-connected PV was first developed continue to dominate the installations history, China has progressed so quickly that it represented the second largest market in 2012, ahead of Italy and the USA. Only Germany installed more PV. From a cumulative perspective China has already reached third position in terms of total installed capacity.

The evolution of growth in Asia and the Americas is quite visible from 2010 to 2012, with the share of Asia Pacific alone increasing from 17% to almost 30%, whilst the European share of the global PV market went down from 82% to 59% over two years. The fact that European installations grew shows the strength of the global market place.

PV technology today has become a major player in the electricity sector globally. At least 110 TWh, or 110 billion kWh will be produced in 2013 by PV systems already installed. This represents around 0.5% of the global electricity demand suggesting some countries have reached significant renewable percentages in their electricity mix.

In Europe, for the second year in a row, PV was the largest source of electricity installed (power-wise), ahead of wind and gas, and ahead of all other sources of electricity, from coal to nuclear. Several countries in Europe have now reached a point where the PV contribution to the electricity demand has passed the 1% mark. Italy has the highest ratio with 5.7% of electricity demand being met by solar energy with Germany closely following with 5.6%. The overall European PV contribution is currently around 2.5% of the European demand.

Australia has also passed the 1% mark but larger consumers of electricity such as Japan, China or the USA will require more

What is IEA-PVPS

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The IEA carries out a comprehensive programme of energy cooperation among its 28 members and with the participation of the European Commission. The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the collaborative research and development agreements within the IEA and was established in 1993. The mission of the programme is to "enhance the international collaborative efforts which facilitate the role of photovoltaic solar energy as a cornerstone in the transition to sustainable energy systems."

In order to achieve this, the Programme's participants have undertaken a variety of joint research projects in PV power systems applications. The overall programme is headed by an Executive Committee, comprised of one delegate from each country or organisation member, which designates distinct 'Tasks,' that may be research projects or activity areas. This report has been prepared under Task 1, which facilitates the exchange and dissemination of information arising from the overall IEA PVPS Programme.

The participating countries are Australia, Austria, Belgium, Canada, China, Denmark, France, Germany, Israel, Italy, Japan, Korea, Malaysia, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States of America. The European Commission, the European Photovoltaic Industry Association, the Solar Electric Power Association, the Solar Energy Industries Association and the Copper Alliance are also members. Thailand is in the process of joining the programme.

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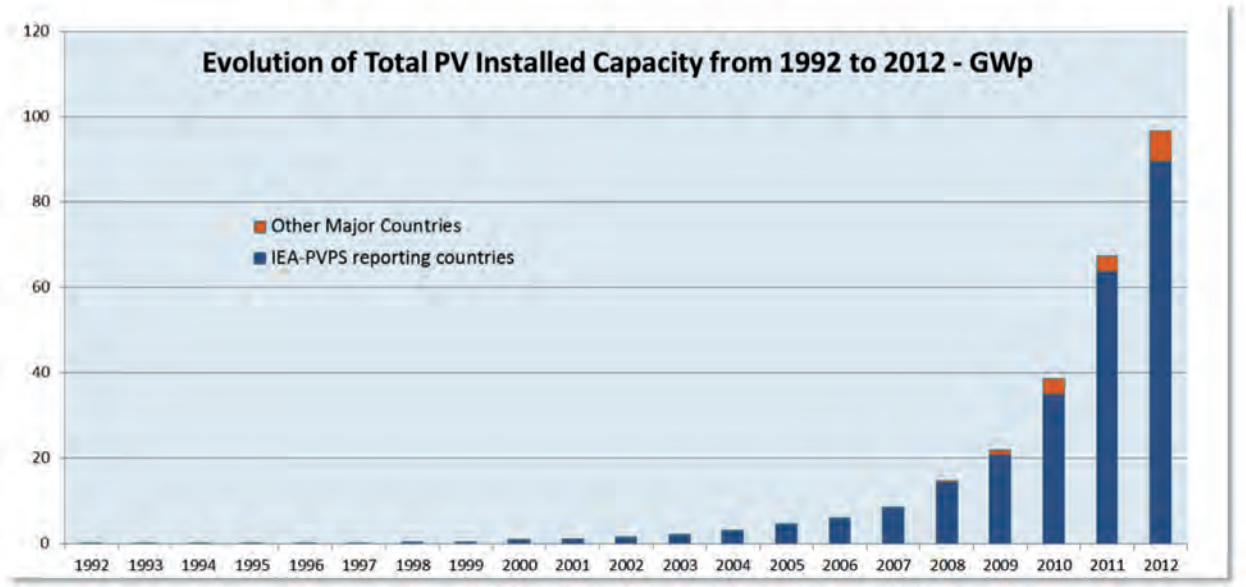


