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Solar cells: Taking efficiency to new highs

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

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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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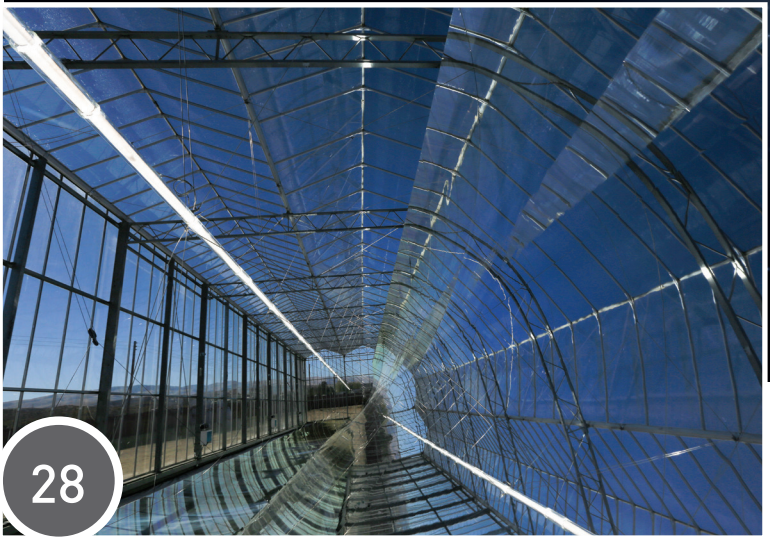

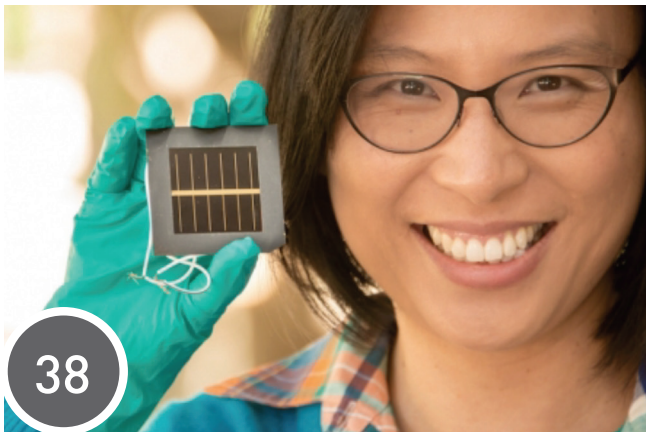

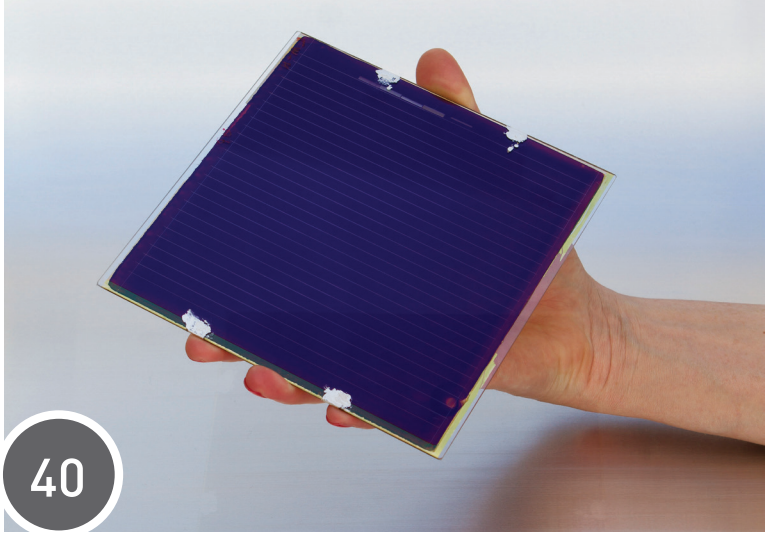

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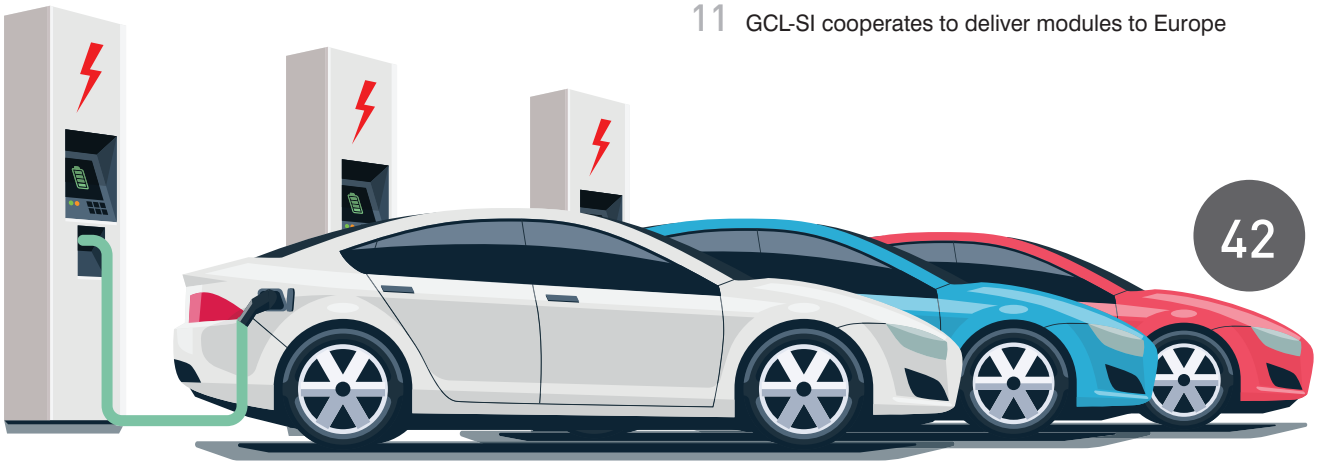


Solar module efficiencies move closer with nanowire breakthrough

SOL VOLTAICS has taken a significant leap towards commercializing its highly anticipated, efficiency-boosting solar technology by completing the manufacture of PV nanowires using its proprietary Aerotaxy process. The breakthrough paves the way for Sol Voltaics to bring its SolFilm PV solutions to market delivering solar module power boosts of up to 50 percent at very low cost.

"Today's achievement is the most significant to date for Sol Voltaics," stated Erik Smith, CEO of Sol Voltaics. "Producing solar nanowires through Aerotaxy is the key to manufacturing our SolFilm. The nanowires are grown such that the top and bottom of the wire have opposite doping profiles.

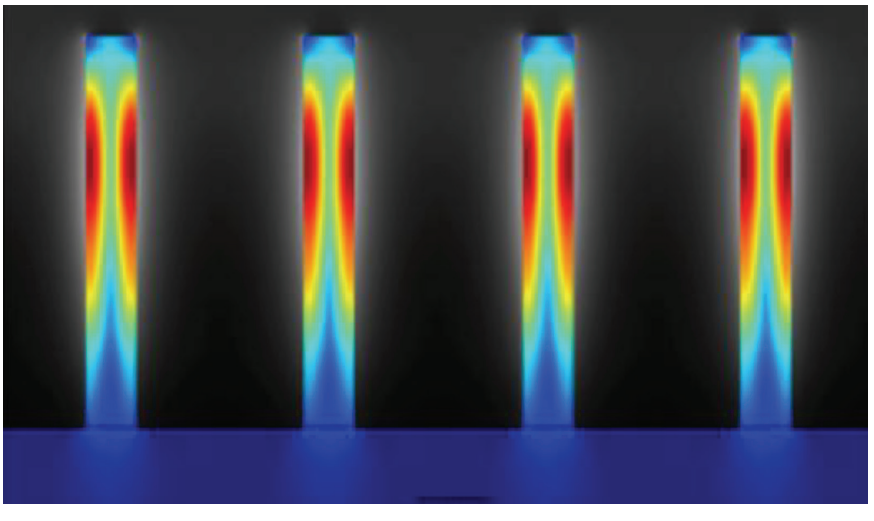
"This makes each nanowire a fully functional solar cell, with a pn junction along the length of the wire. Whether used by module manufacturers as a single-junction, high-efficiency, low-cost solution or as a boosting technology, we believe SolFilm will usher in a new age of solar power efficiencies, bringing tremendous value not only to solar manufacturers but also to businesses and consumers who adopt solar."

Increasing solar efficiencies at economies of scale has dramatically slowed in recent years, with conventional modules seeing an average annual efficiency increase of just 0.2-0.3 percent. With many emerging efficiency boosting technologies continuing to be prohibitively expensive, unstable or lacking reliability, SolFilm offers solar panel manufacturers an economically viable bridge with a proven material to generate previously unreachable solar efficiencies.

A lightweight, easy-to-adopt photonic film, SolFilm consists of billions of gallium arsenide (GaAs) nanowires oriented facing the sun. The nanowires, each of which is a complete solar cell, convert high-energy sunlight directly into power. Gallium arsenide, previously seen in space and concentrated solar projects, has long held great potential for the mainstream solar industry.

However, up to now, its high fabrication costs have prevented economical fabrication of large solar panels. Manufacturing nanowires with Aerotaxy dramatically reduces the required amount of GaAs and removes the need for a crystalline support wafer, significantly lowering material costs.

