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view point

Never mind the rhetoric

UNCOVERING the real costs and challenges of integrating renewable energy with legacy electric grids should be easier. Renewables' share of worldwide energy markets has grown dramatically since 2008. We have experience to guide us, but the swirl continues.

A recent report from the International Energy Agency (IEA) entitled Next Generation Wind and Solar Power seeks common ground. The report attempts to dispel rumors, present facts, and bring a new measure to the discussion. That measure, variable renewable energy (VRE), is proposed to replace levelized cost of electricity (LCOE), which typically excludes some long-range fuel costs and other factors when calculating the relative worth and cost of renewable resources.

The IEA concluded after studying six markets in very different regions that integration problems were insignificant when the share of wind, solar and hydro was in low, single-digits. Integration here '…poses few technical and economic challenges…' they said.

As percentages rose, more coordination and planning was required; older infrastructure might need upgrades such as adding smart grid technologies. The IEA also found that existing operator load balancing practices were typically adequate to balance central and distributed power. It was only when renewables (VREs) dominate a system as they do in Denmark that large-scale cooperation and planning was needed. The IEA qualified its findings by noting that integration challenges depended largely on factors such as system age, the percentage of renewables, and whether utility operators had mixed-generation experience.

Some have already found fault with the IEA, pointing to Denmark's reliance on a robust international electrical grid and resources like hydroelectric to supplement its daily energy cycles somehow points to worrying prospects for successful integration. They are missing the point. The fact that Denmark has been successful is because they planned and their strategy took advantage of electrical grid balancing technology and techniques that already cross international borders whether the power comes from wind, the sun or burning fossil fuels. The fact smooth operation already occurs points to system robustness and the potential to evolve as generation means change.

PV, wind and hydro resources are entering the worldwide energy mix in greater proportion than ever because renewable resources – once cost-effective – make more sense for the long-term health of the planet; they are also good business. It is no longer a question of whether we can integrate, it's a question of how effectively we plan for integration; this requires citizens, power utilities and governments to quit raising spurious arguments, and roll up their sleeves.

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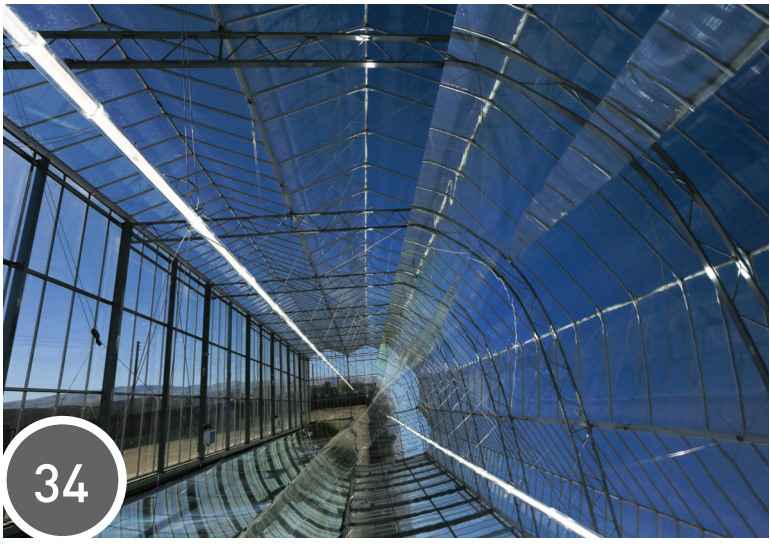

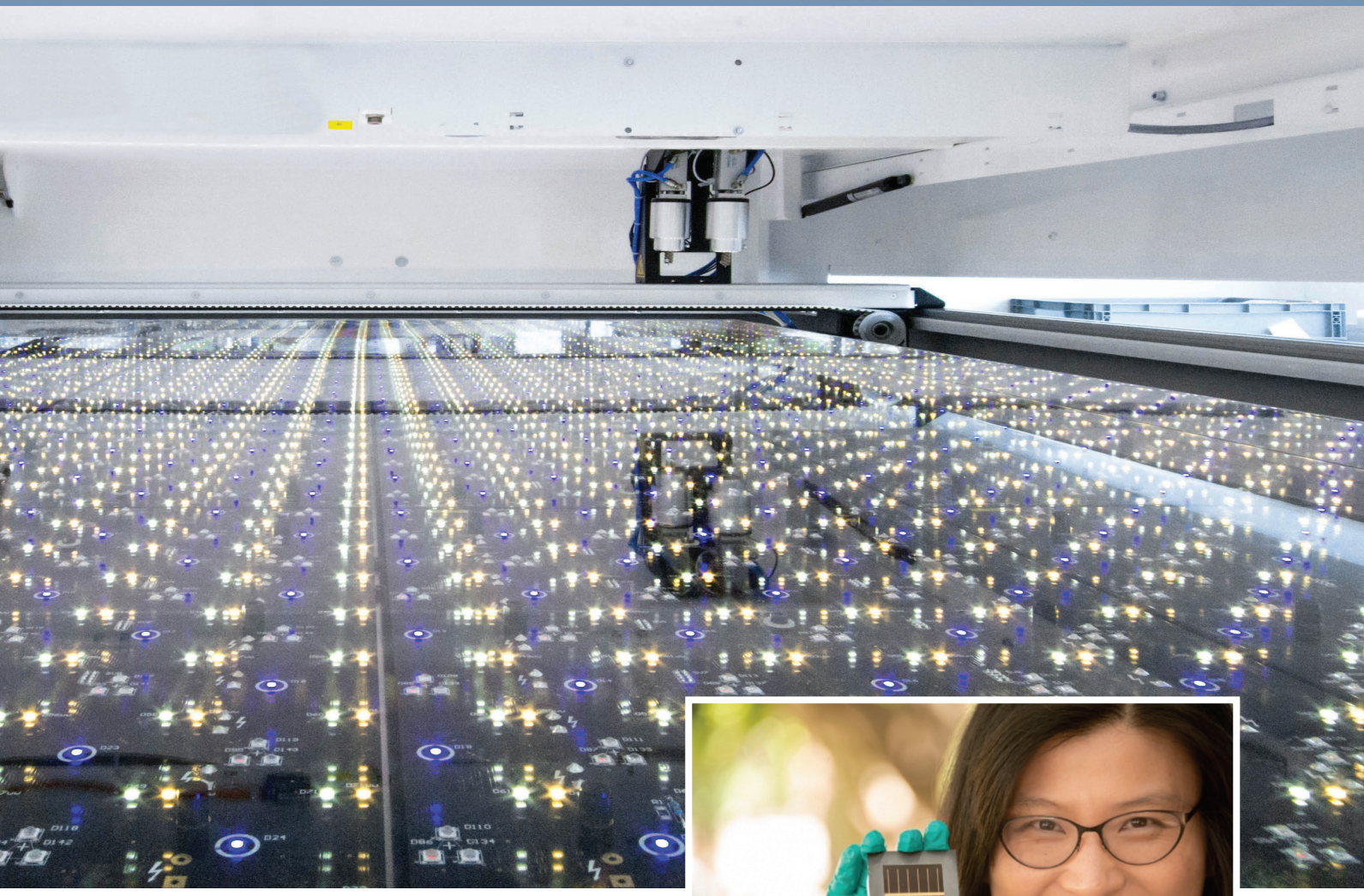

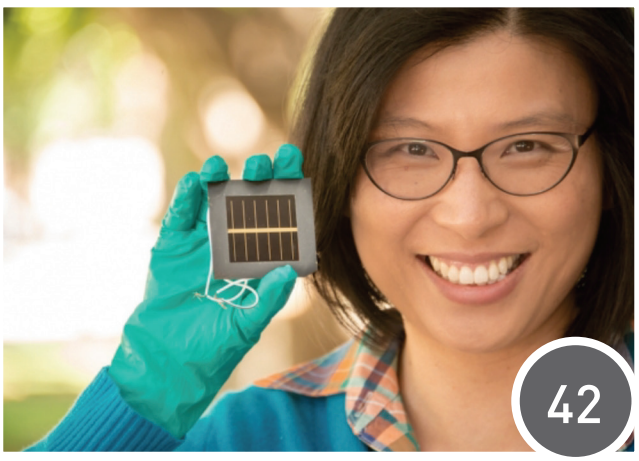

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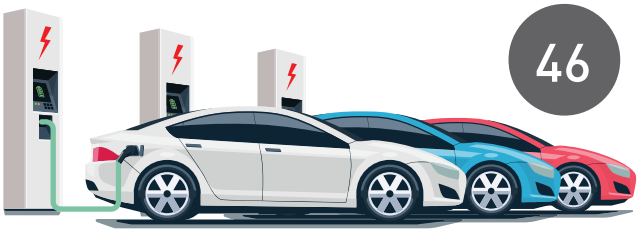


industry news...

Tesvolt develops next-generation storage system

THE COMMERCIAL storage system manufacturer Tesvolt collaborated with Samsung SDI to develop a high-voltage storage system which is setting new standards for safety and also boasts a 30 year lifespan. The battery contains Samsung SDI's new prismatic lithium cells, which BMW recently introduced into their electric cars, thereby almost doubling their range. Each cell is monitored individually to ensure the maximum level of safety. A new cell balancing concept, which for the first time optimises the charging currents not only between the cells within each battery module, but also between the battery modules, contributes to the long service life. Tesvolt will present the new storage system at the Energy Storage Europe trade fair in Düsseldorf.

"The new lithium cells from Samsung SDI are currently opening new doors in the electric automobile industry. Alongside BMW, other automotive manufacturers want to focus on these prismatic, lithium cells based on nickel manganese cobalt oxide, as their enormously high energy density can double the range of electric cars", explains Simon Schandert, Director of Engineering at Tesvolt. "We are combining the new cells with the Active BAT Optimizer – our special battery management system – to ensure active cell balancing between all cells, even between the different battery modules. This allows us to achieve an extremely high battery system efficiency of 98%, and a lifespan of around 30 years", adds Schandert.

The new Tesvolt storage system can complete around 6,000 full charge cycles with a depth of discharge (DoD) of 100 percent, which means that the entire battery capacity can be used. The storage system functions just as well with a low voltage of 48 volts as with a high voltage of 1,000 volts for stationary commercial and industrial applications. "We are delighted to have collaborated with the young, technology-driven company Tesvolt to develop this next-generation high-voltage storage system. The combination of our cells and the Tesvolt battery management system raises the bar in terms of service life and safety. With this premium product, we are continuing to do our bit to promote sustainability efficiently and economically around the world", says Sewoong Park, Vice President of the Energy Storage System Team at Samsung SDI.

Thanks to an integrated cell safety device and overcharge protection, it is impossible for Samsung SDI cells are fire proof, and a pressure relief valve additionally ensures that there is no danger of explosion. The ceramic protective layer within the cell slows down the aging process, thus extending the chemical service life of the lithium battery. At the same time, Tesvolt's smart battery management system monitors the state of each individual cell to prevent damage at an early stage. Battery modules can be exchanged at any point, even years later, and the storage capacity can also be expanded years down the line. Other commercially available lithium storage systems only have the technical capacity to address these two issues within approximately the first year.

The battery storage system is available in all sizes from 4.8 kWh up to power stations with multiple MWh, and clients can assemble their preferred capacity themselves based on 4.8 kWh modules.

Scottish solar manufacturer chosen to work on European project

A SCOTTISH manufacturer of solar panels is the only company of its kind in Europe to have been selected to work on an EU wide project which will promote the development of renewable technology.

AES Solar based in Forres, Moray received a quarter of a million pounds in funding to provide its expertise in the design of solar thermal and solar pv systems.

The firm which was established in 1979 and is the longest running solar thermal manufacturer in Western Europe will work alongside other researchers and companies who specialise in other renewable measures in Spain, Italy, Denmark, Hungary, Bulgaria, Poland, Belgium in the Heat4Cool project.

Grant Feasey, senior design engineer with AES Solar said he was delighted to be working on the project:

"I'm thoroughly enjoying the work on the Heat4Cool project. It is fantastic that we have been selected and are able to contribute our expertise. It's a real accolade for us that we were the solar company that were selected to represent solar from thousands of companies and researchers in the whole of Europe. It just reaffirms that AES Solar are the experts when it goes to solar installations."

Grant who has worked with AES Solar for six years and has attended one

meeting in Brussels and will soon be heading to Bilbao for the next project gathering added:

"The purpose of the project is to create a fully integrated system using all the different renewable measures available, making them work together in the best way. It means we are working with high level partners across Europe and are networking with top industry players. It will also give us new expertise in other renewable energies and will mean that we can identify more opportunities for the business."

Infinity Solar, ib vogt and Solizer secure solar plant under Egyptian FiT

EGYPTIAN-BASED company Infinity Solar S.A.E. and German-based companies ib vogt GmbH and Solizer GmbH & Co. KG have announced the successful closure of a 64.1 MWp solar power plant project in Benban, Aswan, Egypt by the Infinity 50 consortium of which they are members.

The project was approved by the Egyptian Electricity Transmission Company on 6 March 2017, confirming financial close under the first round of the Egyptian Feed-in Tariff (FiT) programme. As part of one of the largest utility-scale grid-connected solar power complexes in the world, the project represents a landmark in the development of renewable energy infrastructure in the MENA Region.

The Infinity 50 Solar Park will comprise a 64.1 MWp solar array over an area of 98.6 ha with almost 200,000 solar panels mounted on a state-of-the-art horizontal tracking system. Once operational, the plant is expected to produce over 110,000 MWh per year, equivalent to the electricity required to power almost 69,000 homes, while preventing over 1,293,000 t of CO2 emissions during its 25-year lifetime. The project is part of the Benban solar development complex with a total capacity of up to 1.86 GW, which will be one of the largest solar generation facilities in the world when completed.

The Infinity 50 project was jointly developed by Infinity Solar S.A.E, ib vogt GmbH and Solizer GmbH and obtained project financing from Bayerische Landesbank for 85% of the debt, with the remaining 15% coming from Arab African International Bank. The loan is covered by the German government through a Euler Hermes ECG.

“We are very pleased to have secured this project and to have been one of the very few consortia able to successfully qualify for the landmark Egyptian round one programme. This is the culmination of many months of preparatory work in what has been a very complex project, representing a very significant investment for the company. It also demonstrates the company’s ability to manage and structure such an undertaking. We would like to thank all of our partners for their efforts in assisting the consortium to secure the qualification for the project, the PPA and to achieve financial close. We look forward to constructing the plant and helping to bring much needed sustainable electricity with all its associated benefits to the country in 2017”, says Anton Milner, Managing Director of ib vogt GmbH.

“We are very proud to have secured this project under the FiT Round one qualifications. We would like to thank all our partners who helped us with this landmark achievement. We look forward to operating the plant in 2017, helping the country to achieve its goals in increasing renewable energy production in its total energy mix”, says Mohamed Mansour, Managing Director of Infinity Solar S.A.E.

“We are excited about this key milestone, demonstrating, together with our partners, our ability to develop and structure such projects in the region”, says Lars Buesching, Managing Partner of Solizer GmbH & Co. KG. The consortium was one of the three out of a total of 39 local and international developers to meet the round one FiT requirements and strict deadlines.

The solar power plant will be constructed and commissioned by ib vogt GmbH as the EPC contractor and O&M services provider. The project will create over 400 jobs in the region during the construction phase. Construction of the plant is already underway and energisation is planned to be reached by early Q4. Once energised, the plant’s entire electricity output will be sold to the Egyptian Electricity Transmission Company (EETC) pursuant to the signed 25-year Power Purchase Agreement and other contracts.

Large-scale energy storage solution for German market

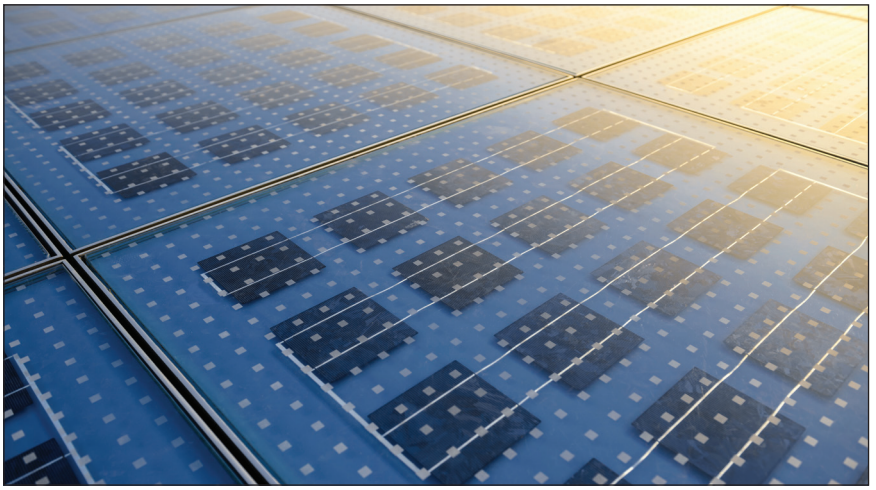
TrinaBESS has announced that the company will introduce its large-scale Energy Storage Solution ‘TrinaMega’ for German Market at Energy Storage Europe 2017, held in Dusseldorf.

TrinaMega is a modular design of thousands of lithium-ion battery cells, integrated and controlled by advanced software giving a futurealternative to traditional methods by assisting transmission, generation and distribution networks. “With advanced battery technology and intelligent Battery Management System, TrinaMega has a big success in UK and Africa market. Now we are working on a Triad and Frequency Regulation project in UK and a micro-grid energy storage project in Mauritania. TrinaBESS provides turnkey solution to the project owners including the consultancy session, solution design, component survey, procurement, system integration, construction, on-site training, commissioning and the demonstration of performance.” said Frank Qi, General Manager of TrinaBESS. “We have conducted an in-depth analysis of German market and found our solution to meet the needs of this market.

