INTERNATIONAL solar

A PV MANAGEMENT MAGAZINE

3D Micromac AG

Laser processes for increasing cell efficiency

AN ANGEL BUSINESS COMMUNICATIONS PUBLICATION

Issue II 2015
www.solar-international.net

ULTRA HIGH CELLS: Improving modeling of high-efficiency solar cells

SOLAR UNITED: Emerging from IPVEA to expand its mission

INDIA: Will the solar rooftop lease model ever take off in India?

Is innovation the key to reducing costs?

THE BASICS of getting more value from sun-based generation appear alarmingly simple. More sun exposure, higher PV cell efficiency, lower-cost materials, efficient manufacturing, creative financing and a host of other 'regulars' all make the lists.

Besides improving the PV cell itself, some manufacturers are making strides by looking for ways to reduce balance of sale (BOS) and other so-called 'soft costs.' One such manufacturer is Cogenra Solar that recently announced a new breakthrough module design delivering 15 percent more peak power per panel.

Using conventional front-contact, mono-crystalline cells, Cogenra announced on 4 March that it had coaxed a record 400W peak power from 72-cell modules. Using multi-crystalline cells they achieved 352W.

Congera is on a roll. The Fremont, California-based manufacturer set previous records with 60-cell format systems (fall 2014). Achievements last year and most recently were verified by the Renewable Energy Test Center.

Cogenra calls its innovation Dense Cell Interconnect (DCI). The DCI process avoids commonly-employed ribbon interconnections that have the disadvantage of shading PV surfaces, which leads to a host of issues including reduced wattage output. Congenra's process rewires the PV module for efficiency; it reduces materials and solder joints. DCI is also compatible with most manufacturing processes—about 95 percent, they estimate. New DCI panels are to be released in April.

While some manufacturers seek new ways to boost existing PV efficiency, researchers are also pushing boundaries for new solar and thermal energy solutions.

A team at the California Institute of Technology (Caltech) is a step closer to harnessing sun to produce fuel utilizing processes mimicking photosynthesis. Professor Nate Lewis and post-doc student Ke Sun worked with their Caltech team to develop a new protective film that enables co-production of hydrogen and oxygen at high efficiencies, low corrosion, and most importantly—no explosions.

An innovation like the Caltech process has been sought for five decades to benefit hydrogen fuel cell technology, researchers estimate. They also caution that steps are needed for commercialization. But the new film is a big step, and yes, patents are pending.

Over at the University of Houston, researchers including Zhifeng Ren collaborated to create a new material that more efficiently generates electricity from vehicle or industrial waste heat. The new thermoelectric material, Germanium-doped magnesium stannide, can repurpose heat from almost any source to create electricity. It could potentially show up in almost any place where heat concentrates. Although not as inherently beneficial as PV-based solar energy, the new technology makes the most of resources. It could even help generate additional electricity as the sun warms PV-system support frameworks.

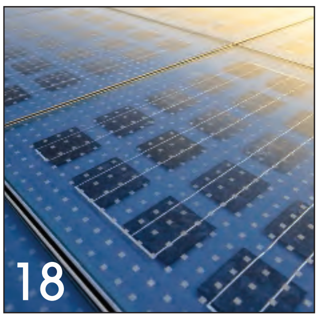
Whether making more out of existing photovoltaic cell technology, creating new solar fuel generators or by channeling waste heat into valuable electricity, today's manufacturers continue to demonstrate that innovation is a hallmark of the solar industry and its many allied fields.

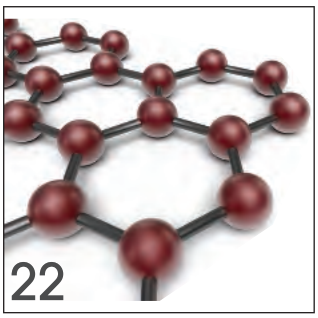
Issue II 2015

what's inside

news

research review





CPF, Panasonic and Coronal Group bring $100 million in financing to Hawaii

CLEAN POWER FINANCE (CPF) has brought together Panasonic Eco Solutions (Panasonic) and Coronal Group LLC (Coronal) with the State of Hawaii to finance up to $100 million of solar photovoltaic (PV) systems. This public-private partnership is part of Hawaii's Green Energy Market Securitization Program (GEMS). GEMS is a sustainable financing initiative of the Hawaii State Energy Office to make clean energy more affordable for and accessible to businesses and nonprofit organizations.

"Enabling access to solar energy for underserved customers through the GEMS Program is just the beginning. Over time, GEMS customers can access additional solutions through our 'Energy-as-a-Service' platform, forming a long-term relationship with one of the most trusted brands in the world."