Figure 1 – Evolution of Total PV Installed Capacity from 1992 to 2012

Figure 2 - Evolution of regional share of PV installations from 2010 to 2012

installations to reach this threshold. An interesting fact about the global PV industry with the recent growth is that the surface area that is covered by PV panels around the world represents roughly 700 square kilometres, or the size of Singapore.

The very fast decline in PV system prices in 2012 has allowed the market to maintain itself at the very high level it first experienced in 2011. Moreover, the current system price levels are unlocking new possibilities for PV development in numerous countries.

IN the coming years all signs are pointing to the Asia Pacific region becoming the major market and provider for the global market. This does not mean other regions will not have healthy markets in their own right with Europe and the Americas continuing to provide solid numbers in installations. There are also emerging markets that will provide new impetus in the coming years. Many of these new markets are applying to become members of the IEA-PVPS with Thailand currently under consideration. Finally, PV has become a major source of electricity extremely rapidly in several countries all over the world. The speed of its development holds in its unique ability to cover most market segments, from the very small individual system for rural electrification to utility-size power plants (above 100 MW). From the built environment to large ground-mounted installations, PV finds its way depending on various criteria that make it suitable for most environments.

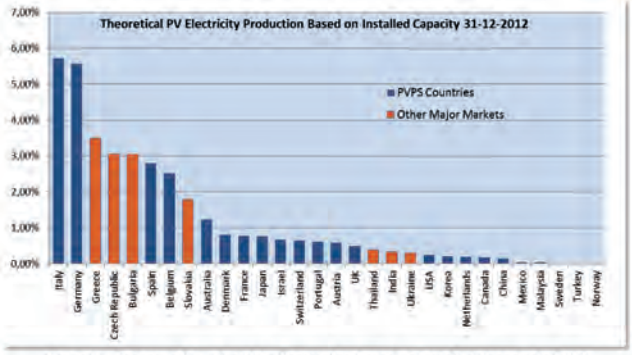
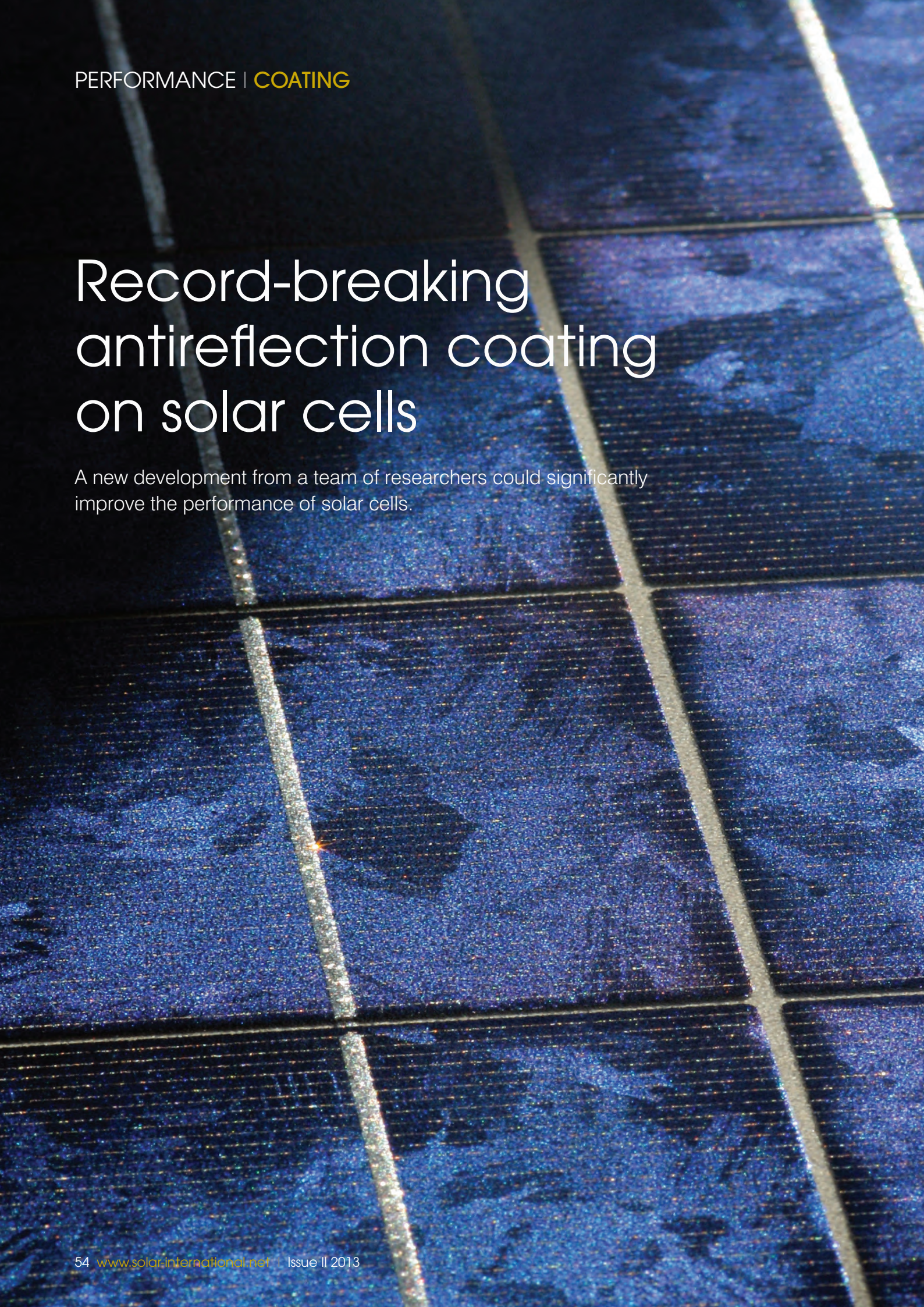
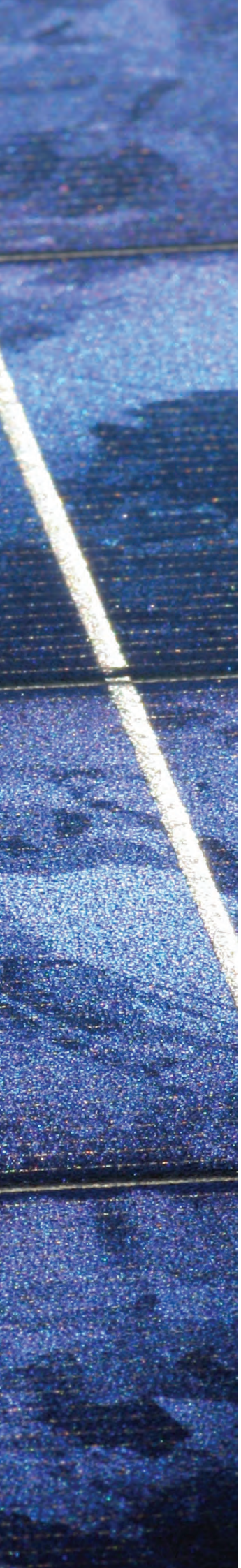


Figure 3 – Theoretical PV Electricity Production Based on Installed Capacity in 2012

Record-breaking antireflection coating on solar cells

A new development from a team of researchers could significantly improve the performance of solar cells.





A team of researchers from Rensselaer Polytechnic Institute (RPI), Magnolia Solar, Inc. and Pohang University of Science and Technology have demonstrated a novel antireflection (AR) coating. It beats the widely employed double-layer AR (DLAR) coating on state-of-the-art triple-junction solar cells.