With the recent results, Sol Voltaics has taken a giant leap towards delivering an unprecedented increase in power for conventional solar modules while reducing the price of solar energy.



Global consortium to accelerate scaling of renewable energy

A GROUP of companies are announcing the launch of the global Bright Minds Challenge to identify and help accelerate the scaling of solutions for 100% renewable energy – focusing on solar and energy storage. The challenge is initiated by DSM, together with Accenture; Greentown Labs; Skoll Centre for Social Entrepreneurship, University of Oxford; Solarcentury; SolarAid and Sungevity. The consortium will provide the most promising emerging solutions with a tailored package of commercial, technical and mentoring support to help scientists scale up their solution as quickly as possible. The companies and organizations behind the #BrightMindsChallenge are committed to 100% renewable energy, and helping to lead the transition to a low carbon economy. The Challenge is designed to help scientists around the world with bright solutions to overcome barriers they face in scaling up their ideas and solutions. Anyone with a solution relevant to renewable energy – focusing on solar and/or renewable energy storage - can submit an entry. The solution needs to be prototyped, and ready to scale up.

After a public vote to determine the top 10, a panel of experts will then shortlist the top three and select the winner. The top three solutions will all receive commercial, technical and mentoring support, with the winner getting 500 hours of tailored help to fast-forward their solution. All entrants will receive valuable exposure for their projects. The hunt for the solutions starts now, with voting taking place in January and February 2017, and the winners being announced in June 2017. The central platform for the #BrightMindsChallenge is www.sciencecanchangetheworld.org

ABB's new microgrid technology lights up rural communities

ABB is bringing affordable, safe and reliable electricity to remote communities thanks to its new integrated microgrid solution, MGS100, that enables solar power and battery energy storage The MGS100 has been built to perform in extreme environments, and can transform lives and businesses for the better in places that struggle to access affordable and reliable electricity.

The scalable system can be connected to multiple power sources to provide electricity for remote places that are not connected to the main grid, or reliable back-up power for small commercial and industrial facilities using an inconsistent grid supply, enabling social and economic development.

MGS100 brings together all the components required for a sustainable microgrid in a single device, making it extremely versatile and flexible. It can tap into cost efficient, renewable energies such as solar photovoltaic [PV] and batteries.

By prioritizing abundant local solar power during the day, the MGS100 switches to battery mode after dark and only uses an AC generator for the rest of the night if the battery runs out. Any excess energy produced throughout the day is used to charge the batteries. Seamless transition between the grid and the microgrid allow operations to continue while the grid is down, and battery energy storage minimizes the need to purchase electricity from local utilities.

Encased in a single container, the MGS100 has three power ratings – 20kW, 40kW, 60kW nominal load power. Installation is quick and easy, as it is factory tested and embedded DC and AC protections make it ready to connect.

With the added benefit of remote monitoring, vital diagnostics are always available and maintenance is simple. The modular scalable design means that capacity can be increased as and when required, and it can even be connected to the grid if this becomes available.

ABB's President of Electrification Products, Tarak Mehta, said: "At ABB we are committed to using the latest technical advancements to support everyone in society and create a new

world of opportunity for these often remote and hard to reach communities. The MGS100 is the first microgrid solution of its kind that makes access to affordable and reliable power a reality, creating life changing opportunities, improving basic living standards and unlocking economic development." The MGS100 will be widely available at the end of 2017.

ABB is currently seeking partners to trial the microgrid solution. For further information about the product and trial opportunities contact Erika Velazquez, Global Product Marketing Manager Microgrid.

Sonnedix acquires 67 MW solar portfolio in France

SONNEDIX strengthens its presence in France through the acquisition of Aloe Energy, a successful Solar PV developer and operator with 67MW in operation as well as a pipeline of projects under development and construction, together with a team of skilled developers and operators.

This is the fifth significant acquisition Sonnedix has completed in the last eighteen months, totalling more than 300MW of operating projects with a total asset value of more than €1.4bn.

These acquisitions have more than doubled Sonnedix's solar capacity in construction and operation, now exceeding 600MW, with an overall portfolio over 1.2GW globally. Sonnedix now ranks as France's 4th largest solar player, controlling 155MW of operating PV plants across France, in addition to more than 100MW in each of Italy and Spain.

"We are excited about the further integration in France and delighted to welcome the Aloe Energy team to Sonnedix, which has just in the last auction demonstrated the strength of their project development capabilities – we look forward to working together to continue our growth in France and across Europe", said Andreas Mustad, Sonnedix's CEO.

Sonnedix acquired Aloe Energy from a consortium including Aloem, Ardian Infrastructure and Debiopharm Investment. Sonnedix was advised by Astris Finance (financial), Linklaters

(legal), OST (technical) and EY (accounting / tax). The Sellers were advised by Gide (legal/tax/structure), Société Générale (financial modeling), G-advisory (technical), PwC (accounting), Arsene Taxand (tax) and PGA (legal).

Sharp showcases PV module and energy management platform

AT INTERSOLAR, Sharp Energy Solutions Europe will show the results of heavy investment in product development over the past 12 months. This includes a highly efficient and award-winning 48-cell back-contact module as well as the flexible “Smart Chap” energy management platform. The platform features a multitude of functions that are easy to use, and is compatible with hardware from a wide range of manufacturers.

“In Europe, we have increased sales’ volume in the last six months by more than 20 percent as compared with the previous year, and we are continuing to grow,” said Peter Thiele, President of Sharp Energy Solutions Europe.

“Due to Foxconn’s investment in Sharp, we are now able to promote our business more aggressively. Sharp has always been known for its visionary focus and innovative force and we are focused on developing new, future-oriented solutions. We are pleased to introduce our latest products, such as Smart Chap and our new back-contact module at this year’s Intersolar in Munich. Interested parties can also find out about our comprehensive portfolio and opportunities for partnership.”

New 48-cell back-contact high-performance module with a module efficiency of 19.8 percent

The NQ-R256A (256 Wp) is a mono-crystalline PV module with a “Best-in-class” module efficiency of 19.8 percent and award-winning design. In Japan, the module has already been successfully established, and has been awarded the “Good Design Award,” a prestigious design award.

The back-contact technology is responsible for the module’s efficiency, which increases the amount of solar radiation used and enables maximum performance on a minimal roof surface area. The large number of contacts on the back of the cell ensures an even and efficient energy dissipation. On hot summer days, an above average solid temperature coefficient of -0.377 percent/°C ensures the highest yields.

Due to its size, 1318 x 980 x 46 millimeters and weighing only 17 kilograms, the module is easy to install, especially in difficult installation conditions - mounted either upright or horizontally. The corresponding IEC certifications (IEC/EN 61215 and IEC/EN 61730) confirm the module’s safety, quality and long service life. A frame featuring two additional support bars and a copper layer on the back of the cell ensure a high degree of stability; the module has also been tested according to IEC 61215 for a snow load test exerting 5,400 Pa. In addition, the connector box is encapsulated within resin and is thus optimally protected against water or contact damage.

Visually, the module has a discreet matt black finish. Reflections are minimized because the electrical contact wires are on the underside of the panel and it uses anti-reflection glass, making the panels less conspicuous.

Sharp Smart Chap is an intelligent, modular home energy management system. The Smart Chap energy manager includes control over battery storage to save the energy produced during the day, which can be used efficiently at any time, even at night. This means that during the summer months, consumers can expect to reduce their dependence on the public electrical grid by up to 95%, with an overall annual average of up to 80%.

The system’s flexibility on the market is unique. It is an open platform so it can connect to hardware (battery storage, inverter, heat pumps, etc.) made by various manufacturers and its system interfaces can be continually expanded.

In addition, the system’s capacity and performance are easy to scale by connecting multiple battery storage devices or battery inverters. The system is suitable as a supplement to any existing photovoltaic system on the market, regardless of which PV inverter was used.

Smart Chap also distributes solar energy produced in the home in a sensible and cost-saving manner. Electrical devices can be switched on via Smart Chap, e.g. when the sun is shining. Sharp also offers various technical solutions for connecting consumers to the system.

The control of devices via the app can be done using Smart-Grid-Ready interfaces, wireless plug sockets or relays. The devices can be switched on or off according to predefined conditions.

Solaris Offgrid raises €1m to tackle electricity poverty

SOLARIS OFFGRID, the pay-as-you-go solar energy solutions provider working to improve access to electricity across rural populations, has raised more than €1M to fund R&D and grow into new markets – providing more homes and businesses with affordable, clean energy. The funding comes as a direct result of Solaris Offgrid's success at The Business Booster, hosted by InnoEnergy, the innovation engine for sustainable energy across Europe. It will be used to support the firm both in growing its operations across the developing world and in continuing to create new, modular and scalable solutions for partners and customers.

Siten Mandalia, co-founder of Solaris Offgrid, says: "We're proud to have brought clean and safe electricity to almost 10,000 people, across six countries, since we began operations three years ago. But that's just the beginning. This latest round of funding will prove crucial as we work towards our ambition of providing power to 10 million people by 2022."

The most flexible off-grid solar solution in existence, Solaris Offgrid's pay-as-you-go technology can be scaled up from basic lighting to full-service communication, refrigeration and productive solutions – as and when customers need it. It has been particularly popular in Tanzania, where the company operates through its subsidiary Solaris Tanzania. Alongside this, the company designs and manufactures integrated solutions for field partners, enabling them to provide affordable and sustainable energy access in off-grid areas – including in Kenya, Uganda, Nigeria, Benin and Senegal.