"The state engaged CPF to structure the product and identify experienced partners to provide significant electric bill savings to underserved non-profits and businesses in Hawaii," said Sean Coletta, managing director at CPF. "We look forward to bringing clean, affordable energy to a broader demographic in Hawaii with a unique product that has the potential to serve as a model for other states and municipalities."

GEMS is the first program in the United States to use rate reduction bonds, which are commonly used by utilities, to finance solar energy. The ability to tap a huge pool of municipal bond capital reduces financing costs for clean energy installations by minimizing overhead expenses and maximizing economies of scale.

"The Coronal-Panasonic platform provides long-term stability and peace of mind to GEMS customers. Our combined team is fully committed to the design, construction, long-term ownership and operation of solar PV systems," said Jamie Evans, head of U.S. Eco Solutions at Panasonic. "Enabling access to solar energy for underserved customers through the GEMS Program is just the beginning. Over time, GEMS customers can access additional solutions through our 'Energy-as-a-Service' platform, forming a long-term relationship with one of the most trusted brands in the world."

Soltage receives new investment

TENASKA AND SOLTAGE, LLC, a full-service renewable energy company developing and operating solar power plants across the United States, has announced a Tenaska affiliate's second multimillion-dollar commitment to support Soltage's corporate equity growth and ongoing investment in new distributed solar photovoltaic (PV) generation projects.

Under the agreement, Tenaska assumes a controlling interest in Soltage, with potential to invest in new project portfolios going forward. This investment will facilitate Soltage's growth trajectory throughout the next few years, with an expectation to deploy more than $250 million for roughly 125 megawatts (MW) of solar projects throughout 2015 and 2016.

"This funding is both a transformative achievement for Soltage and further evidence solar power is a smart investment for forward-looking utilities and customers, alike," said Jesse Grossman, Soltage co-founder and CEO.

"We continue to be thrilled to have such an established and highly respected investor as Tenaska working with us as we help to realize our nation's renewable energy capacity."

"The past 18 months have shown the strength of Soltage's business plan," said David Kirkwood, Tenaska vice president and treasurer. "This investment and potential follow-on investments will allow Soltage to increase its development velocity in the near term."

Soltage develops, finances, installs, owns and operates solar electric generating stations, providing electricity to commercial, industrial, educational, utility and municipal customers under long-term contracts.

Soltage successfully installed 60 MW of new solar capacity in 2014, part of an overall development portfolio of nearly 80 MW since Tenaska's initial investment in 2008.

Tenaska is consistently ranked by Forbes magazine as one of America's largest privately held companies, with approximately 11,000 MW of power generating assets under management, including 280 MW of utility-scale PV projects operating or under construction.

JinkoSolar to supply 75 MW modules to project in US

JINKOSOLAR will supply 75 MW of its PV solar modules to Swinerton Renewable Energy for the Red Horse 2 Wind and Solar project in Cochise, Arizona.

This large project, which was acquired by an affiliate of D. E. Shaw Renewable Investments, L.L.C. (DESRI) in August 2014, will utilize 248,750 of JinkoSolar's high-efficient 72-cell polycrystalline solar panels. Swinerton Renewable Energy will develop and construct the project, in addition to providing ongoing operations and maintenance services to the facility. The hybrid wind and solar project is expected to power approximately 13,500 homes upon its completion.

"JinkoSolar is excited to work with Swinerton Renewable Energy and DESRI on another large-scale project. The Red Horse 2 project is a true example of the advancement of renewable energy in the United States and we are proud to be an integral part of the growing clean energy industry," said Nigel Cockroft, General Manager of JinkoSolar (U.S.) Inc. "This adds to our growing list of projects in the United States. We delivered over 400 MW of modules to US projects in 2014, and in 2015 have so far signed U.S. contracts to supply an additional 750MW. The US has become the second largest market for JinkoSolar after China."

"Swinerton is excited to continue our successful partnership with JinkoSolar -- an innovative leader in the Solar Industry -- and to bring jobs and years of clean power to Arizona residents. Red Horse 2 is an exciting solar and wind project and we couldn't be more eager to work with this team," commented Mr. George Hershman, Vice President and Division Manager of Swinerton Renewable Energy.

DuPont and JinkoSolar sign agreement

DUPONT and JinkoSolar, have signed a strategic collaboration agreement that reflects the companies' interest in furthering the growth and adoption of efficient and reliable solar generated electricity.

"DuPont deploys science to help solve some of the world's most pressing problems – the growing global demand for energy is chief among them," said Walt Cheng, managing director, DuPont Electronics & Communications, Greater China. "By collaborating with leading companies such as JinkoSolar, we can optimize the science of solar technology today and accelerate the development of new advanced materials that will continue to make clean and sustainable solar energy better and increasingly more affordable."