The scientists demonstrated that the solar cells investigated gain over 4 percent in efficiency when replacing the industry-standard DLAR with an optimised four-layer AR coating. What's more, omnidirectional AR characteristics have become important for the rapidly expanding terrestrial application of solar cells. This is because solar irradiance in terrestrial applications usually has a large range of incident angles for non-tracking solar cells.

Both broadband and omnidirectional AR characteristics are attainable by four-layer AR coatings, as demonstrated by the RPI-led team. RPI says that the excellent broadband and omnidirectional AR characteristics of the four-layer AR coating are achieved through solving the problem of refractive index matching at multiple layer interfaces.

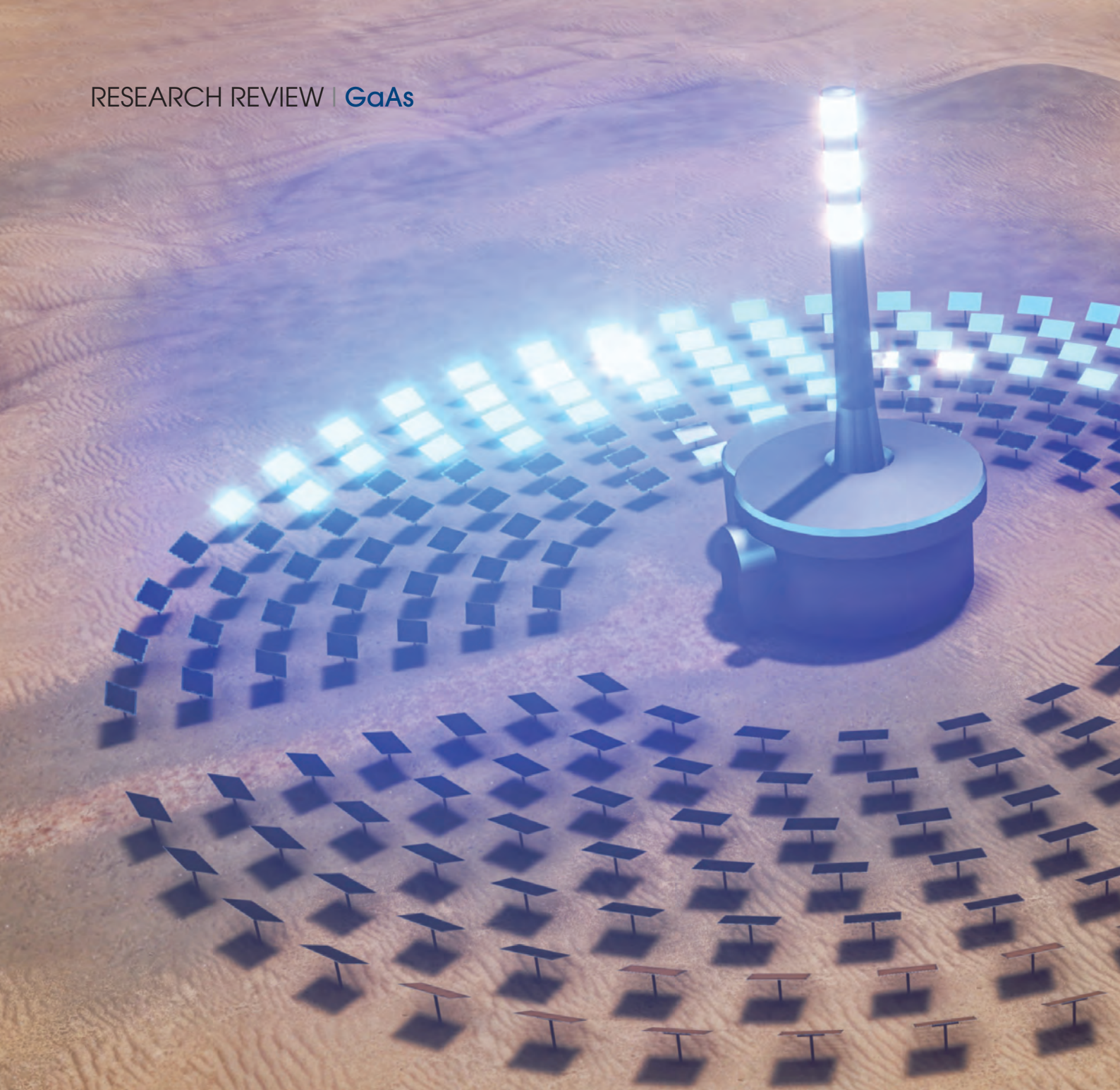
By using tailored and low-refractive index nanoporous silica layers, the team has greatly reduced the refractive index contrast at the semiconductor / AR coating / air interfaces. Through a multilayer design methodology powered by a genetic algorithm optimisation, favourable antireflective properties over a specified wavelength range and angle-of-incidence range were found.