Solaris Offgrid combines its offer of modular hardware with tailor-made business support and cutting-edge proprietary cloud software – meaning that its partners have access to the exact solution that best meets their needs. Josep-Miquel Torregrosa, Business Creation Officer at InnoEnergy, which has supported the venture through its InnoEnergy Highway acceleration program and invested more than €150,000 in the current investment round, says: "We're very proud of the progress Solaris Offgrid has made since joining our programme in 2016 and we're delighted that it is continuing to create impact with this latest investment.

"The success of this funding round, whose lead investor was met at the Business Booster event in Barcelona last year, is testament to the true power of the InnoEnergy offer, with events like the TBB." Solaris Offgrid's investors include but are not limited to: InnoEnergy; rural electrification fund, GAIA Impact Fund; and impact venture builder, Zubi Labs. Hélène Demaegdt at GAIA Impact, says: "We've been impressed by Solaris Offgrid's flexible mindset and focus on innovation.

"With this latest funding, we believe the company is now in a strong position from which to accelerate its growth into new areas, create long-term value for its shareholders and stakeholders, and positively impact the lives of millions affected by energy poverty in Africa."

Flisom showcase CIGS technology at Intersolar

FLISOM AG, a Swiss solar enterprise, in which Tata Industries of the $103bn Tata group is a strategic investor and the Swiss Federal Laboratories for Materials Science and Technology (Empa) is a technology partner, will give visitors a glimpse of its new product range at Intersolar 2017.

The company, headquartered in Zurich, Switzerland, has spent over a decade developing high-efficiency CIGS (Copper Indium Gallium Selenide) thin film solar modules using proprietary roll-to-roll manufacturing technologies.

Flisom's products are based on the technology developed by its research partner Empa, which had achieved a world-record conversion efficiency of 20.4% in a flexible CIGS solar cell. This research partnership ensures that Flisom products remain at the cutting edge of solar thin film offerings.

Flisom modules are super thin (under 2mm), have a uniform, jet black appearance, are ultra-light (in some versions under 500g/m2) with a power to weight ratio of up to 20 times more than conventional silicon panels, and are strong, safe and rollable.

Unlike competitors, Flisom offers not only its standard portfolio of modules, but also offers its technology as a business-enabling platform, which is customisable for the applications of end customers, and the modules are designed and manufactured in-house.

With Flisom gearing up for full commercialisation of its product range this year, the company is focused on enabling solar in ways not possible before, whether for buildings, mobility and transport, and even specialist customized applications, across Europe, United Kingdom and United States.

WIRSOL sell 19 solar projects in the UK

WIRSOL has sold part of its portfolio of solar parks in the United Kingdom to the investment company Rockfire Capital.

The portfolio disposed of by WIRSOL, in conjunction with its British subsidiary WIRSOL Energy Ltd., consists of 19 solar parks, two of them located in Northern Ireland. The 19 solar sites, each ranging between 2.5 MWp and 20.5 MWp, have a total capacity of around 105 MWp.

Cumulatively the portfolio that has been sold produces enough energy to generate almost 100 gigawatt hours a year. This is sufficient to supply power to around 30,000 households in Great Britain and corresponds to a saving of almost 60 tons of carbon dioxide per year.

Collaboration with Rockfire during the transaction was altogether positive. We will be continuing to build further solar parks in Great Britain in future. In the process, we will decide on a case by case basis whether it makes more sense to adopt and operate a plant on our own portfolio, or to pass it on to a suitable investor who is interested in a secure and very longterm investment, for example with a view to providing a stable basis for pension funds,' said WIRSOL Managing Director Peter Vest, explaining the strategy of his company.

'We concluded the deal with the Rockfire team to a very tight schedule. Both WIRSOL and Rockfire worked effectively and with full commitment to bring about this important transaction. WIRSOL Energy Ltd. is already engaged in the development and construction of important solar parks in Great Britain and Australia. We hope to continue this positive and effective relationship with Rockfire with success in future,' stated Mark Hogan, Managing Director of WIRSOL Energy Ltd.

ABB technology drives largest floating PV plant test-bed

LAND SCARCITY has severely limited Singapore's adoption of solar power. Floating solar panels may be a viable alternative for the city-state surrounded by water. Floating panels could be eleven percent more efficient than solar panels placed on precious land. Pioneering technology leader ABB is providing critical components on a landmark one megawatt floating solar photovoltaic test-bed. It measures 1 hectare or 1.5 football fields. The energy generated will be fed into the national energy grid, providing electricity for up to 250 households.

"We are proud to support this important project in Singapore with our technological expertise and domain knowledge," said Tarak Mehta, president of ABB's Electrification Products division. "This project is perfectly aligned with our Next Level strategy around the energy revolution and is an important step in collaborating with partners to

bring more renewables into the future energy mix."

Located in the Tengeh Reservoir in west Singapore, the installation features multiple solar solutions from providers to study the performance and cost-effectiveness of floating solar platforms. ABB supplied 100 kW of market-leading TRIO-50 solar inverters to Phoenix Solar, one of several system integrators for the project. These essential components convert the direct current produced in solar panels into alternating current for use in electrical grids. Additionally, ABB low-voltage molded case and miniature circuit breakers protect the electrical circuits on the water.

TrinaBESS introduces TrinaHome S&T series

TRINABESS has announced the introduction of the long awaited TrinaHome, the residential battery system for all households. The TrinaHome systems will be on display at the world famous InterSolar Europe.

General Manager of TrinaBESS Frank Qi comments:
"We're very excited to be introducing our products to the European market. Europe has long been the light to which everyone is drawn in terms of solar and renewable energy.

The European people's concern with the planet and climate translated into strong government policy in these areas.

As the PV market has become self-sufficient and subsidies are removed the requirement for battery storage grows. There is a large demand in countries with higher electricity prices and we expect this to propagate all over Europe as each country reacts to market trends and see the advantage of distributed storage."

The TrinaHome collection comes in two series the single phase S-series and the three phase T-series. The single phase series comes in with a power rating of 3.7 kW and modular capacity expansion from 3 kWh to 12 kWh whereas the three phase series comes in power ratings of 5.2 kW or 9.8 kW with modular capacity expansion from 6 kWh to 12 kWh or 9 kWh to 18 kWh respectively.

The TrinaHome collection is sleek, discrete and fits in with any other home appliance. The system can be monitored remotely from mobile device or on desktop putting the power in the hands of the user.

GCL-SI cooperates to deliver modules to Europe

GCL System Integration Technology Co. Ltd. (GCL-SI), (Shenzhen: 002506), a subsidiary of energy group GCL, has entered business relationship with Europe Solar Concept (ESC), one of the first wholesalers of solar products in Europe, to offer European countries GCL-SI's solar modules.

Through the partnership, ESC will integrate GCL-SI solar modules into its product portfolio and distribute them to its customers. This is the first time that GCL-SI has cooperated with an European distributor, and the deal will help the company to bring more of its green energy products to European countries and contribute to the construction of local projects.

ESC is a system wholesaler for solar power systems and provides its customers with modules, inverters, storage systems, set-up technologies and all the accessories required for the installation of photovoltaic systems. So far, GCL-SI has shipped 4.2MW modules to ESC, which are GCL-SI's GCL-P6/60 265W and GCL-P6/60 270W modules. In future cooperation, the exact volume will depend upon market demand.

The agreement shows recognition from ESC of GCL-SI's production quality. "We are proud to be one of the first in Europe to provide our customers with quality products from GCL," said Christian Laibacher, Managing Director of Europe Solar Concept.

"We are delighted to work with such a strong partner as Europe Solar Concept," said Philipp Matter, President Europe and Managing Director of GCL Systems Integration Technology GmbH. "ESC will be the first stop to deliver GCL-SI's solar modules to European countries. We hope to work together with the company and make our products available to more countries, and to help European countries build a greener future."

Earlier this year, GCL-SI launched its manufacturing base in Vietnam, where modules for European and US markets as well as the installed cells are produced. From May 31st to June 2nd, GCL-SI will attend Intersolar Europe show at the booth A1.250 with its solar products, including poly module GCL-P6/60, black silicon module GCL-B6/60 & GCL-B6/60B, mono perc module GCL-M6/60 and double-glass module GCL-P6/72GW, as well as energy storage system generation II.

ENcome reaches gigawatt threshold

ENCOME now services photovoltaic power plants with a nominal capacity of approximately one Gigawatt. The leading European independent service provider has also secured Engineering projects in the triple digit Megawatt range. Especially in Australia, ENcome faces strong growth in both business segments Engineering & Advisory and Operations & Maintenance.

"Reaching the Gigawatt threshold gives evidence of our recent business performance and facilitates further increases in our already high service quality", says Andreas Leimbach. "Our international growth confirms our business model as independent service provider to the benefit of our customers", emphasizes Robin Hirschl. In Europe, also due to additional new builds in the „Utiltiy Scale" segment, ENcome's O&M business shows a positive development. Especially in the UK, the company benefits from the current tenders for Operation & Maintenance services since many plants have now reached final acceptance. "More and more power plant owners realize that professional O&M services are not only a means to reduce costs, but the major driver of yields", explains Burkhard Söhngen.