Areas of potential collaboration include technical development efforts to support continued improvements in the efficiency, durability and reliability of solar cells and panels, including through development and supply of advanced materials including DuPont Solamet PV19x series photovoltaic metallization pastes and DuPont™ Tedlar polyvinyl fluoride films, as well as co-marketing collaborations aimed at promoting the broader and faster adoption of solar energy to help address the world's growing energy needs.

"JinkoSolar has worked very successfully with DuPont in the past to help enhance the power output and durability of our solar panels, and we look forward to further advances based on this strategic collaboration," said Kangping Chen, chief executive officer, JinkoSolar.

"Our company's mission is to change the way we generate and use electricity, optimize the energy portfolio and enable a more sustainable future by delivering the cleanest, most efficient and economic solar energy solutions; and we will work to achieve this critical aim together with DuPont."

SunEdison purchases 1,000 energy storage systems

SUNEDISON, INC plans to purchase up to 1,000 vanadium flow batteries (over 100 megawatt hours) from Imergy Power Systems, a leader in advanced energy storage solutions. The vanadium flow batteries will be used to store solar-generated electricity for SunEdison's rural electrification and solar powered mini grid projects in India.

"Energy storage is the perfect complement to solar powered mini grids because it enables us to provide dependable, 24/7 electricity," saidAhmad Chatila, President and Chief Executive Officer of SunEdison. "And Imergy's technology is a great fit for rural electrification because their systems are high performance, low cost, ultra-durable and need very little maintenance."

"Imergy is proud to be working with SunEdison to bring electricity to the under-served in rural India," stated Bill Watkins, Chief Executive Officer of Imergy Power Systems. "Imergy's storage systems are safe and sustainable, and provide the lowest cost and most reliable way to store energy for these mini grids."

SunEdison will also increase its equity investment in Imergy. This strengthens the supply relationship between the two companies as SunEdison begins deployment of its extensive rural electrification program in India.

Conergy receives equity investment From RWE

CONERGY has announced an equity investment by RWE Supply & Trading, the energy trading arm of the giant European utility. The investment comes as part of a larger equity funding round led by Kawa Capital Management and results in RWE owning a minority stake in Conergy.

Kawa Capital Management, Inc., which acquired Conergy in 2013, maintains majority ownership in the Company. The additional capital will be used to support Conergy's global growth plans.

Conergy recently announced a profitable 2014 with nearly half a billion dollars in revenue, in expanding its services providing project development, financing, engineering, procurement and engineering (EPC) and operations and maintenance (O&M) globally. Conergy provides these services across all solar segments: utility-scale, commercial and residential, and in both emerging and high-growth solar markets.

Andree Stracke, Member of the Board of RWE Supply & Trading, said: "Having worked with Conergy successfully in Europe, we are pleased to be supporting the group's worldwide expansion."

The investment follows the partnering between RWE and Conergy for commercial PV 'solar rentals' partnership which targets business customers of RWE Group, initially in Germany, and the finance, construction and sale of one of the UK's biggest solar farms, at Kencot Hill in Oxfordshire. Andrew de Pass, Chief Executive Officer of Conergy, said: "We are pleased to have RWE's financial backing and endorsement of Conergy as one of the most strategic and fastest-growing downstream companies in solar. We look forward to using this capital to develop more projects with new and existing partners in the solar industry as our global pipeline approached 4 GW. With this important stamp of approval, it is clear that the turnaround of Conergy is complete and our growth trajectory is certain"

Alexander Gorski, Chief Operating Officer of Conergy, said: "We've had a very successful business relationship with RWE over the last two years and are pleased to build on that with this equity partnership."

SolarWorld AG expands production in Germany

SOLARWORLD took over the German cell and module production from Bosch Solar Energy AG in March 2014. Now, production of solar cells and modules in Arnstadt is running at full capacity, and 830 jobs have been preserved in solar manufacturing. The addition of crystal production will create about 60 jobs.

Silicon mono-crystals are drawn from the liquid silicon melt, then cut into lengths, or ingots, for further processing into solar wafers and then cells and final assembly into modules. The annual production capacity of mono-crystals in Arnstadt is expected gradually to grow to about 500 megawatts, beginning in the second quarter of 2015. SolarWorld's production site in Freiberg, Germany, will cut the silicon ingots into wafers. In parallel, SolarWorld will expand the PERC technology (passivated emitter rear contact) of a pilot line in Arnstadt to the site's entire cell production of 700 megawatts. As a result of new coating processes on cells' fronts and backs, the PERC technology achieves much higher efficiencies.