With more and more penetration of renewable energy in Germany, large-scale energy storage will be the next big potential market. TrinaBESS has an experienced integrated storage solution team to work on the sophisticated nature of large-scale projects with TrinaMega. Our highly professional engineering team ensures the high efficiency and excellent reliability of our products.” TrinaMega for the electric grid can provide benefits to customers, utilities companies and grid network operators. It can also operate as flexible resources that fulfil multiple grid assisting applications on the generation, transmission and distribution side.

Solliance achieves 12.6 percent efficiency record

SOLLIANCE, a cross-border Dutch-Flemish-German thin-film photovoltaics research initiative, has demonstrated an industrially-applicable roll-to-roll process to produce perovksite solar cells, achieving a record 12.6 percent conversion efficiency on cell level.



Solliance is a joint venture of ECN, TNO, Holst Centre and Imec, that is focusing on using scalable, industrial processes towards the fabrication of large-area modules, eventually suitable for seamless integration in a broad variety of PV systems. Its academic partners are TU Eindhoven, University of Hasselt, TU Delft and Forschungszentrum Jülich, and its industrial research partners include Solartek, Dyesol, Nano-C, Panasonic, VDL Enabling Technologies Group (VDL ETG), Smit Thermal Solutions and Bosch-Rexroth.

The roll-to-roll (R2R) process was developed for both the electron transport and the perovskite layers on the new Solliance dual R2R coating line, as developed by Solliance with partners VDL Enabling Technologies Group (VDL ETG), Smit Thermal Solutions and Bosch-Rexroth.

The in-line roll-to-roll coating, drying and annealing processes were executed at a linear speed of 5 m/min on a 30 cm wide commercial PET/ITO foil and under ambient conditions.

After applying a newly developed off-line single device finishing step, individual solar cells of 0.1cm^2 achieved efficiencies of up to 12.6 percent, measured under maximum power point tracking conditions during 5 minutes. All process steps on this roll-to-roll line were performed using low cost materials whilst keeping the process temperatures below 120°C. This shows the high-volume production potential of this new emerging thin film PV technology.

“The demonstration of R2R processing at 5 m/min of perovskite layers for solar cells indicates that high-volume production, and hence with an expected very low cost, will be possible in the future”, explains Pim Groen, professor of SMART materials at the Technical University of Delft and program manager at Holst Centre/Solliance. “These results show that the Solliance research partners, with their in-depth know-how on processing of thin film PV devices and their extensive sheet-to-sheet and roll-to-roll pilot production infrastructure, are excellently placed to realise this upscaling.”

VDL ETG has been leading the consortium of equipment manufacturing companies that designed and built the innovative R2R coating line. VDL’s CEO Willem van der Leegte comments: “I am very pleased with this world record. It shows that combining process know-how at Solliance with capabilities of high-tech equipment companies in this region can deliver very powerful results that potentially open up completely new business opportunities.”

Richard Caldwell, Dyesol’s MD remarked: “Dyesol is very pleased with this breakthrough; we are committed to developing the industry standard for R2R Perovskite Solar Cell (PSC) PV manufacturing in conjunction with Solliance and this result is an important step along this route. This pioneering work confirms that Dyesol and its partners retain a global leadership position in the industrialisation of PSC Technology, and in particular, its continuous R2R processing for flexible BIPV applications - a core element of its commercialisation strategy.” The current world record efficiency of a small lab scale perovskite-based PV cell is 22.1 percent.

“The challenge is to upscale perovskite cells to larger size, industrially-manufacturable modules with high efficiency and long lifetime at low cost. These 12.6 percent R2R up-scaled perovskite-based solar cells are a first and important step in this development. With this result, we are confident to quickly boost the up-scaled perovskite based PV module efficiency above 15 percent by using low cost materials and processes. Furthermore, we are working hard to improve the stability of these devices under real life operational conditions”, explains Ronn Andriessen, program director at Solliance.
Thanks to its high power conversion efficiency and flexible and light-weight nature, thin-film perovskite PV technology is widely considered as a future key technology for the building-integrated photovoltaics (BIPV) market. It can be seamlessly integrated in building elements, on curved surfaces and can be made semi-transparent.

Combining the industrially-applicable manufacturing processes with Solliance’s proprietary back-end interconnection process allows the creation of perovskite-based PV modules with any form and shape and any desired current-voltage output. These properties will enable customised and aesthetic integration of solar modules for infrastructure, building and vehicle-integrated PV products.

Stion CIGS modules outperform silicon

RESULTS from a multi-year performance comparison by Sandia National Labs reveal that Stion's 'Simply Better' CIGS technology outperformed mono-crystalline by as much as 6 percent. Testing was completed at three climatically distinct US DOE Regional Test Centres (RTCs) in NM, FL and VT.

In the test, Stion's modules outperformed expectations by 1 percent based on their nameplate power ratings. In contrast, the c-Si reference arrays at the RTCs underperformed by 5 percent relative to their rated power. The study which is based on the 'relative efficiency' or performance relative to the nameplate rating of the modules began in January 2014 and was lasted two years.

Not only do the Stion modules slightly outperform their rated capacity but, as irradiance (the amount of sunlight hitting the panels) increases, the efficiency of the Stion modules also increases, which is not generally true of c-Si modules. Stion modules also offer an advantage in northern regions. In Vermont, Sandia observed that Stion's frameless modules shed snow faster than the adjacent monocrystalline framed modules. Stion has observed the same phenomenon in other snowy regions. The accelerated shedding is due to the frameless configuration, which allows snow to slide off the panel without obstruction and to the panels' black aesthetics, which result in snow melting faster once the sun reappears after a storm. This translates into an increase in energy production and therefore a higher return-on-investment

"It's important for companies to have a good understanding of how weather will impact their products over time. The RTC collects and analyses high-quality data to give U.S. companies such as Stion the information they need to ensure their products perform well in a variety of climates," says Joshua Stein, a Sandia photovoltaics researcher and director of the RTC program. The US DOE RTC program, which is funded though the DOE's SunShot Initiative and managed by Sandia for the DOE, aims to increase innovation in the US solar sector by rigorously evaluating the performance and reliability of new solar technologies across multiple climates.

LONGi Green Energy revenue doubled in 2016

LONGi Green Energy Technology's 2016 financial results show that the company posted RMB11.531 billion in revenue, an increase of 93.89 percent from last year, and net profit of RMB1.547 billion, a significant increase of 197.36 percent from 2015. LONGi's noticeable improvement in performance is due to the company's successful effort in breaking free from traditional business model of relying solely on solar wafer, and adding module business to drive revenue growth. Last year, solar module sales reached RMB5.7 billion, surpassing sales of silicon wafer (5.075 billion yuan), and became the company's revenue "cash cow."

The module business gross margin of 27.2 percent is far higher than that of the solar cell and polycrystalline silicon businesses, and is closing in on the 28.16 percent margin for wafer business. The healthy profit margin led to the net profit of RMB1.547 billion for the year. LONGi will continue capacity expansion for solar cell and module business.

A few projects are well under way: 500 MW solar cell and module fab in India, vertically integrated ingot/wafer/cell/module, facility in Kuching, Malaysia, including 500MW cell and module, and 2GW cell and module manufacturing lines in Taizhou.

Meanwhile, in February of this year, leading research firm Bloomberg New Energy Finance, included LONGi Solar (formerly Lerri Solar) in its Tier 1 module supplier list.

Swiss logistics firm invests in Delta inverters

THE FIRM Rieser + Vetter specializes in transportation of goods and materials throughout Switzerland that are large, bulky or delicate, such as fine furniture.

To offset the carbon from the fuel-powered lorries used by the firm the owners decided to install a rooftop PV system at their Frauenfeld distribution center. Besides the environmental benefits, the solar PV system has financial benefits in Switzerland with its feed-in tariff concept. The solar power generated receives an annual remuneration which offsets the operating costs of the firm.

Fuchs Wohnbau AG Solartechnik was selected for the system engineering and main turnkey construction of the solar project.

PV arrays were installed on several warehouse rooftops at the Frauenfeld site. 8293 LG solar modules in total were utilized in the solar PV system. 46 Delta RPI M50A inverters (each with a rated power output of 55 kVA) were selected for the PV project and installed on several of the warehouse exteriors. The solar inverters were purchased from Delta sales distribution partner, Baywa r.e. The RPI-series inverters have a high maximum efficiency of 98.6% to help ensure a good solar energy yield. The rugged aluminum chassis and IP65 protection rating provide a secure moisture seal that is fitting for the periodic rain and snow common in this region of Switzerland.

According to Erich Stutz, the Solar Installation Manager at Fuchs Wohnbau AG, "Delta inverters were chosen due to the compact form factor of the units with a very high power output of 55 kWs. In addition, the good reputation of Delta as a financially viable manufacturer gives us confidence that they will be around in the long term to support their inverters for the entire guarantee period."

Wire production for diamond wire in Colorado Springs to be discontinued

MEYER BURGER TECHNOLOGY will discontinue the proprietary wire production for diamond wire at Diamond Materials Tech Inc. (DMT) in Colorado Springs, USA. Important technology know-how will be transferred to the Technology and Product Centre in Thun.

DMT has been facing a continuing global pressure on prices and margins for diamond wire volume production for quite some time. The company has executed several cost optimisations, capacity adjustments and restructuring measures since 2012. Despite this and since diamond wire production in the solar industry has become a commodity business over the cycle, DMT has not been able to develop the diamond wire production into a profitable business unit. The Executive Board and the Board of Directors have thus decided to discontinue DMT's diamond wire production.

This decision does not influence the strategically important product line of diamond wire based cutting equipment, such as the industrially proven DW 288, which is used to produce high quality silicon and sapphire wafers. Customers will be able to obtain suitable diamond wire for the DW 288 Series 3 and future developments of the diamond wire cutting technologies from third parties. Because of the strategic decision concerning DMT, Meyer Burger can reduce its annualised operating cost base by about CHF 10 million as of the second half of 2017. The decision will lead to a workforce reduction of 72 employees in Colorado Springs.

The decision to discontinue wire production at DMT will lead to one-time non-cash related depreciation and impairment of inventory, technology and manufacturing equipment in an amount of about CHF 12 million, which will be reflected in the income statement as extraordinary result in a separate line directly above the earnings before taxes.

Based on preliminary results Meyer Burger achieved a volume in new orders of CHF 456 million (2015: CHF 418.9 million). Net sales increased by 40% compared to the previous year and reached CHF 453 million (2015: CHF 323.6 million). EBITDA was positive at about CHF 10.5 million (2015: negative EBITDA of CHF -55.9 million).

This result includes, as previously communicated, one-time extraordinary expenses in conjunction with the structural programme of approximately CHF 3.5 million.

Yingli to power the largest bifacial PV plant in Europe

YINGLI SOLAR has announced that Tempress Systems B.V. part of the Amtech Group has begun to construct the Europe's largest bifacial PV plant with a capacity of close to 400 kilowatt (KW). The project is located next to the headquarters of Tempress in Vaassen in the Netherlands and is expected to be completed in the second quarter of 2017. It is expected that the annual energy production of the project will exceed 400 MWh.

The project will contain 1,428 Yingli's PANDA Bifacial modules with a nominal peak power ranging from 275 Watt to 280 Watt each. PANDA Bifacial module contains n-type crystalline silicon solar cells based on the n-PERT technology jointly developed by Yingli, Tempress Systems and ECN, which can generate power not only from the front side, but also from the rear side by making use of the reflected photons that hit the module on the back side*.

Therefore, the power yield of the PANDA Bifacial module can be increased by up to 30 percent compared to a monofacial standard module. In addition, the n-type crystalline silicon solar cells used by the PANDA Bifacial module are more sensitive for low light conditions than regular p-type cells.

The PANDA Bifacial module is comprised of two layers of 2.5mm thick tempered glass, which replace the conventional back sheet and glass structure. It also bears a 30-year-linear warranty exceeding the life time of standard modules. The PANDA Bifacial module has been independently tested for harsh environmental conditions such as exposure to salt mist, ammonia and known PID risk factors.

The project has been designed by Schulz Systemtechnik BV who will also do the installation. The modules will be mounted on a fixed rack specially designed for bifacial modules to optimize the rear side performance and are produced by Benz Alusysteme GmbH. Each module will be equipped with micro inverters from APsystems to ensure optimal energy generation and monitor the performance of each module. This project was granted with a SDE+ subsidy from the Dutch ministry of Economic Affairs to encourage the production of renewable energy in the Netherlands.

"We are proud to be the first in Europe to install a bifacial PV plant of such a large size", said Dr. Albert Hasper, General Manager of Tempress. "Besides electricity generation, this plant will

also be used as a showcase to prove the benefits of using bifacial module technology."

"We are glad to receive substantial orders for our PANDA Bifacial module, which was recently introduced during the SNEC exhibition in Shanghai, May 2016 and has been improved through our continuously technology innovation," said Dr. Dengyuan Song, Chief Technology Officer of Yingli. "Tempress and ECN are our strategic partners for many years and this innovative product is a result of this long-term collaboration."
*Depending on the environmental condition of installation.

JinkoSolar partners with CleanFund Commercial PACE Capital to address US commercial solar market

JINKOSOLAR has announced that its wholly owned subsidiary, JinkoSolar (U.S.) Inc., will partner with CleanFund Commercial PACE Capital to offer long-term project financing to US commercial project customers through the SolarPACE program.

SolarPACE is designed to maximize solar energy cash flow to commercial and industrial (C&I) property owners. CleanFund fully funds the installation of the system, while end users re-pay CleanFund through property taxes over terms as long as 30 years. SolarPACE solves most credit challenges found in commercial solar project financing.

There are solutions for tenants who are leasing their properties, as well as flexible options to utilize solar tax credits. Project developers who use JinkoSolar modules together with SolarPACE will be eligible for incentives that will lower their project costs. "SolarPACE is an excellent fit for the C&I space because it uniquely maximizes cash flow for the end customer, a value proposition we think our customers will find useful for their sales toolkits," said Nigel Cockroft, General Manager at JinkoSolar (U.S.). "We always seek to enhance our installers' competitiveness, and this partnership with CleanFund will be key to that effort."

"As a provider of long-term financing, we appreciate projects integrated with high quality materials from reliable suppliers," said Brandon Deno, Vice President of Solar at CleanFund. "JinkoSolar has a proven reputation as a dependable and world-class module manufacturer."

LED IS THE FUTURE: the future starts now

Inspection and measurement is a routine but important aspect of photovoltaic (PV) manufacturing that ensures high quality electricity production. LED-based solar simulators have entered the market, offering performance and maintenance advantages that other production tools standard xenon simulators cannot match. By: Dr. Michael Fuß from MBJ Solutions GmbH

PHOTOVOLTAIC module inspection is a critical manufacturing step ensuring that each panel meets design specifications and is absent of cracks in semiconductor materials or electrical connections, or other defects that could impede performance or shorten panel lifetimes. Solar simulators can be divided into three broad categories: continuous and pulsed illumination. Xenon, metal halide or quartz tungsten lamps have previously supplied the sun-equivalent illumination necessary for tests, but not without issues. The functional advantages of LED lighting have entered mainstream markets as flexible alternatives to expensive and maintenance-prone arc lamps.

Today LED based solar simulators are increasingly available in the marked as an alternative to the standard Xenon flashers. LED based solar simulators offer crucial benefits compared to the conventional solution of the Xenon technology.
A well-known disadvantage of the Xenon technology is the relatively short life time of the Xenon lamps. They are continuously aging and must be exchanged

Inside view of the LED sun simulator

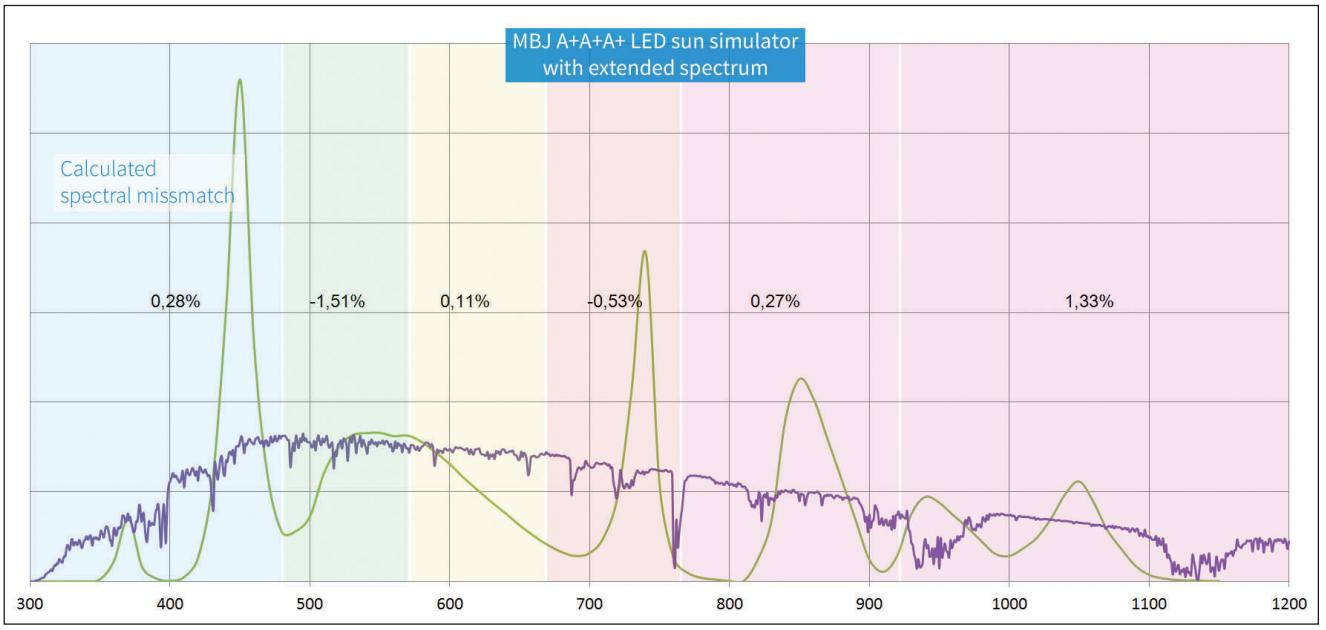
after only a few months. The resulting spare part costs, the personnel expenditure and higher operating expenses caused by the down times lead to considerable maintenance costs of the systems. Another disadvantage of Xenon lamps is the relatively short flash duration. Due to the capacitive effects of today's widely available high efficient solar modules significant measurement difficulties occur.