In their Engineering & Advisory segment, ENcome has a firm order pipeline for Engineering services in Australia and Europe as well as rectification and performance optimization projects, mainly in the UK, Italy, and Germany. Especially promising is ENcome's young Australian business. On the basis of regional support schemes and comprehensive "Renewable Energy Targets", there is a huge potential for a multi Gigawatt market of advanced developed utility scale projects. In Australia, ENcome is active in both business segments Engineering & Advisory and Operations & Maintenance.

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.

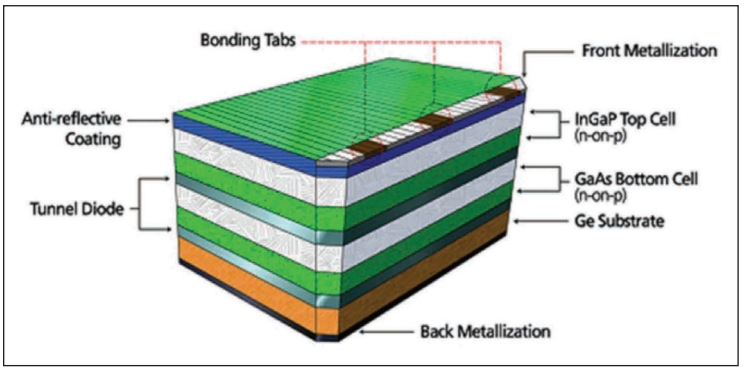


Figure 1. The GaInP/InGaAs/germanium lattice-matched, triple-junction cell is monolithic device that is grown on a germanium substrate.

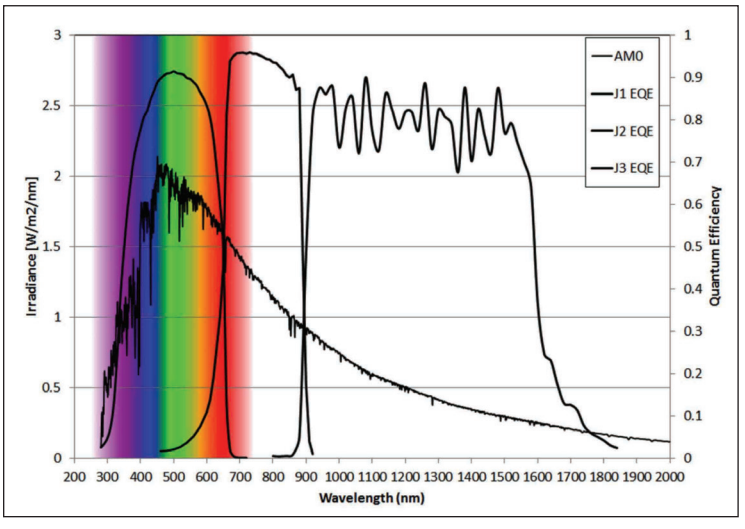


Figure 2. The internal quantum efficiency (IQE) of the Zener tunnel-junction cell overlaid on the space AM0 spectrum.

… 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

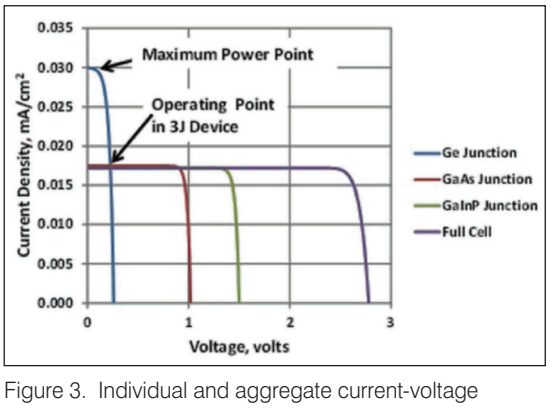


Figure 3. Individual and aggregate current-voltage curves for the GaInP/InGaAs/germanium solar cell. The germanium junction operates at the current-matched point in the complete triple-junction device, rather than at its maximum power point.

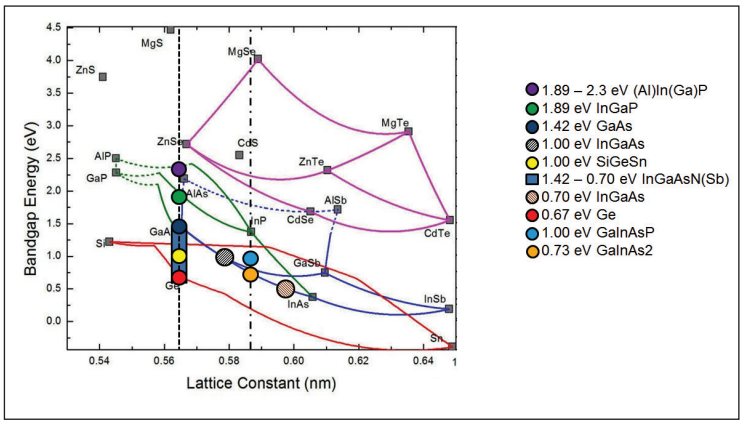


Figure 4: Bandgap and lattice constant for a number of semiconductor materials, with the III-V materials of particular interest for multi-junction cells noted.

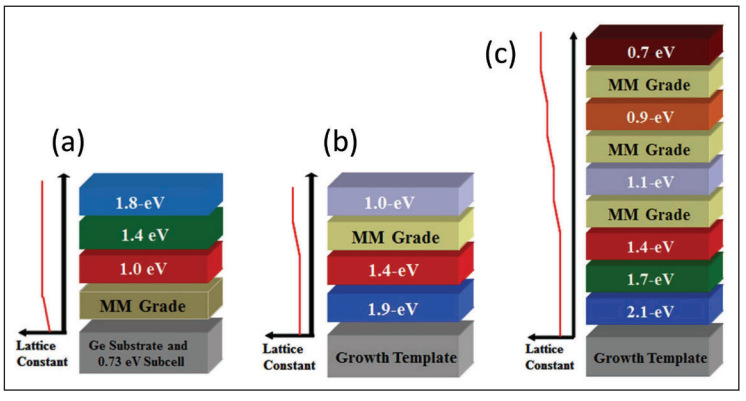


Figure 5: (a) The upright metamorphic four-junction cell has a performance that is compromised by threading dislocations through the entire structure. With inverted metamorphic cells with three (b) or six (c) junctions, only part of the structure suffers from threading dislocations.

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.

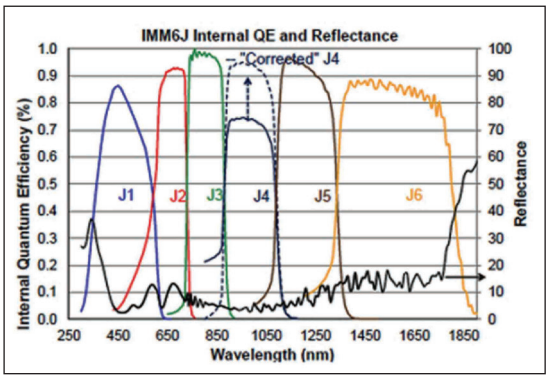


Figure 6: Internal quantum efficiency and reflectance for the inverted metamorphic, six-junction cell.

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.

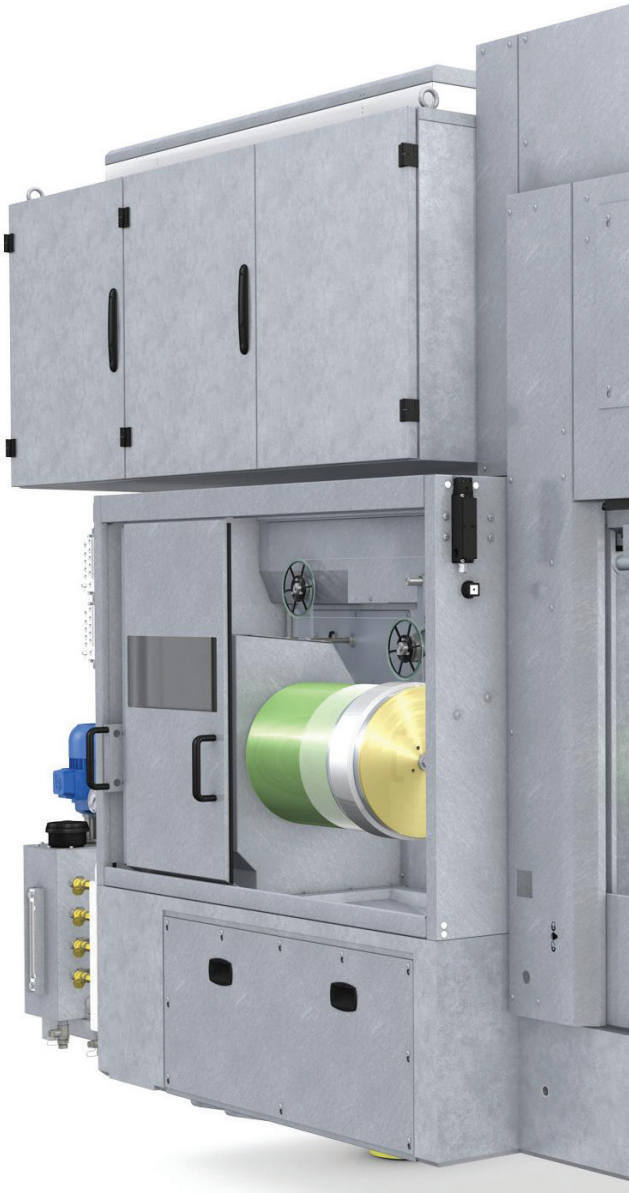
We have also undertaken a comparison between modelled and verified efficiencies (see Table 1, where the numbers in red are the NASA verified measurements, and the black numbers are the results of our model). Note that the performance modelling is based on a 'practical' approach that considers the likes 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.