In the United States, SolarWorld already

produces exclusively PERC cells. In Freiberg, cell production will be upgraded to PERC technology this year, too. In early 2015, SolarWorld achieved efficiency of 21.42 percent, setting a new world record for industrially manufactured monocrystalline PERC solar cells. Asbeck: 'Solar technology is about quality and maximum power efficiency. In both areas, we will further expand our leadership position. We thus consistently focus on our production in Germany and the United States. With new crystal production in Arnstadt, we will extend the vertical range of our value chain. Only sites operating under maximum quality, environmental and social standards, with qualified personnel and at advanced levels of automationachieve top quality.'

Bentek expands manufacturing capacity

BENTEK, a manufacturer of a broad range of OEM power distribution products for the residential, commercial and utility-scale solar PV marketplaces, has expanded its total manufacturing capacity in San Jose California. With the addition of a new 50,000 ft.^{2} facility, Bentek now has more than 100,000 ft.^{2} of manufacturing capacity.

Mitch Schoch, President and CEO of Bentek commented, "Our new facility will be dedicated to the design, testing and manufacture of our expanding line of PV solar products. With this new site, Bentek will benefit from a 40 percent increase in our manufacturing capacity for solar products. This also expands our engineering and test laboratory for new solar product development. This expansion is consistent with the forecasted demand that we are experiencing from our growing customer base. Additionally, the new solar facility frees up greater capacity in our current site to meet the continued growth in our existing manufacturing services business in 2015."

Yingli begins construction of 50 MW solar plant in China

YINGLI SOLAR has announced that it has begun construction of a 50 megawatt (MW) solar power plant on former mining lands in in Huangshi City, Hubei Province, China. It is the first project developed by Yingli on land that has been degraded by mining activities. The 50 MW power plant occupies over 100 hectares of land in western Huangshi City, a region known for its rich mineral resources and extensive mining operations.

The project will contain about 170,000 YGE 72 Cell Series multicrystalline solar panels that are expected to generate approximately 55,000 megawatt-hours (MWh) of clean electricity annually, which will offset the consumption of nearly 22,000 tons of coal and the emission of over 50,000 tons of carbon into the atmosphere. The system is scheduled to interconnect with the local utility grid and begin operations in the fourth quarter of 2015.

Huangshi City was designated a pilot city for the reclamation of abandoned mining lands and former industrial sites by China's Ministry of Land and Resources in January 2013. Therefore, the power plant will serve as a key demonstration project for the integration of solar power into land revitalization programs across China. To help showcase the unique value solar power brings to land reclamation efforts, Yingli also plans to develop an educational visitor's center near the project site.

"This highly replicable project shows how solar power can be integrated into ecological restoration programs, stimulating the local economy and providing clean power to the community while simultaneously aiding in land revitalization," commented Mr. Liansheng Miao, Chairman and Chief Executive Officer of Yingli Green Energy. "We're pleased that our first project on degraded mining lands will deliver concrete economic and environmental benefits to the surrounding community."

Hanwha Q CELLS announces $20 million credit facility

HANWHA Q CELLS CO. LTD has announced that its US entity has signed a $20 million three-year Senior Secured Revolving Credit Facility with Wells Fargo Capital Finance. The credit line will be used for working capital and other general corporate purposes.

Jay Seo, CFO of Hanwha Q CELLS said, "We are pleased to have secured this credit line from Wells Fargo, one of the most well-respected US financial institutions and financiers of renewable energy. Its confidence demonstrates the combined strength of our newly-merged companies (Hanwha SolarOne and Hanwha Q CELLS) to meet rigid credit standards, as well as access funding outside of our traditional sources in China and South Korea." Mr. Seo concluded, "The US is a key strategic market for our company and we are particularly well-positioned to capture share with our diverse 'tariff free' manufacturing base outside of mainland China."

Ms. Kimberly Jablonski, SVP at Wells Fargo Capital Finance noted, "It is a pleasure to work with one of the world's largest solar energy companies, which is rapidly expanding in the US solar market. We look forward to a long-lasting relationship with Hanwha Q Cells Ltd."

JinkoSolar signs RMB3 billion financing agreement

JINKOSOLAR HOLDING CO., LTD has announced that it has entered into a five-year RMB3 billion strategic financing agreement with China Minsheng Banking Corp., Ltd. ("CMBC").

According to the terms of the agreement, CMBC has agreed to provide financing support of an aggregate amount up to RMB3 billion over a five-year period.

CMBC's financing will help expand JinkoSolar's financing channels, and further strengthen the Company's leading position in the development of downstream solar projects and manufacturing capabilities.