LED solar simulators are addressing the disadvantages of the Xenon technology. With an LED Flasher a long flash duration can easily be realized and the LEDs are designed for several million flashes. Under normal operational conditions an exchange of LEDs is not necessary anymore. In lab tests up to 10 million flashes with constant electrical current were carried out to prove it. At the end of the tests the degradation of the LEDs was less than 2% of the initial value. The reduced luminosity can be easily compensated by increasing the electrical current which yields to a constant luminosity over the whole product life time. 10 million flashes correspond to a life span of 10 years with a cycle time of approx. 30s. The result is an immense costs saving compared to the costs occurring for a Xenon flashers product lifetime.

Another advantage of the LED technology is the smart form factor. LED flashers are usually built up as compact table flasher. The integration into the production line is much simpler than before: for the measurement the modules can remain in their normal orientation (sunny side down) without the need to turn the module to a vertical or sunny side up orientation normally required for a tower or tunnel flasher.

An additional advantage of the LED technology is that the single LED or the groups of LEDs can be controlled very precisely. This control allows a nearly steady luminosity over the entire flash duration. The stability of the light source is beneficial for the measurement repeatability. In tests an up to 5 times better repeatability was achieved compared to Xenon solar simulators.

New demands from customers and new module designs provide new challenges to the manufacturers of LED flashers. With the still valid standard for sun simulators IEC 60904-9 edition 2 it was possible to achieve the classification AAA with only 5 different types of LEDs. The new standard IEC 60904-9 edition 3 has a revised partitioning of the spectral areas. To cover the revised spectrum at least 7 different types of LEDs are necessary. Besides the new standard many customers demand that the new solar simulators additionally emits light in



Spectral division IEC60904-9 edition 3

the spectral region below 400 nm (UV) and in the region above 1000 nm (IR). LEDs with the mentioned wavelength are particularly expensive which leads to considerably higher manufacturing costs for these solar simulators. Nevertheless, with the long live time of LEDs and the resulting low maintenance costs this will easily counter balance the initial system costs.

For the new bifacial modules the LED technology offers new possibilities. A bifacial module can be measured by simply putting one additional LED unit above the module. Following the requirements for bifacial modules, the module can be measured first with 1000 W/m² from the sunny side and in a second step with 100-300 W/m² from the back. Next to that, it is also possible to combine the measurement and measure the total power with one flash with predefined settings for each of the two light source (the one for the sunny side and the one for the back side). With the Backend-Solution MBJ Solutions GmbH offers a very compact solution for the inspection of solar modules at the end of the line. Besides an innovative TÜV certified A+A+A+ LED solar simulator, the system includes an isolation test and an electroluminescence test on a very small footprint.

The second generation A+A+A+ LED solar simulator from MBJ is prepared for the new standard Ed. 3. It already includes the increased requirements for the spectral distribution and the option for an enlarged spectrum below 400 nm and above 1000 nm in the new design.

Backend-Solution

The isolation and grounding test for framed modules can be directly integrated in the solar simulator. For unframed glass-glass modules or bifacial modules the isolation test is moved into a separate station. In any case, the requirements of the upcoming standard change to test with a test voltage of up to 11 kV are already fulfilled in the second generation flasher. The contacting of framed modules for the grounding test is simple and reliable. For this test special test probes provide a firm contact through the aluminum oxide of the frame by overlaying rotation with a vertical movement of the contact unit.

For unframed modules such as glass-glass modules the grounding test is not applicable. For the isolation test however, the full length of the glass edge must be reliably contacted. Innovative spring loaded contacts (patent applied) guarantee a reliable and material-friendly contact during the test. The electroluminescence inspection is accommodated in a separate unit following directly after the sun simulator.

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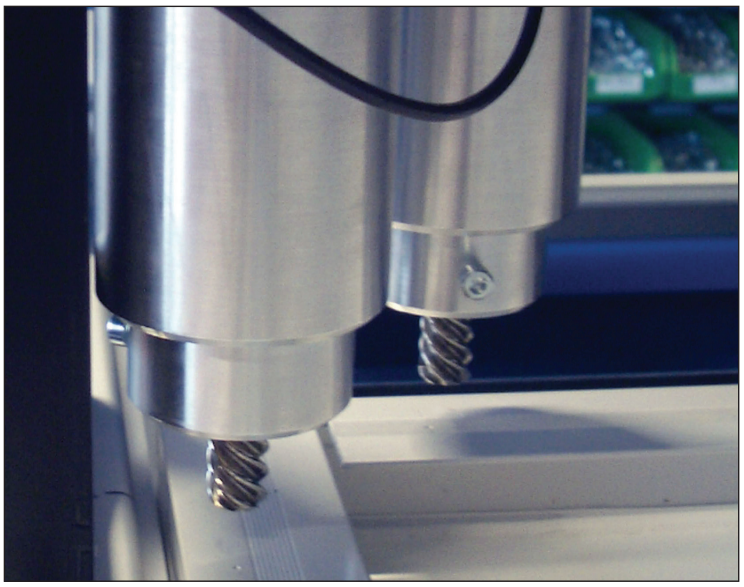

Contacting unit

For the EL test MBJ relies on the proven technology of the EL-quickline series. These systems can be easily adapted to the customer needs. By variation of electroluminescence camera type and number a pixel resolution of up to 180 μm and cycle times of less than 20 sec can be realized. Such a setup makes the system a useful component in fully automatic lines with short cycle times and automated evaluation. Even today a big challenge for electroluminescence measurement systems is the reliable automated image processing for multi-crystalline solar cells. Besides the reliable detection of micro cracks and active cracks the software also needs to detect soldering defects. To fulfill this, the image processing must be a designed in way that allows the customer to setup different criteria based on the requirement of the cell material under test. During the last years MBJ Solutions has invested a lot in the development of a user-friendly software, so that today the customers can adapt these settings themselves and therefore new customer requirements can be easily implemented to the production process.

The system can be complemented with the options diode test, dark current measurement, the automated measurement of the cell layout and the inspection of the cell edges for cracks and breakouts. For diode test the module is measured in reverse current and thus the voltage drop of the bypass diodes can be measured. Thus defective or missing diodes can be reliably detected. The dark current measurement is a smart method for the detection of shunted cells. The automated measurement of the cell layout makes sure that the required distances of the strings and the distance to the glass edge is within the required tolerances. The inspection of the cell edges completes the evaluation of the solar cells. Another option is the inspection of the interconnection area on foreign materials and inclusions. This allows detecting remaining pieces of the ribbons which are dangerous because they can cause short circuits.

The growth of photovoltaic renewable energy technology has benefitted the worldwide goal to reduce global warming while simultaneously decentralizing electric power generation. Producing high-efficiency solar cells and modules is an extremely precise manufacturing process driven by customer expectations as well as governmental regulations that vary by region and country. Accurately measuring PV module performance and ensuring high quality are chief concerns of module manufacturers. To satisfy these expectations, more reliable and cost-effective solar simulation tools are needed that leverage the latest LED technology; these advances help to ensure highly consistent light sources for in-production testing. MBJ Solutions GmbH offers real-world solutions already at work across the global PV industry.

The company provides accurate and low maintenance solar simulators as well as cost-effective / high throughput test environments for electroluminescence, diodes and dark current measurements in addition to automated cell layout and edge inspection. To ensure that PV modules meet ever-changing specifications as well as satisfy end user expectations, rely on test innovations from MBJ Solutions GmbH.

“The automated measurement of the cell layout makes sure that the required distances of the strings and the distance to the glass edge is within the required tolerances. The inspection of the cell edges completes the evaluation of the solar cells. Another option is the inspection of the interconnection area on foreign materials and inclusions”

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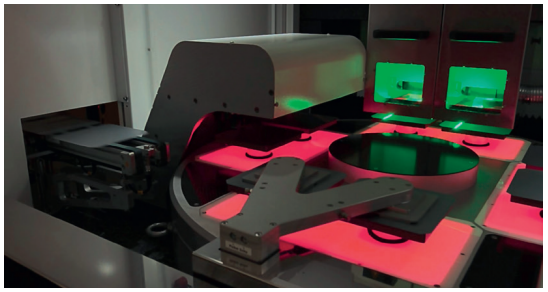

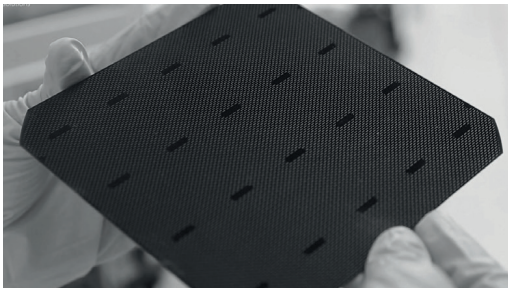

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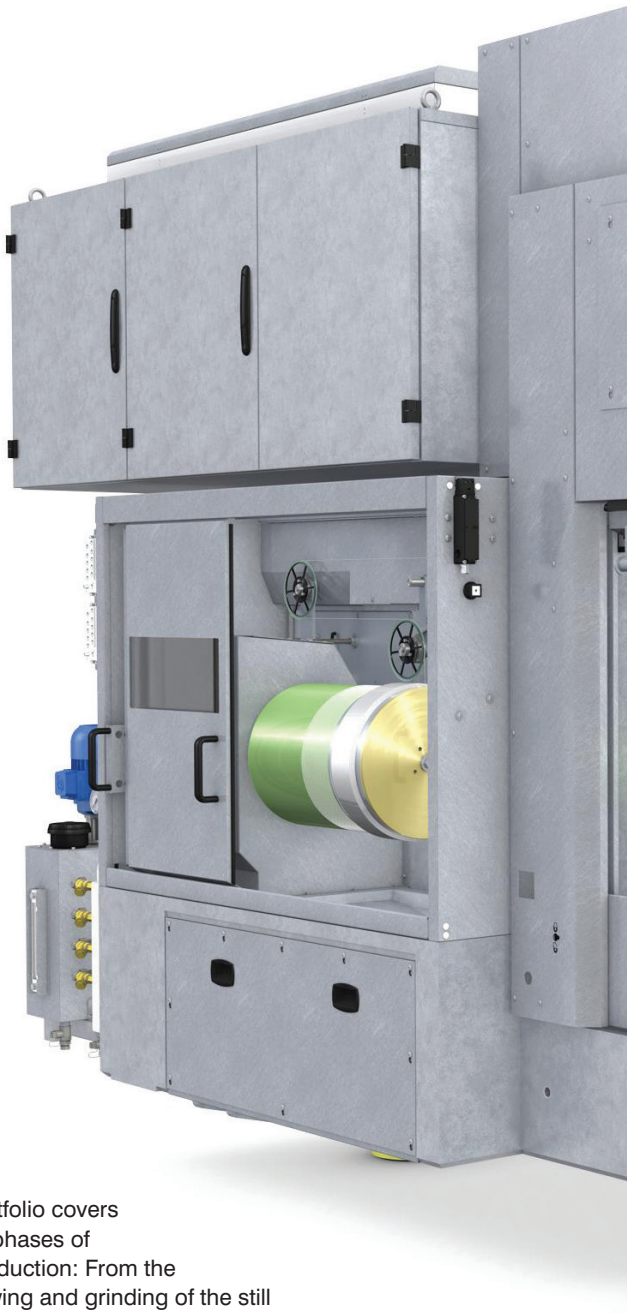
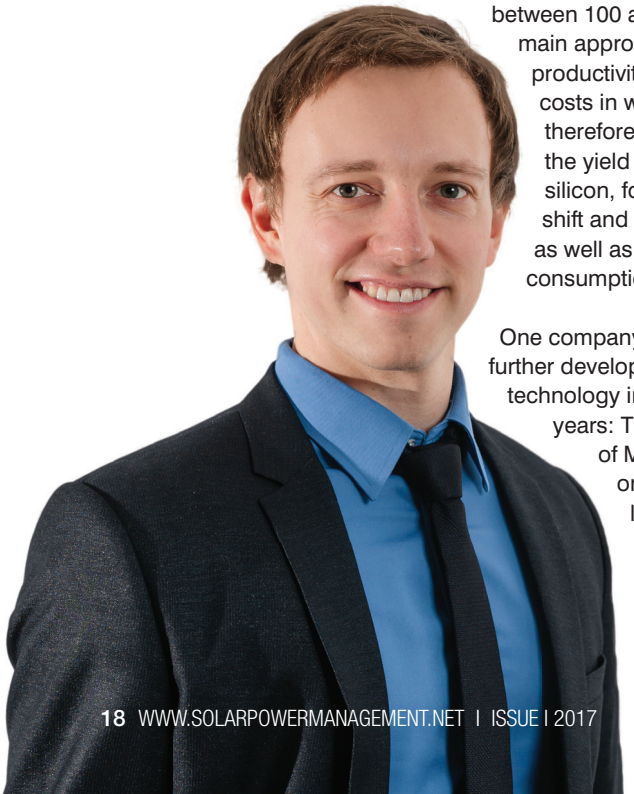
Wire management is key to productivity in wafer production

Freddy Müller, Siemens Switzerland AG, explains the importance of wire saw management which could significantly improve yields quickly.



SUCCESSFUL INVESTMENT in alternative energies takes relevant innovations into account – not only of the energy technology itself, but also of the procedures in component and plant engineering. The best example of this is an innovative wire sawing machine: Significantly improved yields in wafer production, faster processing and minimized consumption of materials have reduced the unit costs to such a degree that competition and market action are influenced with lasting effect – this is underscored by the latest sales figures.

The lion's share of unit costs of a photovoltaic wafer is represented by the raw material of silicon and the diamond cutting wire that is used to slice the silicon brick into wafers with a thickness of between 100 and 180 µm. The main approaches to improving productivity and lowering costs in wafer production, therefore, are to increase the yield for each brick of silicon, for each working shift and for each machine, as well as reducing the consumption of diamond wire.



One company has significantly further developed wire saw technology in the past few years: The Swiss company of Meyer Burger, one of the world's leading suppliers of solutions for the manufacture of PV components and systems. Its portfolio covers all phases of production: From the sawing and grinding of the still round silicon ingots into rectangular "bricks", to the manufacture of finished PV modules and ready-to-install PV systems for integration into roof structures or facades.

Leap in productivity as a result of consistent further development

Meyer Burger has been devoting its attention to the particularly cost-sensitive production of silicon wafers for a considerable time. The most important innovative advances in the last few years were the switch from slurry to diamond wire, the diamond wire management systems developed (and now patented) specially for this purpose, the optimization of process technology, and an automation concept consistently optimized for wire sawing. The first machine, in which all of these aspects have been implemented, is the

"DW288 Series 3" diamond wire saw equipped with Siemens technology.

Wire management saves 20 percent of the diamond wire

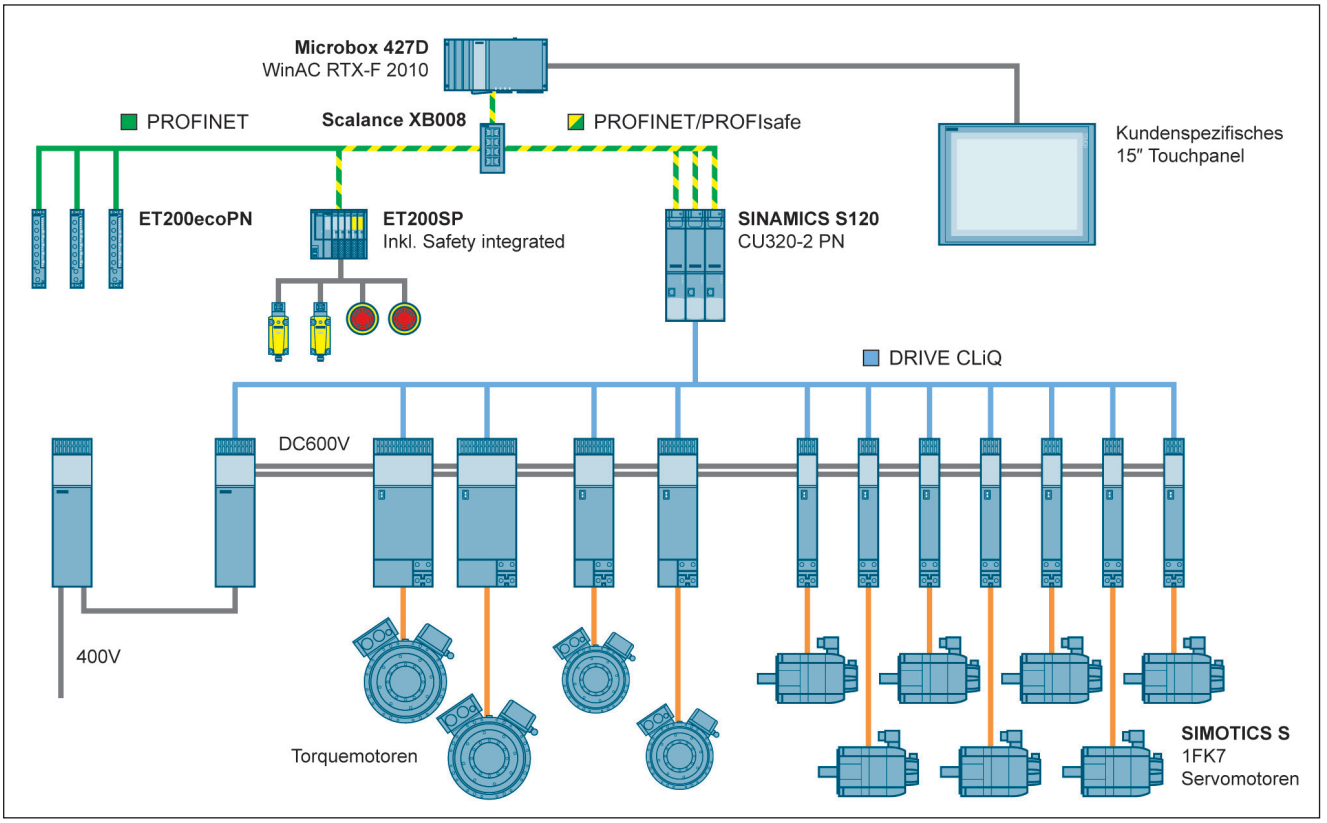
Meyer Burger's patented diamond wire management system (DWMS) is based on a clear separation of the winding areas into a "wire storage area" and a "working area" used for cutting. This winds the section of wire currently in use in a single layer. This means that the very abrasive diamond wire, which is wound in and out during sawing, no longer comes into contact with any adjacent wire, thereby eliminating the wear caused by wire-to-wire contact during the winding processes. The effect is striking: Using Meyer Burger's DWMS wire management system, the service life of the extremely expensive cutting wire is extended by more than 20 percent.