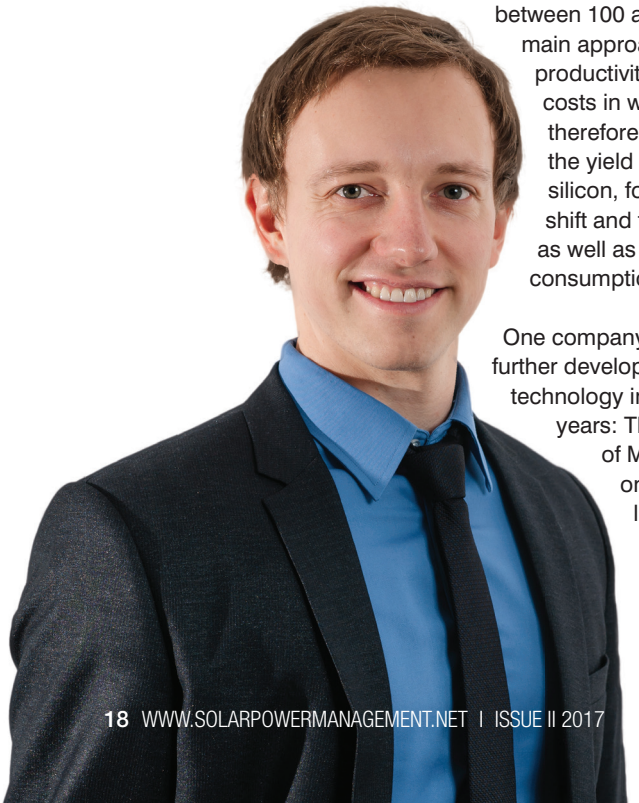
Wire management is key to productivity in wafer production

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

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.

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

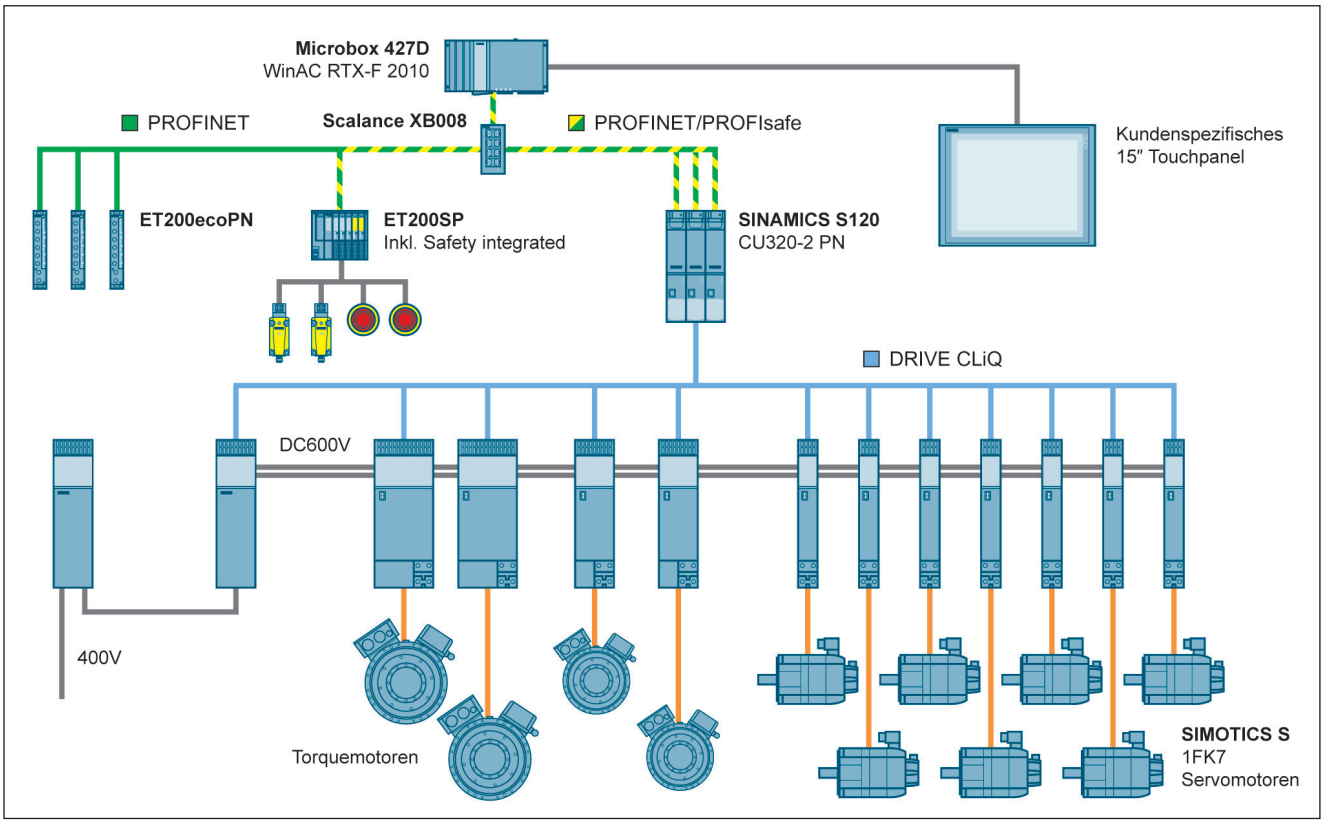
Wire management saves 20 percent of the diamond wire

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.

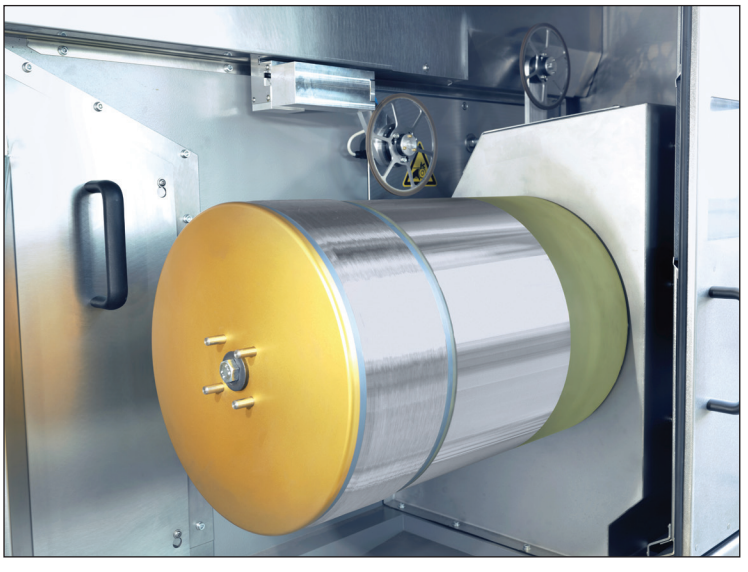
Capable of using the thinnest wires: more wafers due to narrower cuts

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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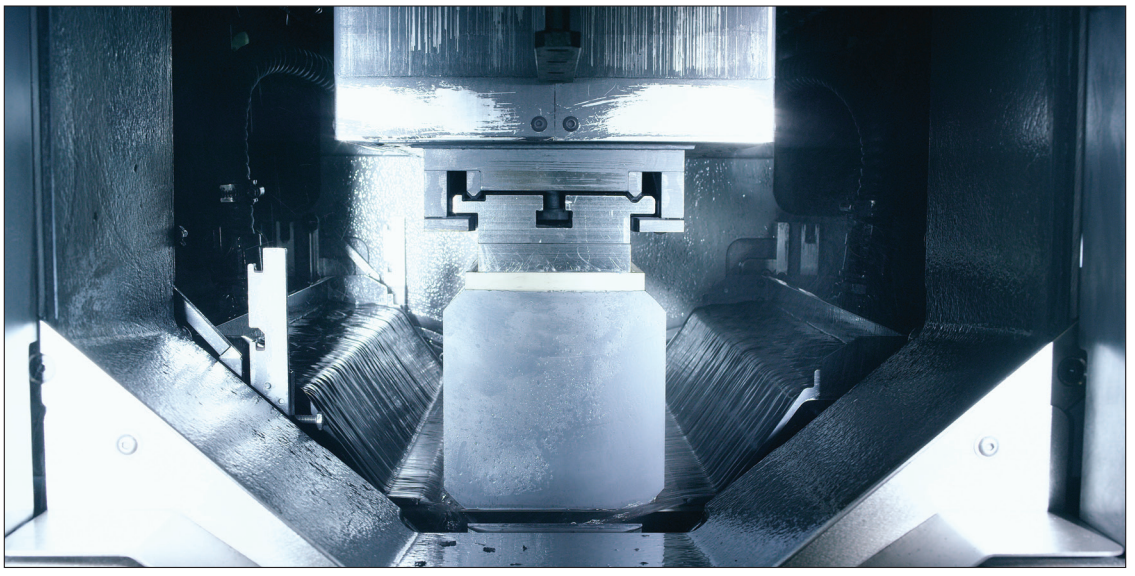


Sophisticated diamond wire technology extracts more high-quality wafers from one brick of silicon.