Two porous layers of the four-layer AR coating were fabricated by oblique-angle deposition of silica thereby resulting in films with refractive indices of 1.32 and 1.11. This is less than the refractive index of silica. The other two layers are dense and were fabricated by co-deposition of silica / titania using sputtering.

According to the photocurrent measurements performed by the team, the angle-of-incidence (0°- 80°) averaged photocurrent enhancement (over an uncoated triple-junction solar cell) of the four-layer AR coating amounts to 34.4 percent. The enhancement of a DLAR coating is only 25.3 percent. In the future, the team members Jaehee Cho and E. Fred Schubert, will integrate this novel AR coating technology on surface-textured devices. They will also investigate innovative fabrication methods for depositing low-refractive index AR coatings on curved surfaces, such as a hemispherical lens.

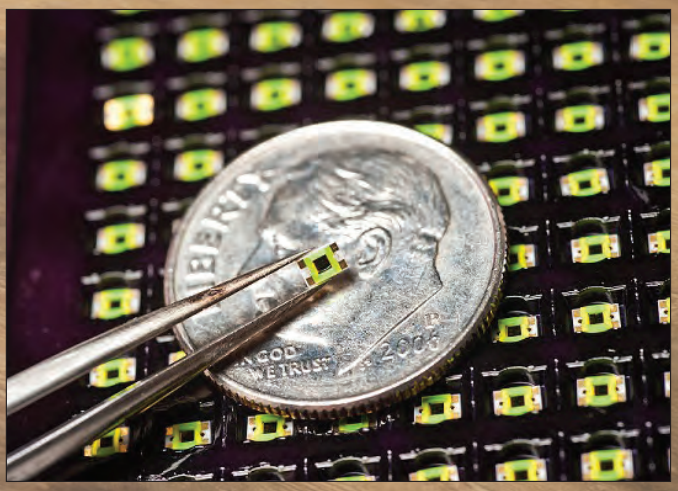
Further details of this research are described in the paper, "Enhanced Omnidirectional Photovoltaic Performance of Solar Cells Using Multiple-Discrete-Layer Tailored - and Low-Refractive Index Anti-Reflection Coatings," by X. Yan et al in Advanced Functional Materials, 23, 583 (2013).

Considering that the solar spectrum is an intrinsically broadband spectrum, such broadband characteristics of the AR coating are undoubtedly beneficial for high power conversion efficiency



Novel solar cells weather industry doldrums

GaAs photovoltaic developer, Semprius, looks set to shine in a solar market where so many are fading.



Semprius modules use hundreds of GaAs solar cells with lenses to concentrate light, boosting the efficiency and making the exotic photovoltaic affordable

After years of development, the concentrated solar power sector finally looks set to take off. Middle East governments recently pledged to spend tens of billions of dollars on large-scale plant at the United Nations Climate Change conference, validating analysts' forecasts of healthy growth.

But just as the market looks promising, the CPV companies are floundering. California-based market leader Amonix recently closed its Nevada manufacturing site, swiftly followed by the demise of Greenvolts, also based in California. And then a few weeks later, San Jose-based SolFocus announced plans to sell, dismissing half of its staff, some 35 employees.