More and thinner wafers in a shorter time and with a lower consumption of diamond wire: Meyer Burger's DW288 Series 3 diamond wire saw combines a patented wire management system, optimized distances and diameters of the wire guiding rollers, and a consistently optimized automation, to create a highly productive overall package with a secure future.

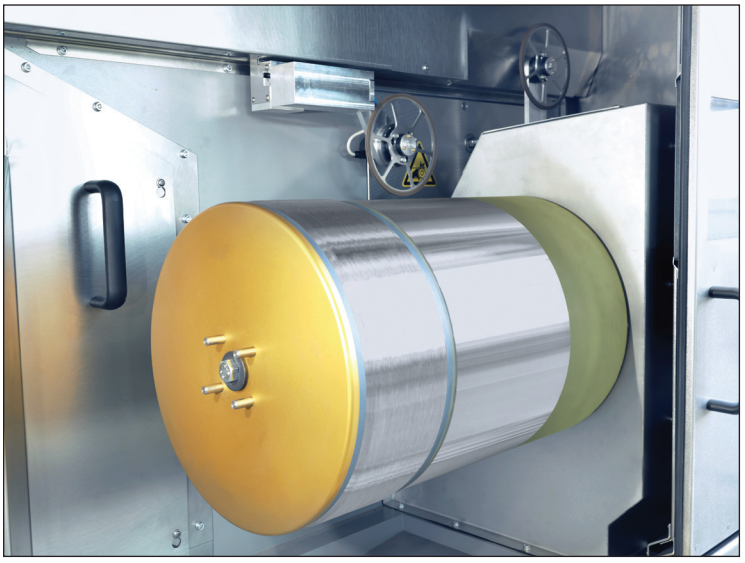
Capable of using the thinnest wires: more wafers due to narrower cuts

With their perfected, low-wear wire guidance and optimum spacing and diameters of the wire-guiding rollers, the DW288 Series 3 wire saws can productively use the thinnest cutting wires for industrial purposes. With a 70 µm wire, a precise and clearly defined cut is possible on the machine in a secure and high-performance process as standard; even the first 60 µm wires are already successfully in service. To give some idea of what this means:

The cutting wires currently in standard use are in the range between 80 and 120 µm, which means they are barely thicker than a human hair. The possibility now of being able to use a considerably thinner wire reduces kerf loss and makes even more efficient use of the expensive raw material: A 10 µm narrower cut represents a material saving of about USD 100,000 per year per machine.



20 percent saving of wire: Meyer Burger's diamond wire management system (DWMS) improves the service life by reducing wear in the winding area and permits an optimization of the drive technology. The expensive wire remains sharp for considerably longer and can be guided more dynamically during the sawing process.



High-performance control – on the basis of standard industrial components

The synergetically optimized drive technology makes a considerable contribution to the great thin-wire capability of the machine. "Because the working wire is wound in a single layer, the diameter of the winding always remains the same. This simplifies the regulating task of the winder and means that more of the regulating dynamic is available for maintaining a constant wire tension," explains Christoph Eggimann, Product Manager Wafering, who is responsible for wire sawing at Meyer Burger at its facility in Thun, Switzerland. "Together with Siemens, we have drawn up an automation concept optimized for this purpose. Controller, drive controller and the servo motors of the wire winder and also the peripheral systems thus form one integrated system from a single source," explains Eggimann.

The system also uses a customer-specific IFP1500 Touch Panel, an IPC427D Microbox, on which the convenient operating program and a fail-safe SIMATIC WinAC RTX-F 2010 run, which also controls the safety responses of the machine. The drive controller has been programmed with Drive Control Chart (DCC) directly in the drive controller of the SINAMICS S120 type. The sensitive wire is guided precisely by 1FK7 servo motors. The sensors and actuators required for this process are integrated via the ET200SP I/O system with IP20 degree of protection and ET200ecoPN with IP65/67 degree of protection, which simplifies the construction of the machine and contributes to the slim design of the system.

The entire communication uses the high-performance Profinet, which also promotes the simple and swift diagnosis of the machine. Ultimately, the decisive

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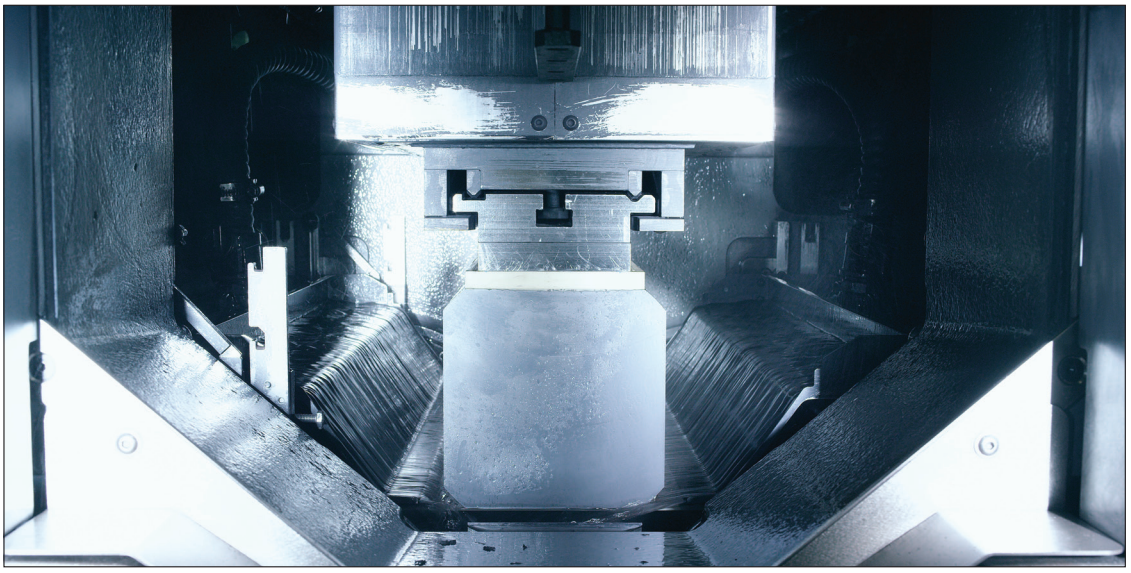


Sophisticated diamond wire technology extracts more high-quality wafers from one brick of silicon.

factor is that, even with the thinnest wires, the sensitive control reliably maintains the extremely fine line between optimum yield and the risk of a wire break: the wire tension remains constant up to 0.5 N. Without exerting any additional stress on the wire, the cyclic acceleration and braking processes can be configured more dynamically and in addition, a higher cutting speed can be maintained – up to 30 m/s.

"The machine operates at the very limit of what is technically feasible today," explains Thomas Weber, TPC Manager in Thun. "The consistent automation technology is therefore a key element for ensuring maximum process reliability." And the concept is bearing fruit: The machine has the lowest quota of wire breaks on the market.

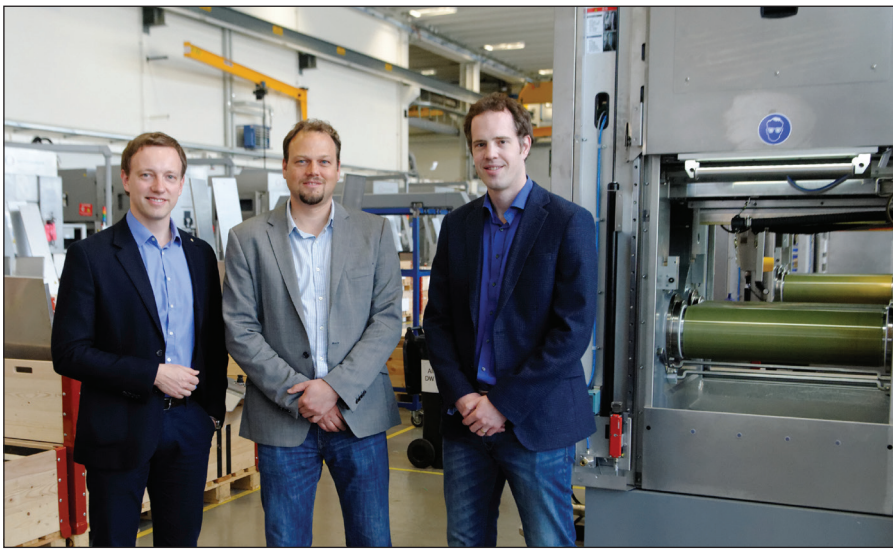
The faster change of cutting direction and the higher cutting speed considerably increase the throughput of the new generation of machines. A 650 mm long brick can be cut in less than two hours into thousands of high quality wafers with a total thickness variation (TTV) of less than 10 µm.

The remarkable thin wire capability of the new wire saw is also the result of the integrated control and drive system developed jointly with Siemens for this specific task. Even with an extremely thin wire, it permits the dynamic change of sawing direction and a high cutting speed – with a constant wire tension. The quota of wire breaks for this machine is therefore very small.

Highly productive – and equipped for the future

The degree of development undergone by wafer manufacture over the past view years is illustrated by a comparison between the DW288 Series 3 diamond saw with the slurry-based DS271 wire saws still widely in use today, in which the cutting particles are applied to the cut not by the wire itself, but by a fluid. For an annual production capacity of 500 MW, 50 slurry wire saws are required. The same output is achieved today by 17 of the DW288 Series 3 machines – and without the enormous cost of storing and recycling large quantities of used slurry. In addition, the amount of kerf loss is minimized by reducing the width of cut from 150 μm to less than 90 μm.

Therefore, the PV manufacturers who switch from slurry-based sawing procedures to the diamond wire technology can make considerable profits by using the latest Meyer-Burger wire saw. In addition to the massive increases in productivity, they also gain confidence in the future, which is urgently needed in the solar energy sector. This is because the trend is clearly toward high-efficiency, thinner wafers. In the case of monocrystalline *n*-type wafers, for example, the switch to the 100 μm technology is already foreseeable. With the new wire saw from Meyer Burger, PV production is well-equipped for these tasks. A manufacturer of PV components prepared in this way can respond quickly to advances in technology and secure their market shares at an early stage.



In order to make optimum use of the synergies between machine building, production technology and automation, the cooperation between Meyer Burger and Siemens often begins at the design stage of new projects. (from left to right: Freddy Müller (Siemens Switzerland AG), Thomas Weber (Meyer Burger (Switzerland) AG, Christoph Eggimann (Meyer Burger (Switzerland) AG)

Background knowledge: Wafering

THE MOST IMPORTANT ELEMENT of a photovoltaic cell is the wafer – a very thin slice of extremely pure silicon. Wafers are cut from blocks or "bricks" of silicon using wire saws. The extremely thin (and very expensive) cutting wire is guided numerous times over two wire guide rollers, so that it forms a narrow field of wire. Oscillating movements of the rollers make this wire grid a "reciprocating saw" for silicon.

There are two cutting methods, one using a rather smooth wire and one with diamond-coated wire. When sawing with smooth wire, the abrasive particles are applied to the cut by means of a fluid (slurry). These slurry-based procedures now only have a limited competitive value due to their cutting performance: The diamond particles in the slurry "roll" at only half the speed of the wire through the cut in the material. Diamond-coated wires, on the other hand, generally achieve more than twice the cutting speed. In addition, slurry-based cutting procedures involve additional high costs for storing, preparing, and recycling the fluid.

The aim in wire sawing is to cut as many functional wafers from one brick as possible. The critical variables therefore are the cutting accuracy and the width of the cut. The surface of the cut wafer must be left in perfect condition for the following texturing cut. The minimum achievable thickness of the wafer is also dependent on the cutting precision. The width of the cut in turn is an indicator for the proportion of silicon shaved off, in other words wasted, during the cutting process – narrower cuts mean more wafers per brick. The cutting of one brick can take several hours, during which time the cutting wire is stressed to its limits – but the process must not be put at risk by a broken wire. To achieve high productivity, therefore, the reliability of the process as well as the cutting speed is decisive.

New PV cell coating
increases efficiency and durability

An innovative new coating technology from MetaShield can make photovoltaic (PV) cell surfaces more durable while it increases efficiency more than 1 percent, all without significant changes in cell or module production processes. By Mark Andrews, Technical Editor.

IMAGINE working years to develop a product to enhance photovoltaic (PV) efficiency, and then at a critical juncture – after more than 40 trials – a test batch falls to the floor, shattering into pieces.

The average researcher would have been doubled-over at the loss. But for MetaShield founder and CEO Martin Ben-Dayan, the lab accident proved to be just the sort of break he had been looking to find.

When everything crashed it seemed the incident was just another frustration in the life of a new business. Anyone who has built a company or worked at a startup can attest that setbacks often outnumber 'eureka!' moments. But as researchers and Ben-Dayan were literally picking up the pieces, they discovered something unexpected. Instead of shattering every test slide, the fall left some intact.

But only slides coated with their 43rd formulation had survived. Every other slide was cracked if not smashed. MetaShield would eventually determine that their breakthrough formula was capable of increasing the break resistance of glass up to four times.

"Up until then, we had been working with polymers; we subsequently transferred over to a silica-based approach," said Ben-Dayan. "When the tray fell some slides broke and others didn't. We found only one group survived and we realized at that point we had something on our hands that was potentially much bigger than we had planned. The coating was super-light and thin and could host nanoparticles. When dried it was super-tough; it made things like glass (or PV cells) much stronger."

Once durability was established, MetaShield moved on to its primary goal: create a coating to improve PV performance. Enhancing nanoparticles were added to the base formula and more tests were conducted.

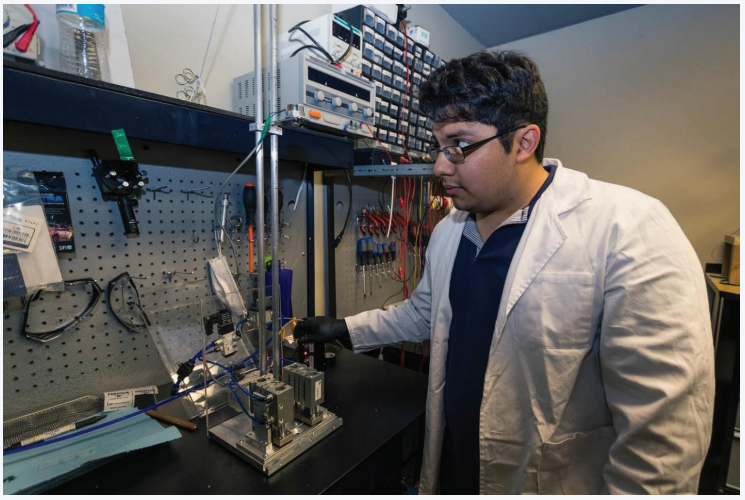
"Durability is great, but could (the coating) enhance efficiency? We found that it could. So now we had a new formulation that could be sprayed on a solar cell; it dried at room temperature without any special treatment. We (also) found it could go on top of the antireflective coatings that PV manufacturers were already using. It increased efficiency one percent or more. That is significant in the solar industry."

Polymers, and to a lesser extent silica coatings, are of course not new in 21st century industry. According to Ben-Dayan, employing nanotechnology made the difference. As MetaShield also discovered, their nanoparticle formula simplified production compared to typical silica or polymer coatings.

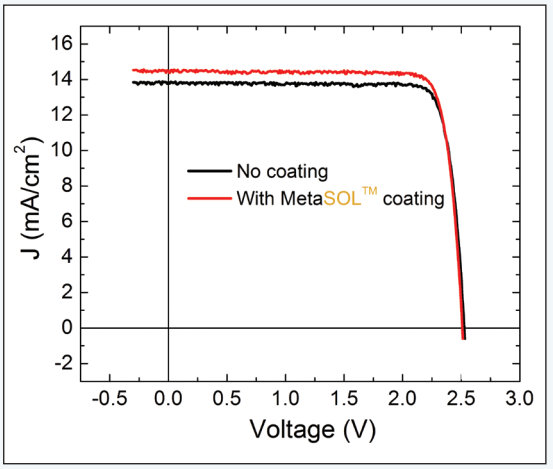
"By now we started to realize that we were part of something very new. If you have a material with all of the benefits of polymers but has the properties of glass, then it is disruptive, even revolutionary. With (traditional) silica coatings you have to use very expensive deposition and baking processes.