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.

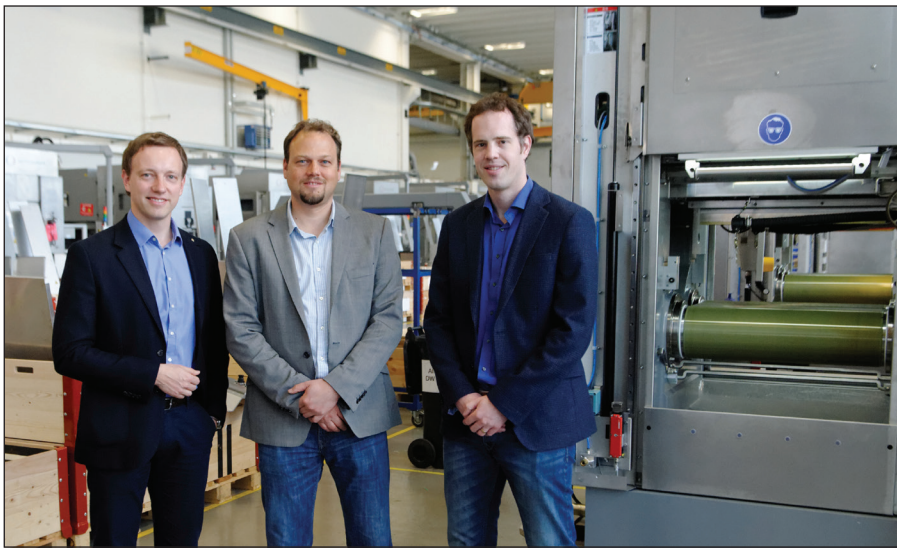
The faster change of cutting direction and the higher cutting speed considerably increase the throughput of the new generation of machines. A 650 mm long brick can be cut in less than two hours into thousands of high quality wafers with a total thickness variation (TTV) of less than 10 µm.

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.

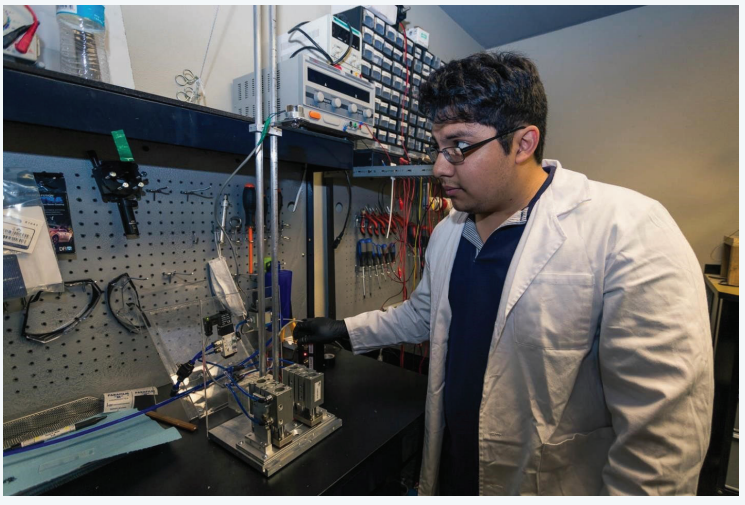
"Durability is great, but could (the coating) enhance efficiency? We found that it could. So now we had a new formulation that could be sprayed on a solar cell; it dried at room temperature without any special treatment. We (also) found it could go on top of the antireflective coatings that PV manufacturers 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.

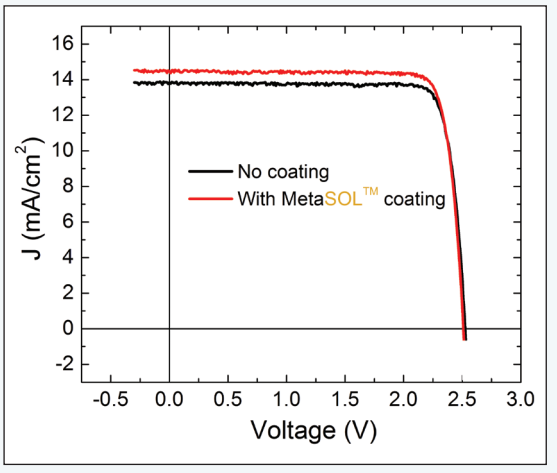
"By now we started to realize that we were part of something very new. If you have a material with all of the benefits of polymers but has the properties of glass, then it is disruptive, even revolutionary. With (traditional) silica coatings you have to use very expensive deposition and baking processes.

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.



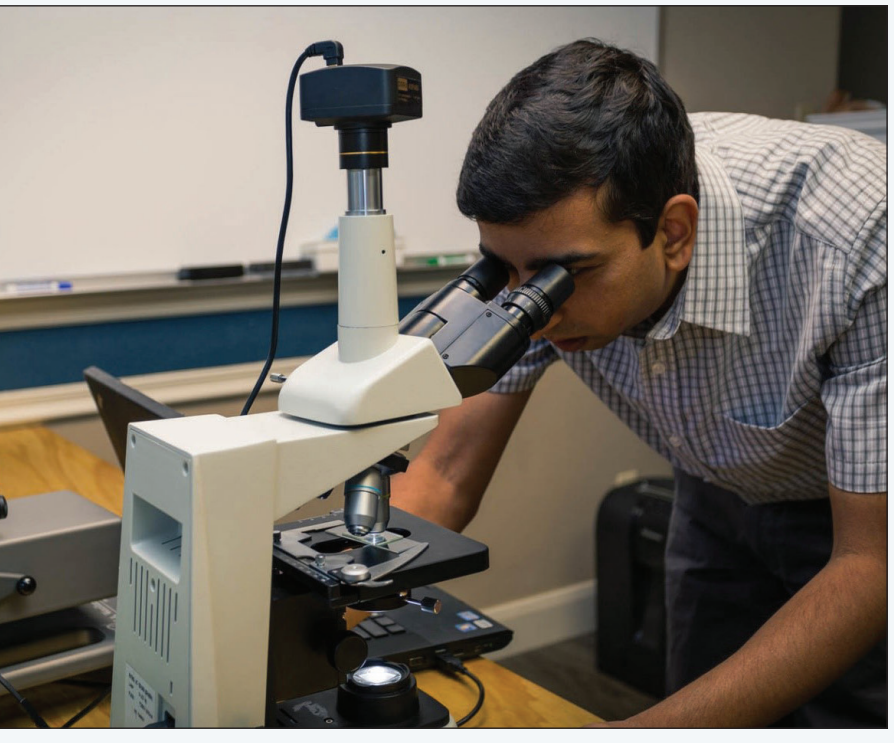
Ernesto Arevalo, MetaShield Lab Technician, tests a coating using a drop ball test (Photo courtesy of USTAR.)



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

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.

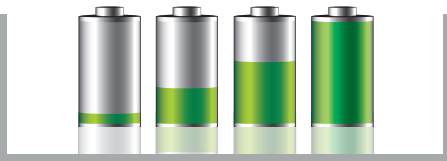
According to GlassPoint, some oil producers use more of their own oil or natural gas to pull hard-to-pump oil out of the ground than they do to generate power; it is an accelerating cycle of higher costs that also drives more self-consumption. Oman uses around 20 percent of its natural gas in its fields, 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.

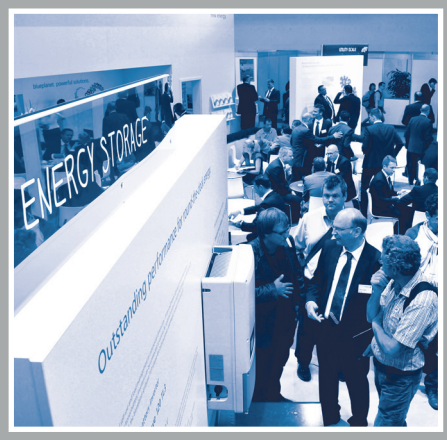
The company's approach to CSP and the oilfield market were just first steps. The company still had to design and create new mirrors and all the related technology needed to carry a concept into practical operation. Before oil producers would trust the company's novel approach to steam generation, a complete 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."