North Carolina-based CPV manufacturer, Semprius, has bucked this trend. In September this year, the firm opened its first manufacturing plant in North Carolina, employing 50 staff poised to produce some 6MW of panel a year. And then in November, the company revealed that US-based Pratt & Whitney Rocketdyne is to install a 200kW system comprising 2400 of its modules at the US Department of Defense Edwards Air Force Base, in the California south-west desert. As Russ Kanjorski, Semprius's vice president for business development, tells Solar International: "This is the perfect location to test our technology for future applications... and is just one commercial-scale project we expect to do in 2013."

So what's its secret? On its website, the company claims to have combined very high module efficiencies - up to a dazzling 33.9% - with industry-standard, low-cost microelectronics manufacturing techniques.

The company's modules comprise hundreds of triple junction GaAs solar cells mounted on an industry-standard backplane. Measuring only 600 by 600 by 10 microns, each cell is minuscule compared to your standard centimetre-sized cell and is designed to convert a relatively wide part of the solar spectrum into electricity, compared to silicon.

However, Kanjorski believes the company's success is also down to the way in which these cells are fabricated, which allows repeated use of the GaAs wafer. Semprius co-founder Professor John Rogers has pioneered a 'micro-transfer printing' technique in which a sacrificial layer is first grown on a GaAs wafer, followed by epitaxial growth of thousands of triple-junction cells. Then, in a massive parallel process, a rubber stamp selectively picks up and transfers an array of cells to an alumina receiver substrate. The stamp is then re-positioned over the GaAs wafer ready to pick-up and transfer more cells to another receiver substrate.

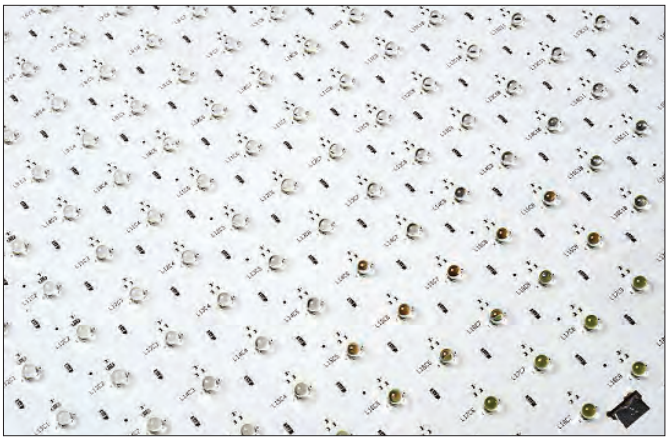
"We receive GaAs wafers from companies like Spectral Lab and Solar Junction and process these into cells," he explains. "We don't cut up the entire wafer as other [CPV manufacturers] do, we just take the top layers and then re-use the substrate."

Kanjorski won't reveal how many times an actual wafer can be used, only commenting 'multiple times' but does add that a single six inch GaAs wafer can be used to fabricate enough cells for up to 50 modules. "We re-use the majority of the wafer, this is an important cost-saving when creating very small cells," he adds. A thin film metallization process follows to form the cathode and anode interconnection, with receiver substrates then surface mounted onto printed-circuit boards using industry standard solder re-flow. These are then placed beneath primary and secondary lenses that concentrate sunlight 1100 times, in effect, increasing materials use by 1100 times, crucial when fabricating cells from expensive GaAs wafers..

"Our optics are different," adds Kanjorski. "We have a primary lens that concentrates the light and a novel secondary optic- a simple glass bead - that can keep the light on the cell if you are slightly off-axis from the sun."

Then factor in that Semprius's modules do not require cooling systems - the small cells generate less heat - and the cost-savings really adding up. So, perhaps this explains how, in just seven years, the North Carolina start-up has bagged some $40 million in funds, built a 6MW pilot plant and now intends to ramp annual production to 80MW come 2014.

Kanjorksi isn't phased by the CPV industry's mixed fortunes. "This is a consolidating period of the industry, but it's not unique to concentrated photovoltaics or even solar power in general," says Kanjorksi. "We've kept our heads down on developing our modules and have tried to develop the most cost effective, high performance module we could. We think it's the best on the market and now we have to ramp that up."