As we spoke to more people in the industry, we realized that while the break resistance and efficiency (gains) in our formulas were impressive, what most

MetaShield formulations are typically delivered to customers in 1-20 gallon containers tailored to manufacturing needs and transportation requirements.



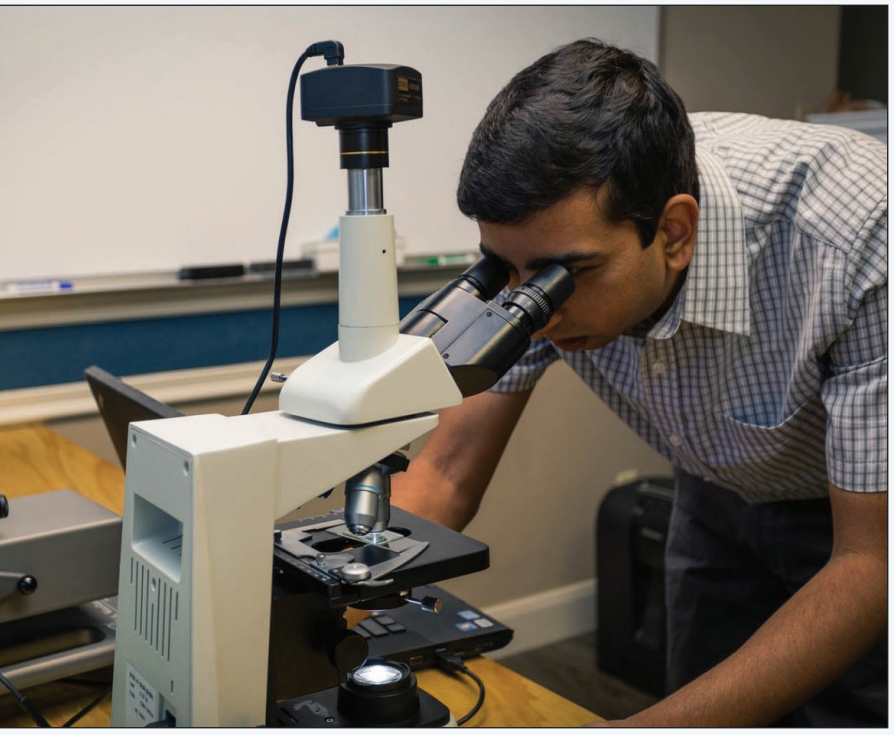
Ernesto Arevalo, MetaShield Lab Technician, tests a coating using a drop ball test (Photo courtesy of USTAR.)



Graphical representation of a test solar/photovoltaic cell with and without MetaShieldPV coating.

people were interested in was the fact it could be applied and dried at room temperature. That made a real difference," he remarked. Ben-Dayan said his company's quest to enhance PV cell efficiency started six years ago. With offices in New York and Utah, the company had originally pursued optical filters to boost solar cell efficiency. They struck on the idea of using holographic optical elements to change the direction of light to strike the active areas more effectively, thereby boosting the yield of PV cells.

"That product worked, but the value metrics for us and the economics were not beneficial. So after a year or so, we transitioned into nanotechnology



Dr. Puruswottam Aryal, MetaShield Senior Physicist, reviews crystal formations during a recent formula test session. (Photo courtesy of USTAR)

to help manipulate what was going on as the light waves entered through the filter (layer). We had tried quite a few formulations with various nanoparticles, but in the process we discovered it did so much more."

Now armed with a product that could appeal to many industries, Ben-Dayan set out to market his technology. Since the product increased durability and efficiency, MetaShield representatives spoke with aerospace companies developing satellites for defense and commercial applications that rely on high-performance, triple junction PV technology for electrical power in space.

The company also received a grant from the Utah Science Technology and Research Initiative (USTAR) to prove the potential of its new coatings and thereby establish greater credibility with potential customers.

That study was conducted at MetaShield R&D facilities in Utah with results verified late in 2016 by OAI-Optical Associates, a leading testing company in San Jose, California.

Tests found that MetaShieldPV, when applied to triple junction solar cells, boosted their efficiency 1.2 percent (absolute). This increase amounts to what industry watchers like GTM Research expects from five years of conventional PV cell technology evolution as manufacturers pursue product improvements over time; about 0.2 percent each year is average.

The initial study focused on triple junction GaInP/GaInAs/Ge solar cells. These devices were coated with MetaShieldPV; before they were not encapsulated; they had already received commercial

antireflective (AR) coatings. The current-voltage measurements (J-V curve) of the devices were measured under AM1.5 simulated solar spectrum illumination at OAI-Optical Associates, before and after the coating was applied. The comparison revealed an increase in device efficiency from 29.39 percent to 30.59 percent, an absolute increase of 1.2 percent.

While test results with more conventional c-Si cells coated in MetaShieldPV are still pending, Ben-Dayan said he expects the company's own performance reviews to be verified by OAI-Optical Associates.

The precise formulation of MetaShield base coating products is proprietary, but Ben-Dayan said the base is primarily silica, water and ethyl alcohol. The nanoparticle formulation is also proprietary. Upon application, the product solidifies in the open air at room temperature without any special industrial gases, heating or pressurization. The liquid hardens into a thin film layer with a refractive index of ~1.5, according to the company.

The MetaShieldPV coating employs plasmonic and dielectric nanoparticles to enhance the forward scattering of light incident on solar cells and through this process increases the short circuit current and the overall photo-conversion efficiency of PV cells, explained Glenn Mesa, MetaShield's director of research and development.

Once the core of its lineup was fashioned, Ben-Dayan and his team went to industry events and conferences, this time to introduce their new products. They leveraged early aerospace contacts, expanding outreach to defense contractors. They have also engaged with major smartphone and glass manufacturers because of the coatings' ability to protect any glass-like material including mobile device screens.

The current product line includes MetaShieldPV for the solar energy industry, MetaShieldGLASS for consumer electronics applications and MetaShieldUV for aerospace markets. "The application and the principle is disruptive technology with seamless integration. We are mindful that the solar industry is a graveyard for companies that came up with different ideas that did not sell.

They have also engaged with major smartphone and glass manufacturers because of the coatings' ability to protect any glass-like material including mobile device screens.

Those products always seemed to have a deficiency along the way, and we observed that most of the efficiency boost ideas (that failed) required changes in manufacturing or processing—that was their challenge.

"MetaShield represents practically zero change from what manufacturers are doing now. It is simply another coating that goes on before encapsulation. But it makes the cell more durable and it could increase efficiency 1 percent or more. It's that easy," he said.

They have also engaged with major smartphone and glass manufacturers because of the coatings' ability to protect any glass-like material including mobile device screens. The current product line includes MetaShieldPV for the solar energy industry, MetaShieldGLASS for consumer electronics applications and MetaShieldUV for aerospace markets

SOLAR CELLS: TAKING EFFICIENCY TO NEW HIGHS

An inverted metamorphic architecture offers a route to making lightweight, incredibly efficient, cost-competitive cells for space

BY PAUL SHARPS, DANIEL DERKACS AND ALEX HAAS FROM SOLAERO TECHNOLOGIES

ALTHOUGH III-V multi-junction cells have been deployed on earth to generate electricity, they are delivering their greatest commercial success in space. Out there they are highly valued for their high efficiency and robustness, particularly to particle radiation. What's more, they offer tremendous economic value at the system level by reducing satellite launch and operating costs. Together, these attributes make III-V cells ideal for supporting satellite missions requiring either a high specific power (W/kg) or a high power density (W/m^2).

At SolAero Technologies of Albuquerque, NM – which took over Emcore's solar business in late 2014, while retaining all its expertise and capability – we have a great track record in improving the efficiency of our III-V multi-junction cells. Between 1998 and 2008 the measured efficiency of multi-junction cells under conditions replicating those in space increased from 23 percent to 29.5 percent (for these measurements, radiation was incident under no concentration (1 sun) with a spectrum mimicking that of the sun's before it passes through the earth's atmosphere (AM0)).

These efficiency figures might suggest that our focus is on the production of a handful of cells with incredibly high efficiencies. But that is certainly not the case: we pride ourselves on the production of vast numbers of highly efficient cells. Over the past 18 years we have manufactured more than 3 million large-area space cells, defined as having an area of at least 26 cm^2. The knowledge gained from this has helped us to produce cells that have an initial efficiency of 29.5 percent and deliver 85 percent of this value at the end of a 15-year geosynchronous mission. Even now, we are not resting on our laurels, but pursuing a roadmap that involves the development of far more efficient devices that incorporate metamorphic structures and more absorbing layers.

Solar designs

Manufacture of our solar cells is based on multi-junction designs, rather than single-junction variants, because this leads to better spectral utilization and reduced thermalization losses. Multi-terminal and mechanically stacked architectures are options for the fabrication of these multi-junction devices, but we prefer two terminal devices, because this trims costs associated with cell fabrication and system integration.

In a two-terminal device, the cells are connected by lattice-matched Zener tunnel diodes, which reverse the polarity between each of the subcells. This allows multiple *n*-on-*p* subcells to be monolithically stacked on top of each other. The voltage produced by the multi-junction device is equal to the sum of those produced by each subcell, and optimisation requires the design of each *n*-on-*p* junction to produce the highest voltage possible without reducing the photo-generated current.

During the last two decades, the primary source of satellite power has been the triple-junction device formed from lattice-matched layers of GaInP, InGaAs and germanium (see Figure 1). The foundation for this is a *p*-type germanium substrate, on which GaInP and InGaAs layers are grown by MOCVD. During growth, the group V element from the nucleation layer diffuses into *p*-type germanium, converting a thin layer on the surface to *n*-type. This creates a

diffused *n*-on-*p* junction. To provide precise lattice matching to the germanium substrate, a small amount of indium is added to the middle InGaAs junction.

With this device, the internal quantum efficiency of all sub-cells approaches 100 percent (see Figure 2). Consequently, there is little room left for improvement in the current collection in this device.
Where gains can be made is in photocurrent. In these monolithic, two-terminal multi-junction cells the subcells are connected in series, so the same current must flow through all of them. This means that it is possible for one or more subcell to fail to operate at its maximum power point. For example, in a device with a GaInP/InGaAs/germanium architecture and bandgaps of 1.88 eV/1.40eV/0.67 eV, the germanium subcell is capable of generating twice as much current as it does in this triple-junction stack (see Figure 3). Due to this, the multi-junction cell will deliver an inferior performance to that of a cell with all junctions operating at individual maximum power points.

Improvements could result from increasing the bandgap of the bottom junction so that it adds to the operating voltage while still generating enough current to avoid limiting the overall device. Alternatively, gains could be made by lowering the bandgap of the top two subcells to increase cell efficiency through superior spectral utilization and improved current matching at each subcell's maximum power point. With either of these approaches, or by adding to the number of junctions, it is possible to improve upon the AM0 efficiency limit of approximately 30 percent for the GaInP/InGaAs/germanium device. It is worth noting, however, that the obvious approach of adding more junctions suffers from a law of diminishing returns. So, assuming that the cost of every added subcell is the same, there is a point at which the increased efficiency comes at a price that the market will not bear.

Attempts to increase solar efficiency tend to involve either employing mechanical stacks, turning to novel materials, or creating metamorphic structures. Here we will we briefly describe the first two, before discussing in more detail the third option, which is the one that we pursue. Note that there are many III-V semiconductor materials that can be combined into multi-junction devices (see Figure 4), and we limit ourselves to monolithic devices, because, as previously stated, this trims cell fabrication and integration costs.

Pros and cons of stacking…

Mechanical stacking of cells to improve performance has made the headlines, because this class of device holds the efficiency record for devices operating under concentrated illumination (sunlight is focused by a factor of several hundred on to the cell). The great attraction of mechanical stacking is that it removes the bandgap/lattice constant constraint, opening the door to designs that combine a wide range of bandgaps with different lattice constants. One example of a mechanically stacked cell is the

pairing of a GaInP/GaAs dual junction grown on a GaAs substrate with a GaInAsP/GaInAs dual junction grown on InP. The resulting device, with bandgaps of 1.89 eV, 1.41 eV, 1.00 eV, and 0.73 eV, is close to ideal for the maximum conversion efficiency for the space spectrum. This device is created by wafer bonding, a process that forms a mechanically robust, optically transparent, electrically conductive interface

between the component multi-junction cells. The challenge is cost. This approach requires a separate growth for each of the component multi-junctions, one of which involves a very expensive InP substrate. Costs could fall by turning to epitaxial lift-off, but this technology is still to be demonstrated to the degree required to significantly lower the substrate growth costs. Another drawback is that to ensure that the surfaces are adequately flat for wafer bonding, they must be polished with a chemical-mechanical process. If particles or growth imperfections are present, they prevent wafer bonding in local areas. Due to all these issues, despite its high efficiencies, mechanical stacking is simply too expensive to be considered for space applications.

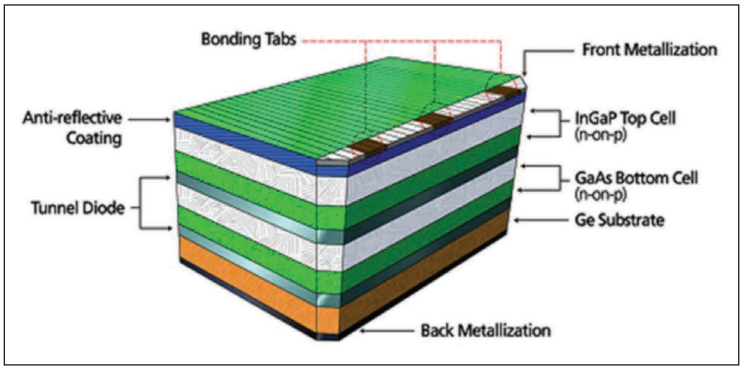


Figure 1. The GaInP/InGaAs/germanium lattice-matched, triple-junction cell is monolithic device that is grown on a germanium substrate.

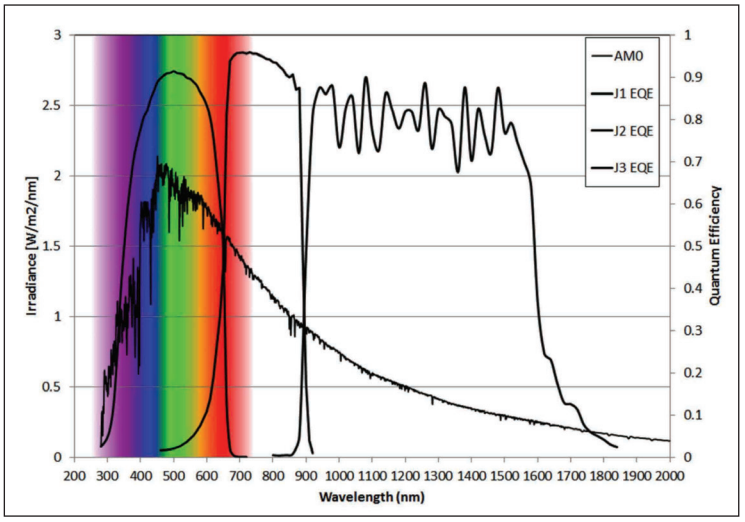


Figure 2. The internal quantum efficiency (IQE) of the Zener tunnel-junction cell overlaid on the space AM0 spectrum.

… and novel materials

Novel materials are attractive, because they provide the opportunity to replace the germanium subcell with one of a higher bandgap, or to insert a 1.00 eV subcell between the germanium and InGaAs subcells to create a four-junction device. With the latter approach, a 1.0 eV subcell is grown directly on the germanium substrate prior to the growth of GaInP and InGaAs subcells.

The two most popular candidates for a 1 eV cell are the dilute nitride InGaAsN(Sb) and the ternary SiGeSn. Both materials have the virtues of an independent lattice constant and bandgap (within ranges). This allows a tuning of bandgap while retaining lattice matching to GaAs or germanium. A four-junction cell based on InGaP, GaAs, InGaAsN and germanium was first proposed in 1997 by a group at Sandia National Labs in Albuquerque, NM. However, due to the poor material quality of the MOCVD-grown InGaAsN junction, this cell never realised its expected performance. In addition, the device was expensive to grow. Progress has been made since then, by growing the InGaAsNSb layers by MBE, and incorporating them into triple-junction GaInP/GaAs/InGaAsNSb cells. These devices have produced an efficiency in excess of 30 percent under 1 sun, AM0 conditions, but the MBE growth process is expensive, partly because of the low throughput.

Development of the alternative, SiGeSn, is still in its infancy. Junctions made from this ternary are yet to produce voltages consistent with their bandgap. Another concern is that this material is meta-stable, and requires a growth temperature of less than 400°C. Further fundamental studies are needed before this ternary can be incorporated in a multi-junction device.

Mighty metamorphics

We advocate a metamorphic approach, which includes upright and inverted structures. If upright metamorphic multi-junction structures are produced, the lowest bandgap subcell should be grown first, followed by higher bandgap subcells (see Figure 5(a)). With this architecture, the bottom junction is typically made from germanium, and above this are the metamorphic grading layers and finally the metamorphic subcells.