CHARGING THE FUTURE



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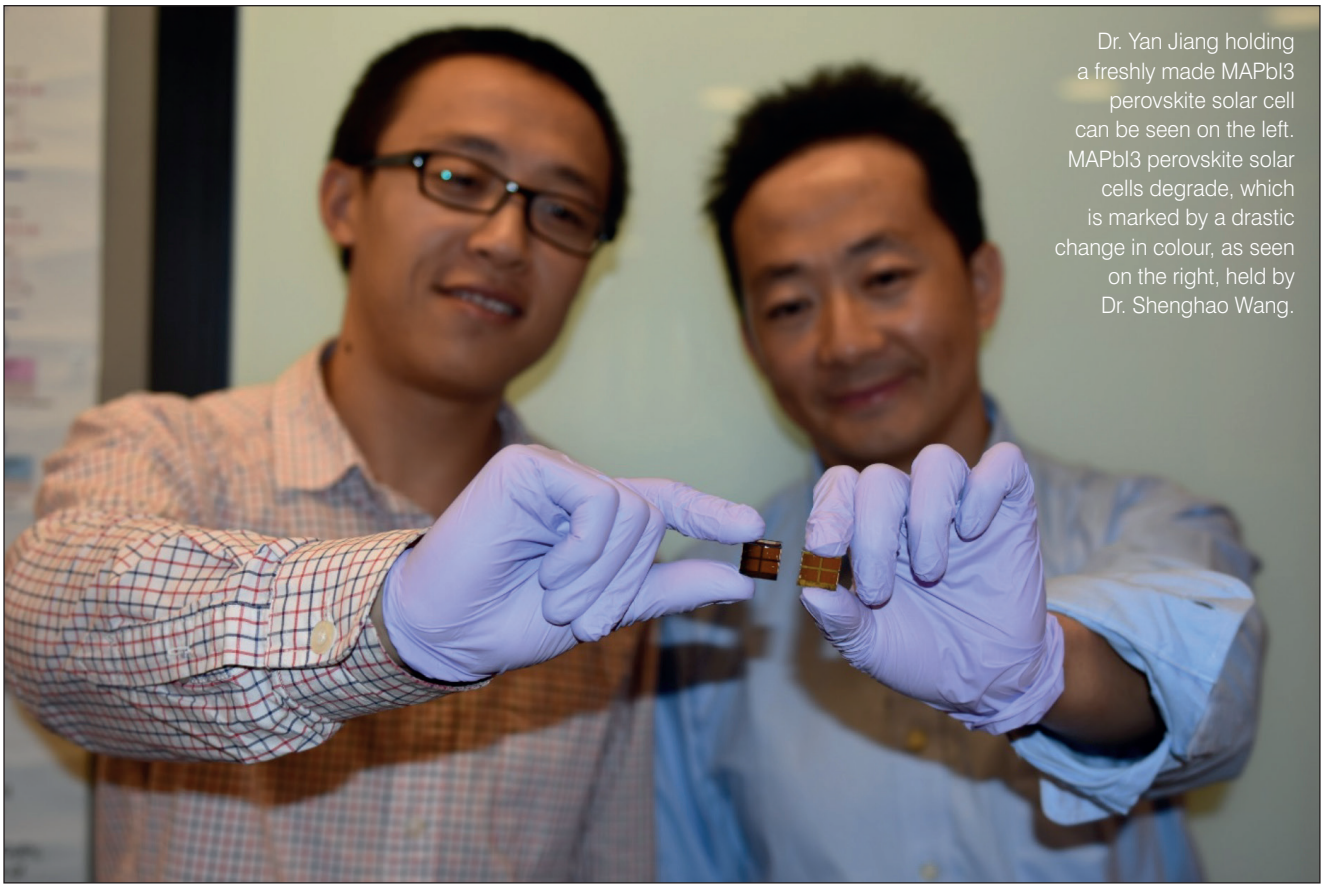


Dr. Yan Jiang holding a freshly made MAPbI3 perovskite solar cell can be seen on the left. MAPbI3 perovskite solar cells degrade, which is marked by a drastic change in colour, as seen on the right, held by Dr. Shenghao Wang.

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.

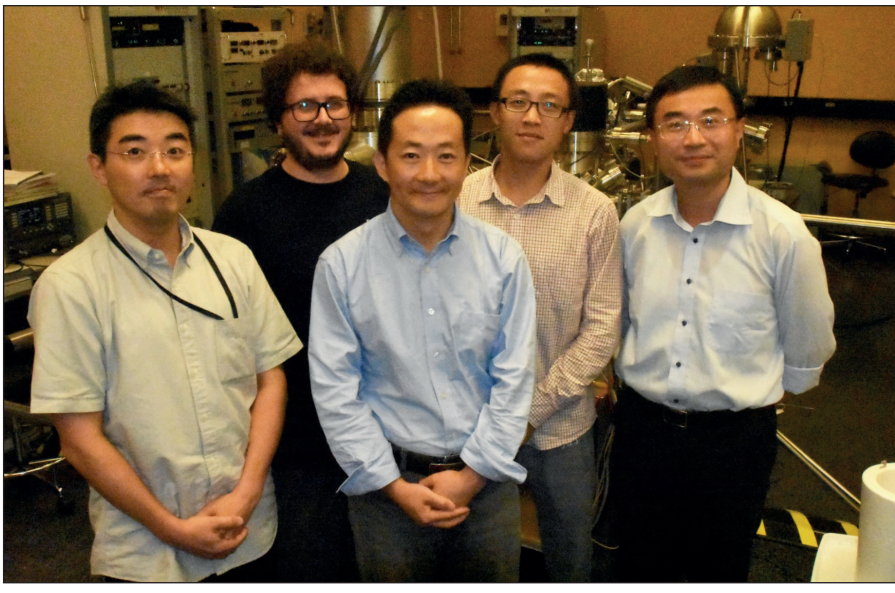
His research reveals that iodide-based perovskites will universally produce a gaseous form of iodine, I2, during operation, which in turn causes further degradation of perovskite. While many researchers have pointed to other sources, such as moisture, atmospheric oxygen and heat as the cause of MAPbI3 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.

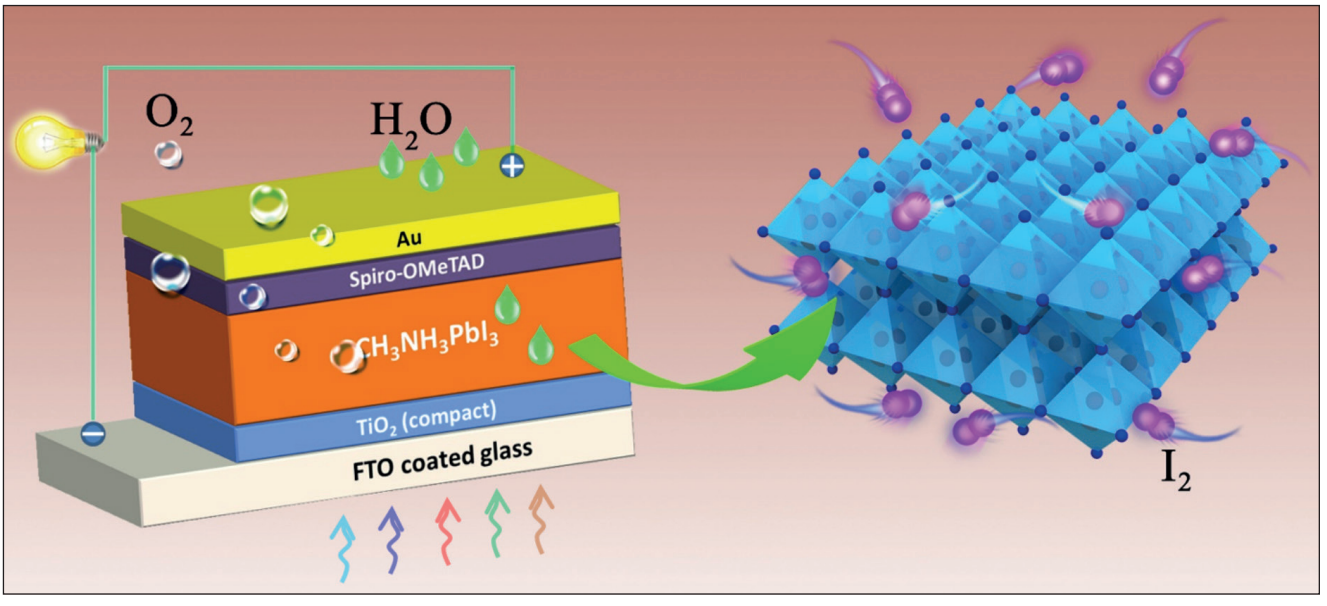
The schematic drawing showing that various factors (e.g., moisture, oxygen, light illumination, applied electric field, etc.) during the operation of MAPbI3 perovskite solar cells can generate iodine, which leads to degradation of solar cells.

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."