The GaAs is the black square on each cell; Semprius's micro-transfer printing process is poised to make these exotic solar modules cost effective

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Solar cycle to set record in traverse across Sahara

STARTING AT THE END OF APRIL, Simon Milward, 36, will attempt to be the first person to ride across the Western Sahara Desert powered only by a solar panel (with no pedaling and no external energy source). His challenge is being supported by AKT Solar and powered by an AKT Solar panel.

Simon Milward begins his journey at Guelmin in Southern Morocco and travelling 1,200 km – the full length of the Western Sahara Desert – until he reaches the border with Mauritania. The challenge is expected to take two to three weeks, and Simon will be raising money for OXFAM.

Simon Milward said "The Sahara Desert is awe-inspiring in its scale, cutting right across northern Africa, from the Atlantic Ocean to the Red Sea and dominating 11 African countries. In the two to three weeks it will take to cycle across the desert, the solar panel on my bike will generate over 30,000W of electricity. In homes without access to mains electricity, this would be enough to provide light at night for over two years.

"This will really show the potential of solar power. Solar energy is a versatile, pollution-free and inexhaustible fuel source that can supply electricity anywhere in the world. Every hour the Earth receives enough energy from the sun's rays to satisfy global energy needs for an entire year and yet we still have over 1.2 billion people – 20% of the world's population – who don't have access to electricity. If we can help spread this technology to where it's most needed we could make a real difference to so many people's lives."

"It should also be an excellent adventure." He added.

In order to make the most of the sunlight Simon will be riding for around 10 hours a day with few or no rest stops. The solar photovoltaic panel produces about 27V dc directly from the sunlight and this electricity feeds into the brushless electric motor in the hub in the rear wheel of the bike. The power from the panel is greatest when the sun is shining directly on it but it also produces electricity in cloudy or overcast conditions, which is fortunate in the Sahara as the scirocco wind can cause dust storms rivaling even the foggiest weather in the UK.

Simon has registered his plan with Guinness World Records and the money Simon raises will go to the charity OXFAM.

Solar visionary honoured with charity run

BRIAN ROBERTSON was the Chief Executive Officer at Amonix, Inc., a company specializing in the design and manufacture of utility-scale solar power systems, headquartered in Seal Beach, CA. Brian was a successful entrepreneur, dedicated solar pioneer and visionary for a greener future. Within his working life he always made time for others and was a keen encourager of education and supporting young people. Sadly Brian died in a plane crash on December 22, 2011.

Brian and his wife Eileen and their children Melanie, Brooke and Max, often devoted time and energy to earth-friendly and family-focused activities. In keeping with this theme and in a positive way to maintain his memory and continue his work, Brian's family hosted an Earth Day fun run at the end of April 21 in his honour.

The BDR Earth Day Family Fun Run is a community service event celebrating Earth Day in addition to celebrating Brian's legacy and impact on environmental science and technology. All proceeds from the BDR Fun Run will go to the Brian D. Robertson Foundation. The event, which features a one mile run as well as a 5K and 10K, will raise funds for the BDR Solar Schools Foundation, which was created in memory of Brian Robertson.

Organizers say they envision the event becoming a day dedicated to Earth Day activities and awareness. Local sponsors and other community organizations had tents with family-friendly activities pertaining to Earth Day. Fifty percent of the proceeds raised from the run will go towards the BDR Solar Schools Foundation. The remaining 50 percent of the proceeds will go to local organizations.

Robertson died piloting his plane to Newtown for Christmas in 2011. He was a solar pioneer who created and led three major solar companies across North America. The Foundation was created by his family to introduce students to solar power with a goal of having a total of 20,000 solar energy systems installed at K-12 schools across the nation by 2020.

"The 20/20 Vision of Solar in America will put solar electricity within reach of millions of students across the country, a goal that embodies Brian's belief that education is critical in developing a green energy economy and strengthening our nation's future," according to a press release.

The Brian D. Robertson Foundation supports organizations and causes that were most important to Brian Robertson, including the YMCA Indian Princess/Guide Program, the Solar Foundation, The Montesorri Greenhouse Academy, the Orange County Community Foundation and the American Heart Association.

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