For this class of metamorphic cell, which tends to feature GaInAs-based metamorphic subcells, compositions of the III-Vs follow the GaAs-InAs tie line. The indium content is gradually added to the step grades to reach the appropriate lattice constant. A major downside of this approach is that all of the epitaxial layers are lattice mismatched with respect to the substrate, and consequently contain threading dislocations. This is a major drawback, because the threading dislocations act as carrier recombination sites that degrade solar cell performance through increased dark current and reduced photo-generated carrier collection. Since all of the epitaxial layers are metamorphic in these upright multi-junction structures, all tend to suffer from non-optimal performance for the particular bandgap. Defects are minimised, and cell performance optimized, by using the other class of metamorphic – the inverted metamorphic multi-junction. In this case, devices are grown 'upside down'. This means that

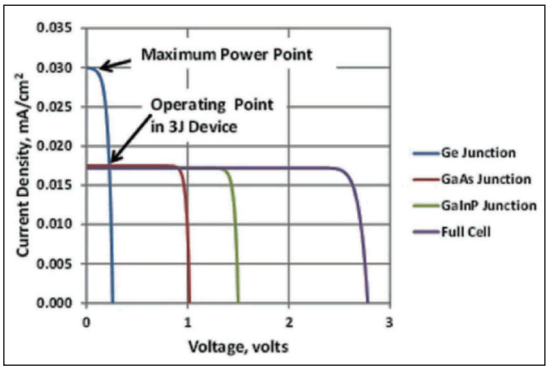


Figure 3. Individual and aggregate current-voltage curves for the GaInP/InGaAs/germanium solar cell. The germanium junction operates at the current-matched point in the complete triple-junction device, rather than at its maximum power point.

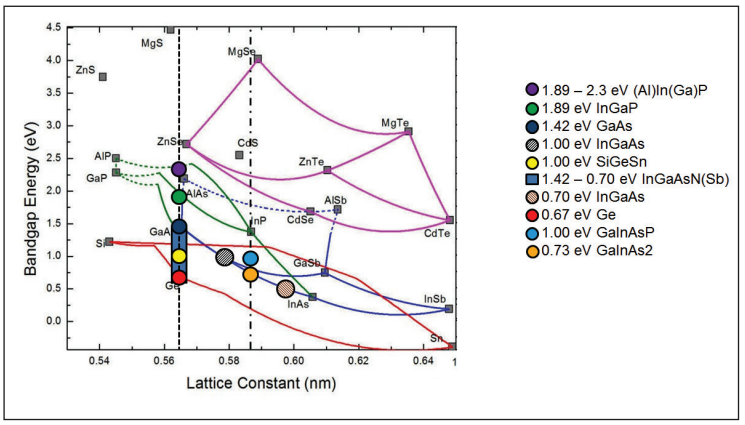


Figure 4: Bandgap and lattice constant for a number of semiconductor materials, with the III-V materials of particular interest for multi-junction cells noted.

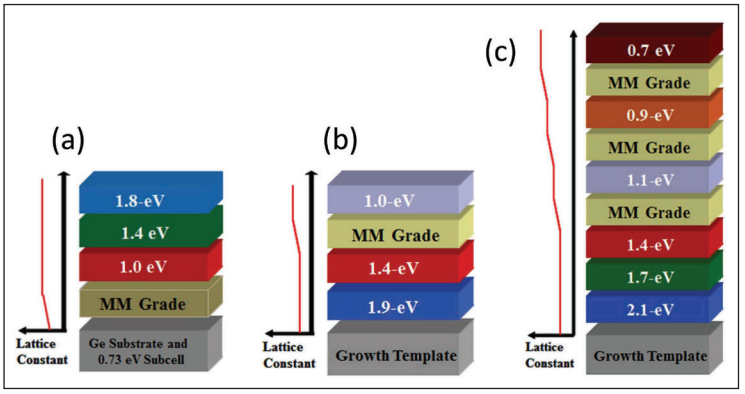


Figure 5: (a) The upright metamorphic four-junction cell has a performance that is compromised by threading dislocations through the entire structure. With inverted metamorphic cells with three (b) or six (c) junctions, only part of the structure suffers from threading dislocations.

the high bandgap junctions are grown first, lattice matched to the substrate, followed by lower bandgap metamorphic 'boost' junctions. An example of this – a triple-junction inverted metamorphic – is shown in Figure 5(b). It features two lattice-matched subcells and one metamorphic subcell. The initial high bandgap subcells, such as GaInP, GaAs, InGaAlP and AlInGaAs, are grown lattice matched to the germanium growth substrate, and they generate the majority of the power from the cell. The metamorphic subcells, meanwhile, produce a smaller proportion of the generated power than they would in an upright metamorphic multi-junction structure.

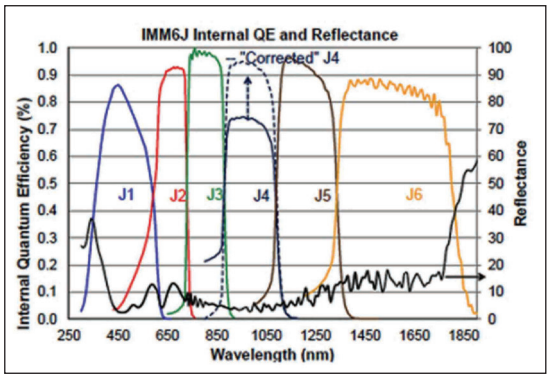


Figure 6: Internal quantum efficiency and reflectance for the inverted metamorphic, six-junction cell.

To produce this class of cell we attach the structure to a 'processing handle', such as silicon or kapton, before removing the growth substrate. Epitaxial layers are between 10 μm and 15 μm thick, depending on the number of subcells in the device, and the processing handle can be temporary, necessary only for processing; or it can be permanent, providing an integral part of the final device. There is great freedom with this approach as devices can be flexible or rigid, and structures can be packaged for the end application. Selection of an appropriate permanent handle enables a very light cell, and ultimately a very high specific power (W/kg). This approach is ideal for epitaxial lift-off, where the epitaxial layers are removed from the substrate along a laterally etched release layer.

We have demonstrated inverted metamorphic cells with three, four and even six junctions (see Figure 5(c) for a representation of a six-junction cell, and Figure 6 for internal quantum efficiency and reflectance measurements from an actual six-junction cell). Using such a high number of junctions is cost competitive with current, commercially available space multi-junction cells, because production employs existing MOCVD growth technology and known fabrication practices.

We have also undertaken a comparison between modelled and verified efficiencies (see Table 1, where the numbers in red are the NASA verified measurements, and the black numbers are the results of our model). Note that the performance modelling is based on a 'practical' approach that considers the likes of optical reflectance and series resistance. Based on these findings, we have a path for increasing efficiency beyond 30 percent to nearly 38 percent. Given this promise, the inverted metamorphic cell is expected to be the core technology in the next generation of commercially available cells for space applications.

Device structure	Number of Metamorphic Junctions	Efficiency	Voc, volts	Jsc, mA/cm²	FF
Three Junction	1	32.8	3.00	17.0	86.8
		32.4	3.02	16.9	85.6
Four Junction	2	34.8	3.28	16.6	86.5
		33.9	3.26	16.9	83.3
Six Junction	3	37.8	5.20	11.3	87.2

Table 1. Comparison between modelled space inverted metamorphic cell (black) performance and NASA verified (red) performance, for the 1 sun, AM0 spectrum.

THE NEW FACE OF CSP IN 'BIG OIL' COUNTRY

Oil producers are discovering that the best way to recover challenging petroleum reserves may be had in new concentrated solar power (CSP) technology from GlassPoint Solar. Interview with VP John O'Donnell.

THERE IS NO MISTAKING a traditional CSP plant from its photovoltaic counterpart; a high tower in a field of mirrors represents CSP the way that blue or black rectangles of silicon testify that PV modules are on the job.

A new approach to concentrated solar power from GlassPoint Solar seeks to change the look and feel of CSP, opening new industrial markets to renewable energy while upending ways that fossil fuel companies pump oil from the ground.

GlassPoint business development vice president John O'Donnell said his company's solar technology and oil production are not the 'strange bedfellows' that they might appear. He explained that CSP and oil production represent a classic case of two very different industries finding common ground and profitability. Oil producers need a way to inject hot steam into the earth to unlock reserves of heavy oil while renewable energy entrepreneurs look for ways to build businesses that leverage the sun's potential. Both sides benefit from the GlassPoint approach, said O'Donnell.

GlassPoint got its start in California in 2009. Its Chief Technology Officer and co-founder, Pete von Behrens, had worked for years developing electromechanical systems combining unique motors with alternative energy sources including solar thermal. Von Behrens' designs had earned slots in BMW and Mercedes vehicles. He and co-founder Rod MacGregor looked for a way to bring new value to the solar thermal market since it was clear by 2009 that photovoltaic solar was going to win at the expense of solar thermal in the residential and grid-scale electric power markets.

Not wanting to forego their belief in CSP, the founders sought ways to reduce costs and to create new industrial products that were not already in the market. Ideally, its products would be novel/ something that PV solar could not address. Why industrial applications? O'Donnell answers by pointing to the fact that far more energy is consumed by industrial production than our needs for residential electric power. GlassPoint sees power generation as a natural niche for PV solar, which typically puts 'empty' portions of a building (its roofline) into service for generation equipment racks. Grid-scale electric power has also proven a great fit for solar PV.

Solar thermal is most efficient when it simply heats things. GlassPoint efficiencies can reach 60

percent compared to 20 percent for the best retail PV modules. It also happens that heated water in the form of steam remains a tremendous industrial requirement. GlassPoint realized that if it could find a practical, new approach to CSP there was potential across wide swaths of industry.

As predicted, PV solar costs have fallen a lot since 2009 (more than 50%) while solar thermal expenses have not declined as quickly. Although the classic solar thermal concept is simple—use the sun to heat water or oil to spin turbines that generate power—it is complicated and expensive in practice since every site is different, requiring new engineering and planning for every installation. Traditional CSP relies upon acres of mirrors that have to be soundly anchored and structurally reinforced to resist high winds, rain and snow. Hundreds or thousands of CSP mirrors have to work in concert, tightly focusing on target areas no matter what the weather holds. CSP as it existed eight years ago could not compete with PV solar; a new approach was needed.

"The GlassPoint founders had this completely disruptive idea … it started almost as an insider's joke, 'what if we could put the mirrors indoors?'" remarked O'Donnell. "They realized a simple fact: while concentrating solar power is an exercise in building very cheap, large mirrors it is quite a precise exercise and is very expensive. If there was a way to bring the process indoors, they could cut costs by controlling the environment, which would totally change the economics."

O'Donnell said GlassPoint soon realized it was not only possible but practical to reduce CSP generation costs by doing what they had at first joked about: put mirrors and boiler tubes inside something else. The key turned out to be century-old technology: agricultural greenhouses.

"For 100 years farmers have been optimizing greenhouses, and that appealed to us. Greenhouses transmit light well. They are a low cost, high sunshine-using structure that enabled us to build a new type of indoor parabolic trough that is a tenth the weight and a fraction of the cost (of traditional CSP mirrors), and is completely protected from the elements. There are greenhouses in every part of the world and that industry has evolved around the simple idea of low cost, high efficiency use of sunshine."

Once GlassPoint had its concepts established, the company started looking for industrial applications requiring steam since heating water remains one of the most efficient CSP applications. Oil production uses more steam than most other industries since steam is an essential element of enhanced oil recovery (EOR) employed at almost all older oilfields. "The oil industry is one of the single largest users of energy on earth. It burns more fuel for oil production than electric power producers use to generate electricity for industry. If you look region by region this is a significant market that is essentially zero-penetrated by solar for its heating needs," said O'Donnell. The industrial steam market is also a 'sweet spot' that photovoltaic solar cannot now touch in terms of price, efficiency and ease of integration with oilfield operations, remarked O'Donnell.

GlassPoint's key technology differs from traditional CSP in that large parabolic mirrors are suspended inside agricultural greenhouses by a durable system of wires, pulleys and controls that keep the mirrors angled to track the sun each day. During off-peak

and non-generating hours, oil producers burn natural gas to create steam. The mirrors heat oily water inside stationary boiler tubes – water drawn from the oilfields themselves. The water is boiled to produce high-pressure steam that is injected into the oil reservoir using the same pipes and distribution network that oil producers already have in place for enhanced oil recovery. The GlassPoint system can deliver up to 80 percent of the energy needed for those operations.

While steam generated from CSP cannot meet every oilfield need, it is exactly what producers require to recover much of the so-called heavy oil that remains in older fields across the world.

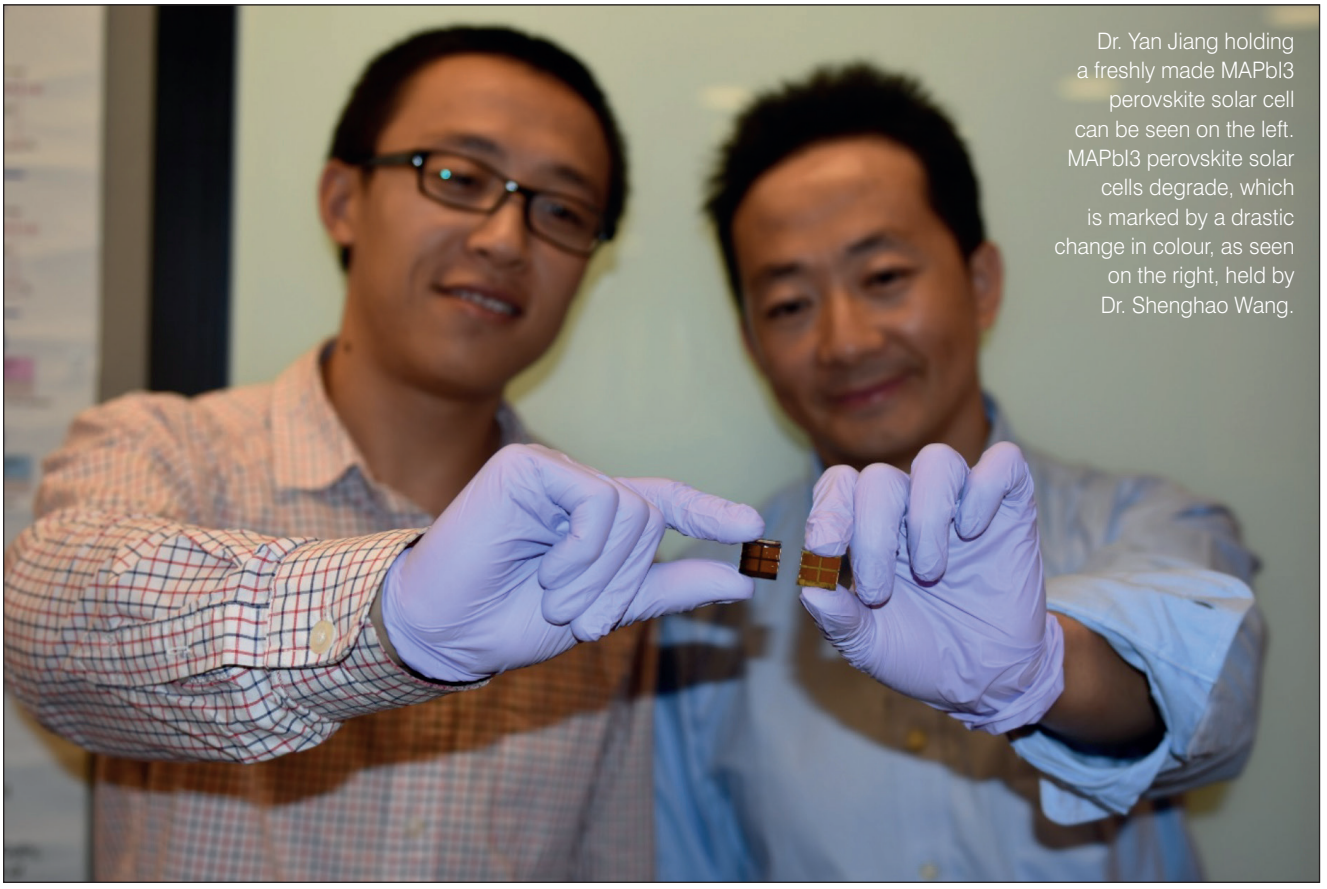
Oil producers typically use enormous amounts of natural gas to coax heavy oil from depleted wells via thermal EOR. The gas-fired approach is like heating a cubic mile of earth to extract the oil. Thermal EOR involves injecting steam into a depleted oil field to thin the remaining oil and move it toward wells for extraction. This technique has been used for decades and accounts for more than 40 percent of EOR production in the US, mostly in California, says the US Department of Energy. Enhanced oil recovery using natural gas, nitrogen, or carbon dioxide injection accounts for nearly 60 percent of EOR production in the remainder of the US, while steam (thermal EOR) approaches are favored in other parts of the world.

According to GlassPoint, some oil producers use more of their own oil or natural gas to pull hard-to-pump oil out of the ground than they do to generate power; it is an accelerating cycle of higher costs that also drives more self-consumption. Oman uses around 20 percent of its natural gas in its fields, primarily for thermal EOR. According to the EIA, 10 percent of the natural gas burned in California is consumed in Kern County for oil production. Kuwait's thermal EOR program calls for burning more gas in oil recovery than what is used to generate electricity.. These percentages are expected to increase as remaining 'light crude' oil reserves are depleted, forcing more advanced techniques to recover the remaining heavier and thicker oil. Even if the world continues to shift electricity production to renewable resources, fossil fuel will remain significant for power generation through this century. Even as electricity generation sheds its oily and coal soot roots, the world still needs oil for other industrial applications including manufacturing, transportation, plastics, medicines and more. GlassPoint says that oil's long term prospects create opportunities.