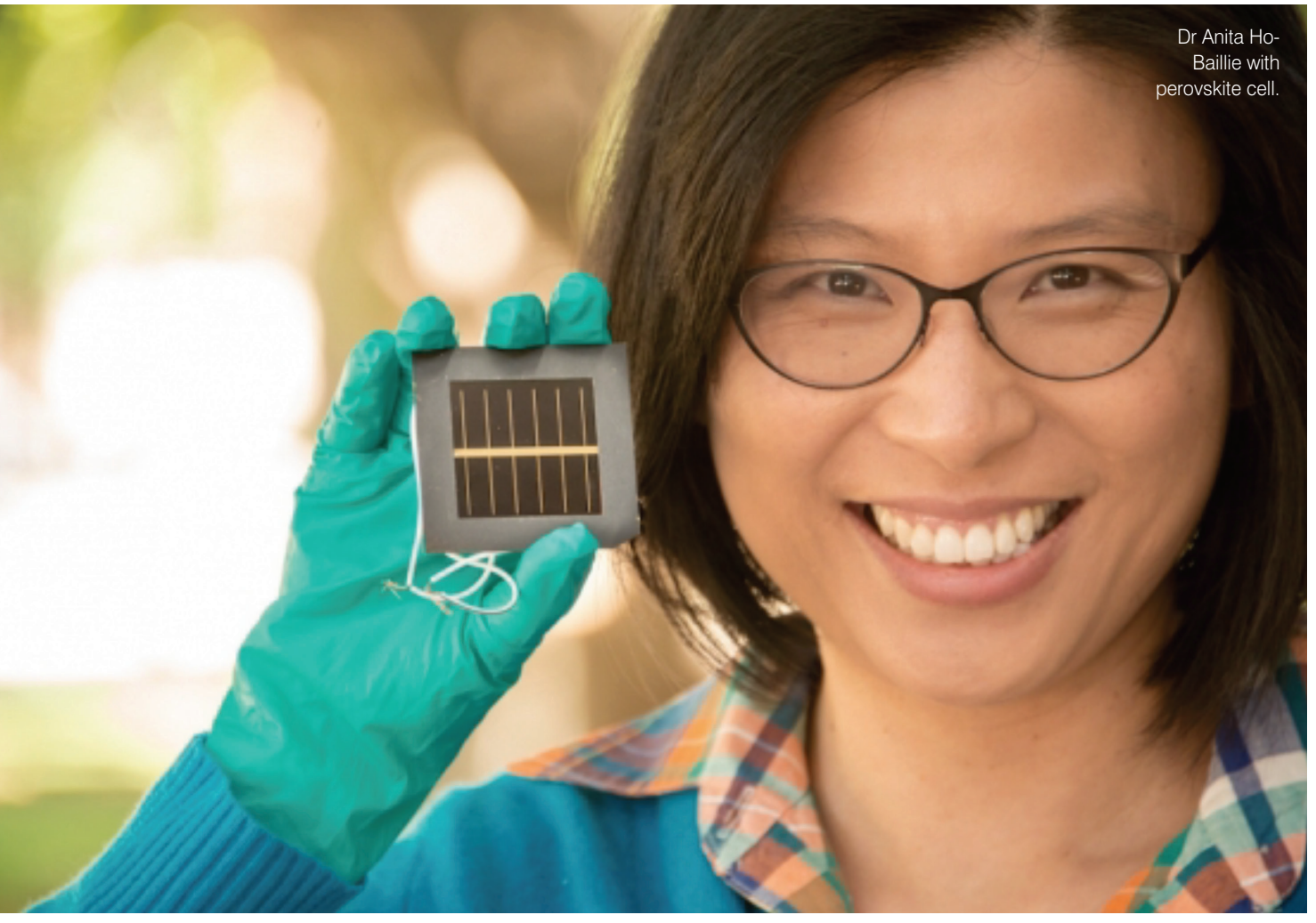
Thin films aren't the sole answer, but "I can envision that a technology like the one that we're developing could be part of a collaborative materials system to help replace glass in next-generation PV applications," he said.

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.

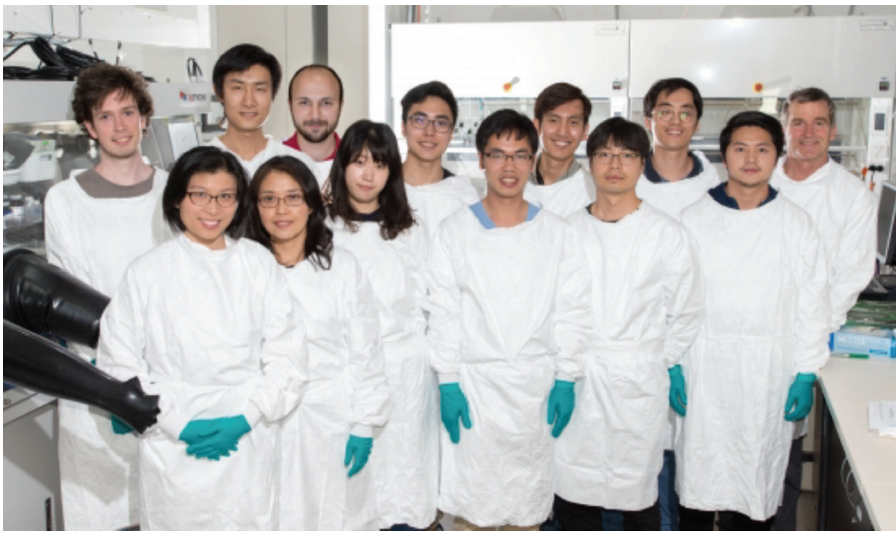
But although perovskites hold much promise for cost-effective solar energy, they are currently prone to fluctuating temperatures and moisture, making them last only a few months without protection. Along with every other team in the world, Ho-Baillie's is trying to extend its durability. Thanks to what 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.

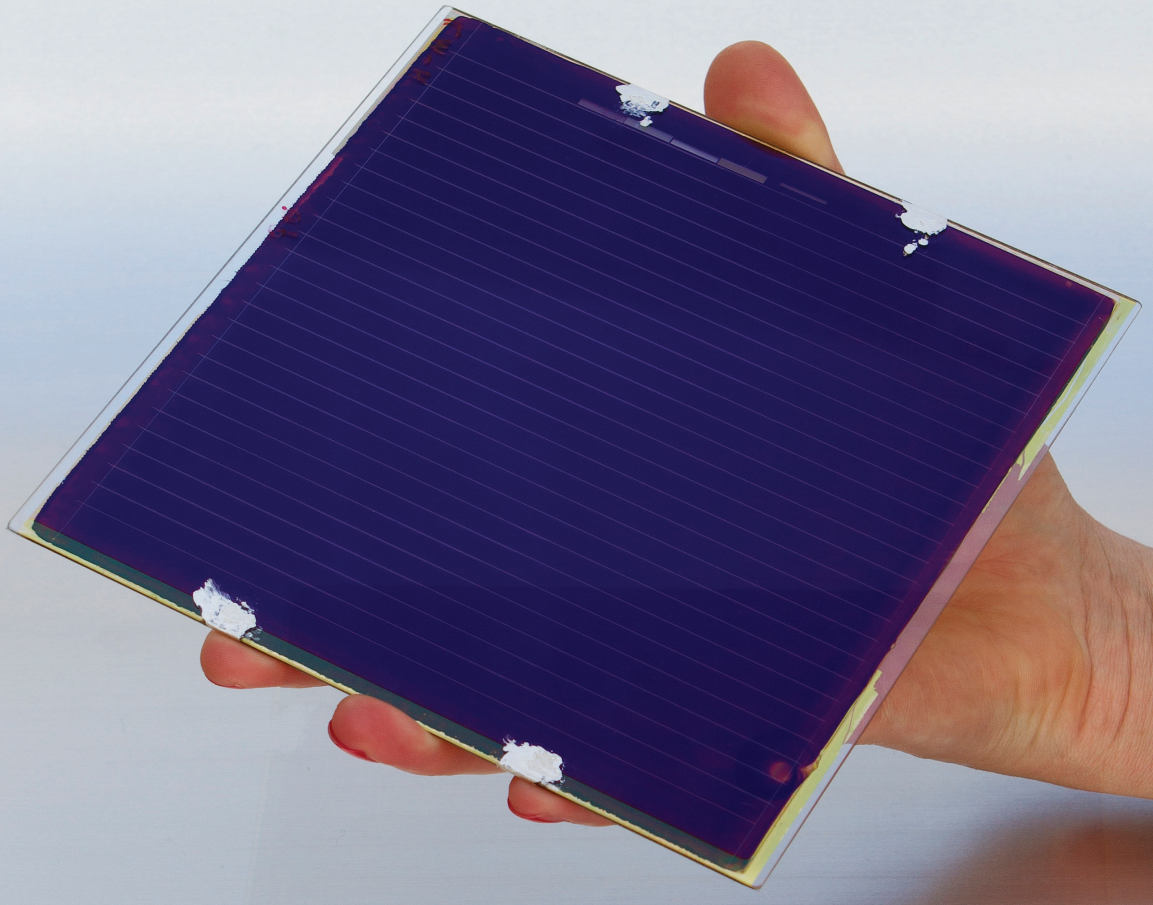
Professor Martin Green, Director of the Australian Centre for Advanced Photovoltaics at UNSW.
The research is part of a collaboration backed by $3.6 million in funding through the Australian Renewable Energy Agency's (ARENA) 'solar excellence' initiative. ARENA CEO Ivor Frischknecht said the achievement 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 inch^2 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 cm^2 modules, the Solliance team was able to quickly transfer this to a 6x6 inch^2 sized glass substrate using the developed blade coating process and the optimised mechanical patterning technology. In this case a 156 cm^2 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 cm^2 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.

azymuth

Micro smart grid enables sustainable and efficient energy supply

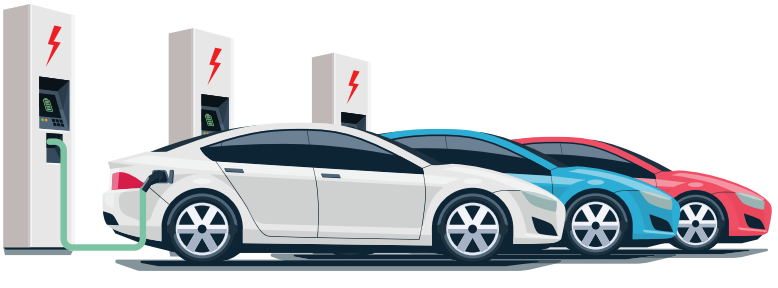
What will intelligent, decentralized energy management look like in the future?

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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