The company's approach to CSP and the oilfield market were just first steps. The company still had to design and create new mirrors and all the related technology needed to carry a concept into practical operation. Before oil producers would trust the company's novel approach to steam generation, a complete system had to be built and tested. This led the company to build its pilot project in Kern County, California; successful work there in tandem with Berry Petroleum led to further confidence in the investor community as well as with oil producers. GlassPoint has received more than USD $85 million in funding that includes stakes from its strategic partners: Oman's State General Reserve Fund and Royal Dutch Shell, who together led a $53 million equity round in 2014.

GlassPoint's 2011 California pilot program was followed by the start of its first major project outside the US when ground was broken in November 2011 in Oman at the Amal West field with the country's largest oil and gas producer. That 7MW project was completed in December 2012, to be followed by the start of a 1GW solar project in Oman that is now under construction. An advantage for the company is the fact that unlike conventional approaches to CSP, GlassPoint's technology is by nature designed to be replicated. Even though oilfields do vary, the concept works any place that there are older wells and ample sunshine. The company's novel CSP approach fits into existing energy production processes and appears to be gaining momentum within the fossil fuel community, per O'Donnell. GlassPoint was recognized with a technology innovation award at the SolarPACES 2016 Conference.

"We've enjoyed success with our (CSP) approach, and have demonstrated it has appeal at volume. We are cost effective and oil companies can use their products for export rather than self-consumption," O'Donnell said. "As (global) energy needs continue to grow with population, solar power can play an important role in reducing emissions and expanding energy supply … As the world goes through this energy transition, there will be decades still of oil production, and if we can reduce the costs and the emissions we are contributing both to supply and sustainability."



Dr. Yan Jiang holding a freshly made MAPbI3 perovskite solar cell can be seen on the left. MAPbI3 perovskite solar cells degrade, which is marked by a drastic change in colour, as seen on the right, held by Dr. Shenghao Wang.

Stability challenge in perovskite **solar cell technology**

WHILE solar cell technology is currently being used by many industrial and government entities, it remains prohibitively expensive to many individuals who would like to utilize it.

THERE is a need for cheaper, more efficient solar cells than the traditional silicon solar cells so that more people may have access to this technology. One of the current popular topics in photovoltaic technology research centres around the use of organic-inorganic halide perovskites as solar cells because of the high power conversion efficiency and the low-cost fabrication.

Perovskites are a type of crystalline material that can be formed using a wide variety of different chemical combinations. Of the many different perovskites formulations that can be used in solar cells, the methylammonium lead iodide perovskite (MAPbI3) has been the most widely studied. Solar cells made of this material have been able to reach efficiencies exceeding 20 percent and are cheaper to manufacture than silicon. However, their short lifespans have prevented them from becoming a viable silicon solar cell alternative. In order to help create better solar cells in the future, members of the Energy Materials and Surface Sciences Unit at the Okinawa Institute of Science and Technology Graduate University (OIST) have been investigating the cause of rapid degradation of these perovskite solar cells (PSCs).

Dr. Shenghao Wang, first author of the publication in Nature Energy, suggests that the degradation of MAPbI3 perovskites may not be a fixable issue.

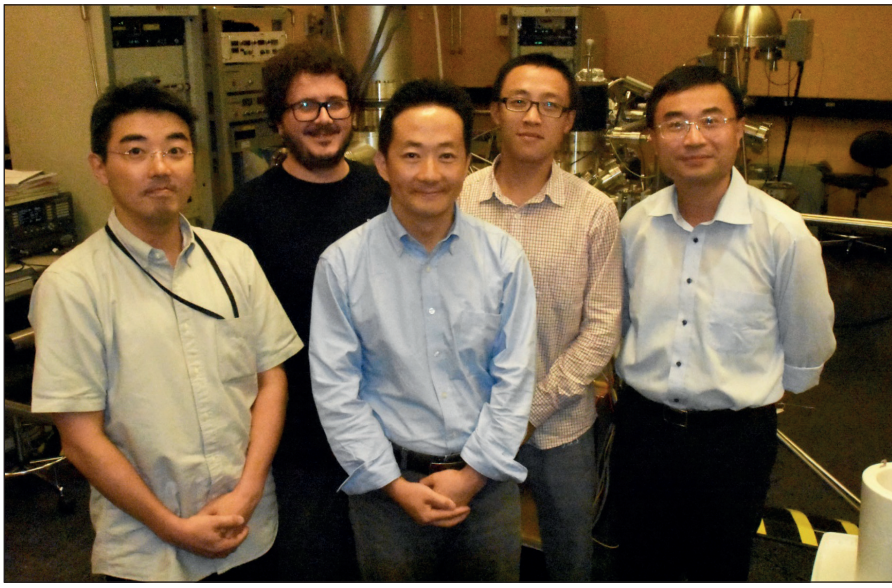
His research reveals that iodide-based perovskites will universally produce a gaseous form of iodine, I2, during operation, which in turn causes further degradation of perovskite. While many researchers have pointed to other sources, such as moisture, atmospheric oxygen and heat as the cause of MAPbI3 degradation, the fact that these solar cells continue to degrade even in the absence of these factors led Wang to believe that a property intrinsic to these PSCs was causing the breakdown of material.

"We found that these PSCs are self-exposed to I2 vapour at the onset of degradation, which led to accelerated decomposition of the MAPbI3 perovskite material into PbI2." Wang explained, "Because of the relatively high vapour pressure of I2, it can quickly permeate the rest of the perovskite material causing damage of the whole PSC.

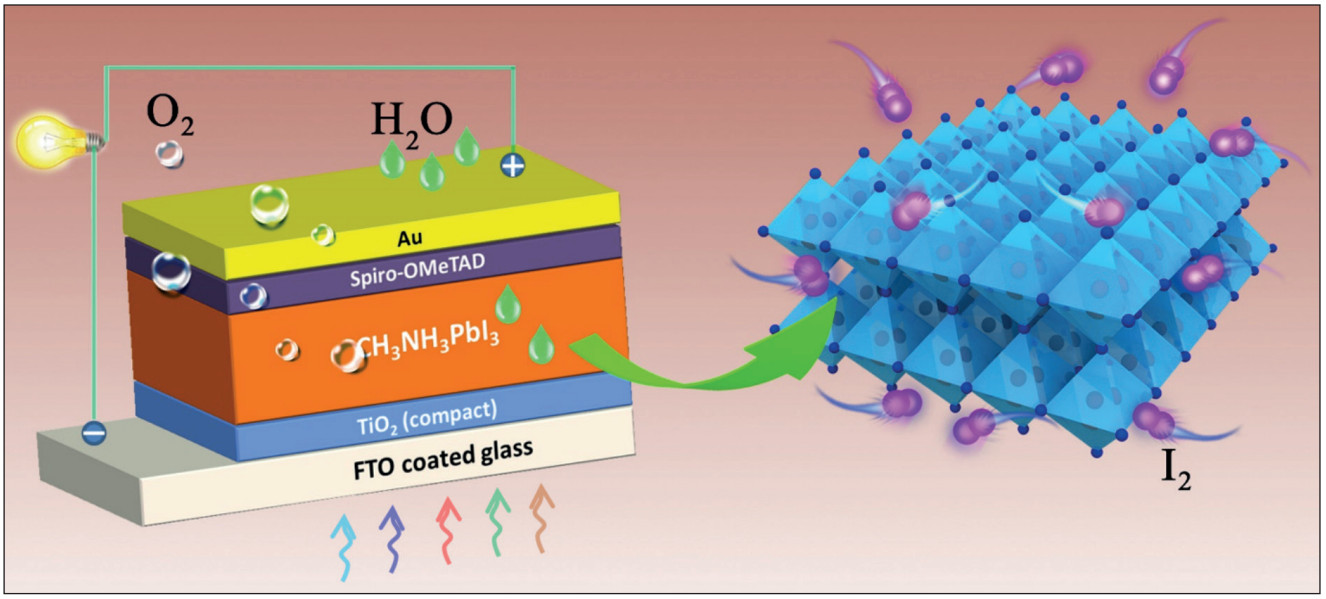
The schematic drawing showing that various factors (e.g., moisture, oxygen, light illumination, applied electric field, etc.) during the operation of MAPbI3 perovskite solar cells can generate iodine, which leads to degradation of solar cells.

This research does not rule out the probability of using perovskites in solar cells, however. Professor Yabing Qi, leader of the Energy Materials and Surface Sciences Unit and corresponding author of this work, expounds "our experimental results strongly suggest that it is necessary to develop new materials with a reduced concentration of iodine or a reinforced structure that can suppress iodine-induced degradation, in addition to desirable photovoltaic properties".

These researchers at OIST are continuing to investigate different types of perovskite materials in order to find more efficient, cost-effective, and long lifespan perovskite material suitable for use. Their ultimate goal is to make solar cells that are affordable, efficient and stable so that they will be more accessible to the general population. Hopefully, better, cheaper solar cells will entice more people to utilize this technology.



Scientists from the Energy Materials and Surface Sciences Unit who contributed to this research. From the left: Dr. Luis K. Ono, Dr. Emilio J. Juarez-Perez, Dr. Shenghao Wang, Dr. Yan Jiang, and Prof. Yabing Qi



The schematic drawing showing that various factors (e.g., moisture, oxygen, light illumination, applied electric field, etc.) during the operation of MAPbI3 perovskite solar cells can generate iodine, which leads to degradation of solar cells.

Battling corrosion

to keep solar panels humming

Researchers study corrosion to help industry develop longer-lasting photovoltaic panels and increase reliability.

PEOPLE THINK of corrosion as rust on cars or oxidation that blackens silver, but it also harms critical electronics and connections in solar panels, lowering the amount of electricity produced.

"It's challenging to predict and even more challenging to design ways to reduce it because it's highly dependent on material and environmental conditions," said Eric Schindelholz, a Sandia National Laboratories materials reliability researcher who studies corrosion and how it affects photovoltaic (PV) system performance.

Sandia researchers from different departments collaborated to accelerate corrosion under controlled conditions and use what they learn to help industry develop longer-lasting PV panels and increase reliability.

"One of our primary goals is to predict how fast corrosion will occur and what damage it does, given certain environments and materials," Schindelholz said. "This, in turn, gives us information to select the right materials for design or to develop materials for corrosion-resistance for a particular environment. It also allows us to assess the health and operational risk of systems as they age. This is especially important for solar energy systems, which are susceptible to corrosion but are expected to last for decades."

Corrosion is no small problem. A 2002 study by the National Association of Corrosion Engineers, backed by the Federal Highway Administration, estimated corroding metals in various industries, infrastructure and manufacturing cost $276 billion annually

Corrosion is no small problem. A 2002 study by the National Association of Corrosion Engineers, backed by the Federal Highway Administration, estimated corroding metals in various industries, infrastructure and manufacturing cost $276 billion annually.

Reproducing environment

Researchers simplify complex environmental conditions in labs to study how materials corrode. It's not easy deciding which environmental conditions to reproduce.

"Along the coast of Florida, its humidity and sea salt in the air. In Albuquerque, we have high ultraviolet (UV) radiation, so UV might be one of the important parameters here. The parameters driving corrosion shift with location and materials," Schindelholz said. "The challenge lies in identifying the important parameters — and then tuning the knobs in the lab to get something that replicates what we see in an outdoor environment."

Sandia belongs to a new consortium aimed at speeding up development of new materials for photovoltaic modules, increasing reliability and lowering the cost of solar power-generated electricity. The Durable Module Materials National Lab Consortium (DuraMat) wants to build bridges between the national laboratories and industry so research at the labs can benefit the PV community. DuraMat's importance is underscored by the fact materials account for about 40 percent of total PV module costs.

DuraMat, led by the National Renewable Energy Laboratory in partnership with Sandia, Lawrence Berkeley National Laboratory and the SLAC National

Accelerator Laboratory, will receive about $30 million over five years from the Department of Energy's (DOE) SunShot Initiative. The consortium is part of the Energy Materials Network, created by the DOE's Office of Energy Efficiency and Renewable Energy.

Using accelerated aging, forensics to see what's happening

Lavrova leads projects on the reliability of PV systems, studying how aging affects solar cells and components and how everything performs together. Her team works with Schindelholz on two projects under the SunShot Initiative, a national effort to make solar energy cost-competitive with other forms of electricity by decade's end. She also contributes to the module durability effort under DuraMat.

One project, in collaboration with the Electric Power Research Institute, studies PV modules from different manufacturers to give the makers information on what kind of degradation they might expect over 30 years to help identify ways to slow it down. Sandia applies accelerated aging principles to speed up studies of slowly developing effects, including corrosion.

The second project, with Case Western Reserve University, studies corrosion and other degradation from a forensic angle — looking back to see what's already occurred. Lavrova's team takes a big data analysis approach to study and analyse information from existing installations worldwide. "Is it 1 percent degradation a year or is it 2 percent? Maybe we'll see some that are a half percent, maybe we'll see some that are 10 percent. Was it a bad original product or was it installed in Costa Rica where the humidity is 80 percent every day?" she said.

Spoerke's team wants to block corrosion altogether. Collaborating with Texas A&M professor Jaime Grunlan, the team is developing nanocomposite films made from inexpensive materials as barriers against water vapor and corrosive gases. The team hopes such composite materials, some 100 times thinner than a human hair, will improve ways to protect solar cells from corrosion. Inorganic components and organic polymers that make up thin films must be designed and mixed carefully. "It's about assembling those structures in the right way so that you can use inexpensive materials and still get the benefits you want," Spoerke said. "If you build a house, it's not just piling together the drywall and two-by-fours and shingles. You've got to use the two-by-fours to make the frame, set the drywall on the two-by-fours, and assemble the shingles on the roof."

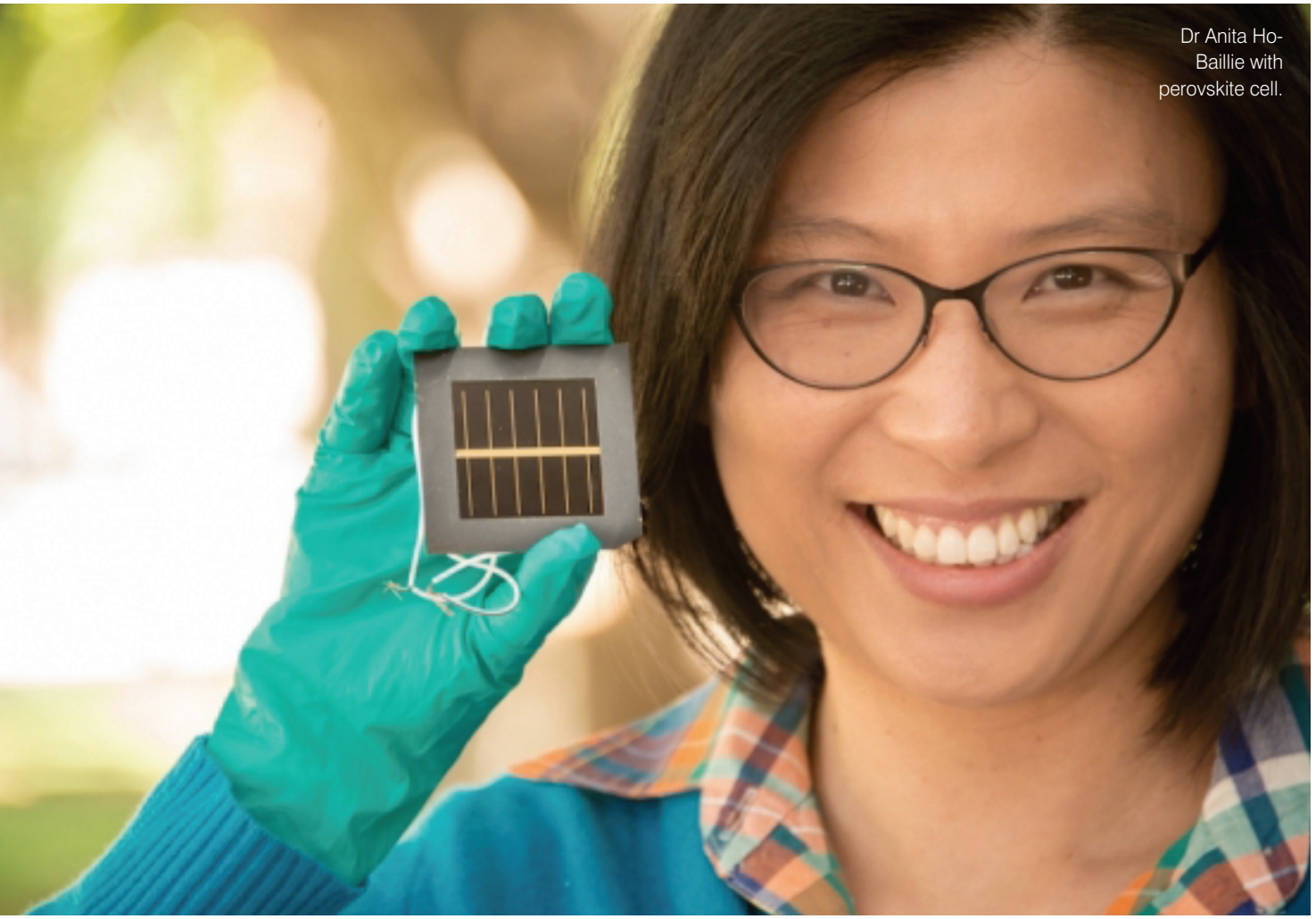
Thin films aren't the sole answer, but "I can envision that a technology like the one that we're developing could be part of a collaborative materials system to help replace glass in next-generation PV applications," he said.

Sandia National Laboratories researchers, left to right, Eric Schindelholz, Olga Lavrova, Rob Sorensen and Erik Spoerke examine points that can corrode on photovoltaic arrays. Sandia researchers collaborate to accelerate corrosion under controlled conditions to help industry develop longer-lasting panels and increase reliability. Credit: Sandia National Laboratories/Randy Montoya

Metal subject to corrosion

Sandia has studied corrosion for decades, analysing the problem in all kinds of systems because anything containing metal is susceptible. Solar cells' electrical components are protected from corrosion by encapsulating polymers, sealants and glass, but water vapour and corrosive gases can permeate as materials and packaging degrade.Materials, for example, typically corrode faster in the higher temperatures and humidity of tropical coastal regions than in coastal Antarctica.

Researchers accelerate these real-world conditions in environmental chambers to examine corrosion of electronics and other PV system components. Accelerated tests artificially speed up the corrosion effects of temperature, humidity, pollutants and salt water. For example, salt on icy winter roads or near oceans corrodes cars over time. Since automotive manufacturers can't wait decades to see how their products resist that, accelerated laboratory tests might spray salt continuously on a surface to qualify coatings and body materials to ensure they'll be safe and reliable over a product's lifetime. Engineers use corrosion chambers to study different materials in systems that must meet particular corrosion requirements, or to expose an electronic component to the environment to see what happens over time.



Dr Anita Ho-Baillie with perovskite cell.

Trendy solar cells hit new world efficiency record

They're flexible, cheap to produce and simple to make – which is why perovskites are the hottest new material in solar cell design. And now, UNSW engineers have smashed the world efficiency record.

THEY'RE FLEXIBLE, cheap to produce and simple to make – which is why perovskites are the hottest new material in solar cell design. And now, engineers at UNSW in Sydney have smashed the trendy new compound's world efficiency record.

Speaking at the Asia-Pacific Solar Research Conference in Canberra on Friday, Anita Ho-Baillie, a Senior Research Fellow at the Australian Centre for Advanced Photovoltaics (ACAP), announced that her team at UNSW has achieved the highest efficiency rating with the largest perovskite solar cells to date.

The 12.1 percent efficiency rating was for a 16 cm2 perovskite solar cell, the largest single perovskite photovoltaic cell certified with the highest energy conversion efficiency, and was independently confirmed by the international testing centre Newport Corp, in Bozeman, Montana. The new cell is at least 10 times bigger than the current certified high-efficiency perovskite solar cells on record.
Her team has also achieved an 18 percent efficiency rating on a 1.2 cm2 single perovskite cell, and an 11.5 percent for a 16 cm2 four-cell perovskite mini-

module, both independently certified by Newport. "This is a very hot area of research, with many teams competing to advance photovoltaic design," said Ho-Baillie. "Perovskites came out of nowhere in 2009, with an efficiency rating of 3.8 percent, and have since grown in leaps and bounds. These results place UNSW among the best groups in the world producing state-of-the-art high performance perovskite solar cells. And I think we can get to 24 percent within a year or so."

Perovskite is a structured compound, where a hybrid organic-inorganic lead or tin halide-based material acts as the light-harvesting active layer. They are the fastest-advancing solar technology to date, and are attractive because the compound is cheap to produce and simple to manufacture, and can even be sprayed onto surfaces.

"The versatility of solution deposition of perovskite makes it possible to spray-coat, print or paint on solar cells," said Ho-Baillie. "The diversity of chemical compositions also allows cells be transparent, or made of different colours. Imagine being able to cover every surface of buildings, devices and cars with solar cells."

Most of the world's commercial solar cells are made from a refined, highly purified silicon crystal and, like the most efficient commercial silicon cells (known as PERC cells and invented at UNSW), need to be baked above 800˚C in multi high-temperature nature steps. Perovskites, on the other hand, are made at low temperatures and 200 times thinner than silicon cells.

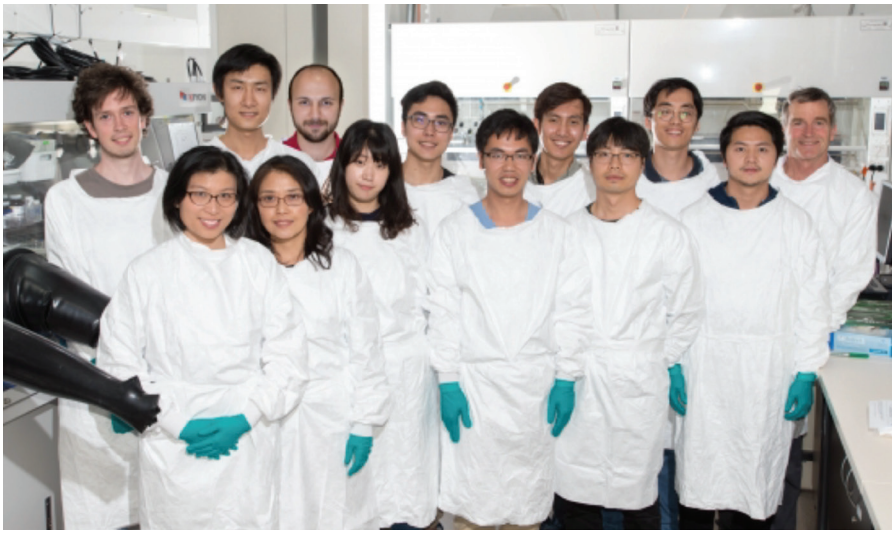
But although perovskites hold much promise for cost-effective solar energy, they are currently prone to fluctuating temperatures and moisture, making them last only a few months without protection. Along with every other team in the world, Ho-Baillie's is trying to extend its durability. Thanks to what engineers learned from more than 40 years of work with layered silicon, they're are confident they can extend this.

Nevertheless, there are many existing applications where even disposable low-cost, high-efficiency solar cells could be attractive, such as use in disaster response, device charging and lighting in electricity-poor regions of the world. Perovskite solar cells also have the highest power to weight ratio amongst viabale photovoltaic technologies.

"We will capitalise on the advantages of perovskites and continue to tackle issues important for commercialisation, like scaling to larger areas and improving cell durability," said Martin Green, Director of the ACAP and Ho-Baillie's mentor. The project's goal is to lift perovskite solar cell efficiency to 26 percent.

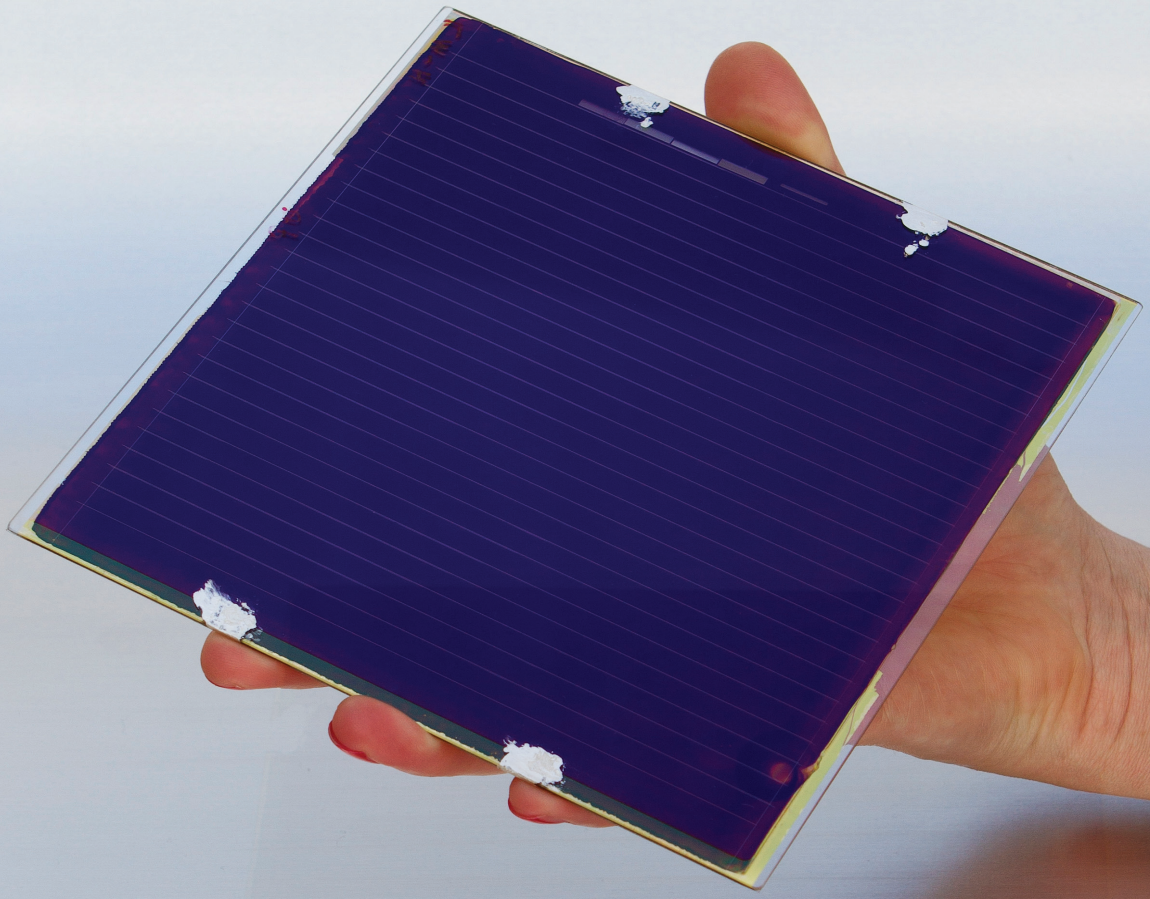
Professor Martin Green, Director of the Australian Centre for Advanced Photovoltaics at UNSW.
The research is part of a collaboration backed by $3.6 million in funding through the Australian Renewable Energy Agency's (ARENA) 'solar excellence' initiative. ARENA CEO Ivor Frischknecht said the achievement demonstrated the importance of supporting early stage renewable energy technologies: "In the future, this world-leading R&D could deliver efficiency wins for households and businesses through rooftop solar as well as for big solar projects like those being advanced through ARENA's investment in large-scale solar.""
To make a perovskite solar cells, engineers grow crystals into a structure known as 'perovskite', named after Lev Perovski, the Russian mineralogist who discovered it. They first dissolve a selection of compounds in a liquid to make the 'ink', then deposit this on a specialised glass which can conduct electricity. When the ink dries, it leaves behind a thin film that crystallises on top of the glass when mild heat is applied, resulting in a thin layer of perovskite crystals.

The tricky part is growing a thin film of perovskite crystals so the resulting solar cell absorbs a maximum amount of light. Worldwide, engineers are working to create smooth and regular layers of perovskite with large crystal grain sizes in order to increase photovoltaic yields.



Dr Anita Ho-Baillie's research team

Ho-Baillie, who obtained her PhD at UNSW in 2004, is a former chief engineer for Solar Sailor, an Australian company which integrates solar cells into purpose-designed commercial marine ferries which currently ply waterways in Sydney, Shanghai and Hong Kong. The Australian Centre for Advanced Photovoltaics is a national research collaboration based at UNSW, whose partners are the University of Queensland, Monash University, the Australian National University, the University of Melbourne and the CSIRO Manufacturing Flagship. The collaboration is funded by an annual grant from ARENA, and partners include Arizona State University, Suntech Power and Trina Solar.



Solliance paves way to upscaling perovskite PV modules

SOLLIANCE, a partnership of R&D organisations working in thin-film photovoltaic solar energy (PV) in the ELAT region (Eindhoven-Leuven-Aachen) has demonstrated a record 10 percent aperture area power conversion efficiency for its up-scaled thin-film perovskite photovoltaic modules. The efficiency was measured on an aperture area of 168 cm^2.

25 cells were serial connected through an optimised P1, P2, P3 interconnection technology. The PV module was realised on a 6x6 inch² glass substrate using industrial scale-able slot die coating in combination with laser patterning. Furthermore, the PV module was packaged by applying a flexible barrier using a lamination process.

This result could be realised due to the intensive collaboration within Solliance. Based on previous optimisation on 16 cm² modules, the Solliance team was able to quickly transfer this to a 6x6 inch² sized glass substrate using the developed blade coating process and the optimised mechanical patterning technology. In this case a 156 cm² aperture area module with 10 percent efficiency was realised comprising of 24 interconnected cells.

This was then used as starting point for the realisation of above mentioned 168 cm² PV module. These results demonstrate the up-scalability of this new thin film PV technology. Apart from the electrodes currently used, all layers can be processed in ambient environment and at temperatures below 120°C. This shows the low production cost potential of this new emerging thin film PV technology.

Further, the deposition and interconnection technologies used for obtaining these results are industrially available for Sheet-to-Sheet as well as for Roll-to-Roll manufacturing. The latter allows for creating high volume production in the future. The current world record efficiency of a small lab scale perovskite based PV cell is 22.1 percent.

"The challenge is to upscale perovskite cells to larger size industrially process-able modules with high efficiency and long lifetimes at low cost. The current result, presented on an aperture area comparable to standard commercial silicon solar cells, shows that Solliance, with its in depth know how on processing of organic PV and CIGS and its vast Sheet-to-Sheet and Roll-to-Roll pilot production infrastructure, is excellently placed to realise this upscaling. These 10 percent up-scaled perovskite based PV modules are first and important steps in this development, " explained Ronn Andriessen, program manager of the perovskite based PV program at Solliance.

"We are confident to boost quickly the up-scaled Perovskite based PV module efficiency further above 15 percent by using very low cost materials and processes. But besides demonstrating the up-scalability of these highly efficient Perovskite based PV devices, we are also currently working hard to stabilise further the performance of these devices under real life operational conditions", he added. Solliance is conducting advanced research on the development of Perovskite based PV modules and its applications with its industrial partners Nano-C, Solartek, DyeSol and Panasonic. With this result the Solliance R&D partners and their industrial partners demonstrate the strength of their research framework for the development of industrial Perovskite based PV modules.

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Solliance partners are: ECN, imec, TNO, Holst Centre, TU/e, Forschungszentrum Jülich , University Hasselt and Delft University of Technology. Solliance is supported by the Dutch province of North Brabant, which has dedicated € 28 million to Solliance. On June 12, 2014 Solliance opened a new large shared laboratory at the High Tech Campus in Eindhoven with pre-pilot production facilities, complementing the partner's labs which are also available to the other partners.

Micro smart grid enables sustainable and efficient energy supply

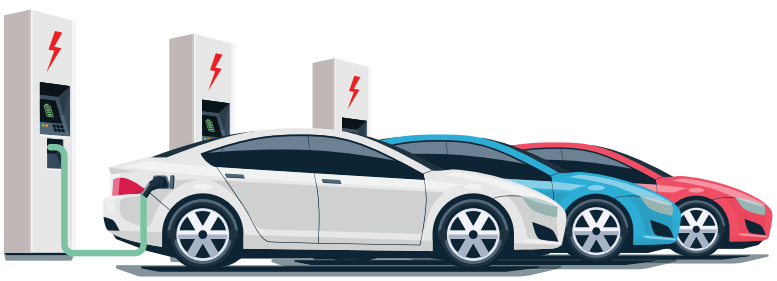
What will intelligent, decentralized energy management look like in the future?

Using its own Micro Smart Grid and control systems developed in-house, the Fraunhofer Institute for Industrial Engineering IAO is exploring how to efficiently coordinate energy producers, storage systems, and consumers as well as how to test the innovative technologies required. The research parking garage houses 30 charging spots for electric vehicles, Europe's fastest high-speed charging station, as well as Europe's first hydrogen storage system based on LOHC technology.

By the year 2050, most energy in Germany will come from renewable sources such as wind or solar power. But completely overhauling the current energy supply system poses challenges with respect to grid stability and security of supply, which in turn calls for new technologies and scalable solutions.

With the Fraunhofer IAO Micro Smart Grid, the institute is pursuing a decentralized approach to the coordination of energy production and consumption. It therefore guarantees local security of supply and a grid-friendly connection to superordinate power grids. Merging multiple micro smart grids in the future will allow energy systems to be integrated into a larger smart grid in a gradual process that keeps pace with demand.

Using the institute's facilities, the research team can apply the local situation to "play out" and test future smart energy management solutions already today. This takes place in the parking garage at the Fraunhofer Institute Centre in Stuttgart and the "players" are the various energy producers, storage systems and consumers on the research site. These include a charging infrastructure for electric vehicles with over 30 charge spots, as well as several direct current quick-charging stations with up to 150 kW of power per vehicle. The entire vehicle power supply is produced by a photovoltaic system located on the roof of the parking structure.



A lithium-ion battery storage system achieves the best possible balance between differences in energy production and consumption. What is special about this setup is that all components are operated under scientific supervision and real-life conditions. "The centrepiece of our Micro Smart Grid is the energy management system we developed ourselves," explains project manager Florian Klausmann. "This system gives us the means to manage and monitor all energy providers, storage systems and consumers within the context of a variety of optimization goals."

Having real-life data makes it possible for the research team to test various application scenarios in a realistic setting. The system will also allow them to use simulation interfaces to evaluate potential future operating models featuring, say, dynamic electricity pricing or forecast-based facility management. Another important part of the transition towards a new energy economy is harnessing innovative technologies.

A brand-new feature of the Fraunhofer IAO Micro Smart Grid is Europe's first hydrogen storage system based on LOHC (liquid organic hydrogen carrier) technology. This technology bonds hydrogen molecules within a carrier oil, eliminating the need for expensive pressure storage solutions or refrigeration units for liquid hydrogen. With 2000 kWh of storage capacity, the LOHC system constitutes a viable long-term storage option for the Micro Smart Grid, connected to the power supply via a fuel cell. So, when it comes to the massive energy surpluses we can expect during the energy transition, LOHC storage will mean that renewable energy production doesn't have to be curtailed.

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