CMBC'S financial services will include but are not limited to project finance, merger and acquisition finance, supply chain finance, bridge loans, letters of guarantee and related trade finance. In addition to downstream project financing, the agreement will also cover working capital finance and foreign currency cash pool management for JinkoSolar's domestic and overseas subsidiaries, allowing the Company to optimize its debt structure, and reduce financial costs.

"As a global leader in the solar PV industry, we are extremely excited to have the opportunity to build a new strategic partnership with China Minsheng Bank," commented Mr. Xiande Li, Chairman of JinkoSolar.

"This strategic financing agreement with one of China's premier commercial banks demonstrates the confidence we both have in the future development of the global PV industry. We look forward to working closely with CMBC on the development of our downstream business and in particular DG projects, as well as our manufacturing business.

"We truly value this relationship and will leverage this platform to create new opportunities and green energy projects that will yield sustainable and long-term value for our shareholders."

Egyptian government and SkyPower, IGD sign historic solar agreement

SKYPOWER GLOBAL and International Gulf Development (IGD) have signed a historic agreement with the Government of Egypt for the development of 3,000 megawatts (MW) of utility-scale solar photovoltaic (PV) projects to be built over the next four years.

The agreement represents an unprecedented milestone in Egypt's strategic plan to develop a sustainable renewable energy industry, creating thousands of new green energy jobs and attracting billions in capital investment.

SkyPower, in partnership with IGD, finalized the agreement with the Egyptian government at the first ever Egypt Economic Development Conference (EEDC) during a signing ceremony where many key infrastructure projects were unveiled for Egypt's prosperous future. "The availability of energy and managing the demand for it is one of the main priorities on the Egyptian development agenda," said President of Egypt, Abdel Fattah Al-Sisi.

On signing the agreement, SkyPower President and Chief Executive Officer, Kerry Adler applauded the country's ambition and reiterated its support for its economic vision.

"SkyPower commends the leadership of Egypt for swiftly executing its well-designed strategic blueprint to ensure a bright and prosperous future for all Egyptians, for generations to come," said Mr. Adler. "The signing of this monumental agreement demonstrates the shared passionate aspirations of global partnerships that will substantially impact the country's GDP, contributing approximately US$16.1 billion, resulting in increased opportunities for skills training,employment, youth and education."

Bringing together extensive international expertise, the venture – in which SkyPower joins forces with Middle Eastern infrastructure specialists IGD – will entail a multi-phase development that will result in the production of clean, sustainable and cost-effective energy to support the growing energy needs of Egypt and directly contribute to the government's goal of producing 20% of energy from renewables by 2020.

Working closely with the Egyptian Ministry of Electricity and Renewable Energy in the development of the solar PV energy projects, SkyPower IGD's phase one will reach commercial operation in late 2015.

First Solar secures interconnection rights for three PV plants in Turkey

FIRST SOLAR, INC. has announced that it has been awarded interconnection rights for three planned utility-scale solar photovoltaic (PV) plants in southern Turkey. The rights were issued following a competitive tender, administered by the Turkish Electricity Transmission Company (TE A), as part of the country's Renewable Energy Resources Support Mechanism (YEKDEM) program.

Subject to regulatory approval, the three projects, with a combined capacity of 19 megawatts (MW)AC, will be developed in the Mu la, Burdur, and Urfa provinces, in southern Turkey. When complete, the plants will produce an estimated 31.5 million kilowatt hours of electricity per year, sufficient to power an estimated 14,000 average homes in the country. All three projects will be powered by First Solar's advanced module technology. "We entered the Turkish market, less than twelve months ago, with a strong belief in its potential to evolve into one of Europe's first truly sustainable PV markets. Our success in securing these connection rights vindicates our position and reinforces our confidence in the country and in the strength of its regulatory framework for renewable energy," said Christopher Burghardt, Vice President for Europe at First Solar. "We look forward to building on our success in Turkey and to contributing towards realizing the country's energy security ambitions."

A vertically integrated solar energy company, First Solar recently set a new world record for cadmium-telluride (CdTe) PV solar cell conversion efficiency, achieving 21.5 percent efficiency certified at the Newport Corporation's Technology and Applications Centre (TAC) PV Lab in the United States. The achievement places First Solar ahead of its established research cell roadmap, and validates CdTe's continuing competitive advantage over traditional crystalline silicon technology.

Trina Solar to supply 48 MW of modules to India

TRINA SOLAR has announced it has signed an agreement to supply 48 MW of solar modules to ACME Cleantech Solutions Ltd. This new agreement brings the total sales of solar modules to ACME to 70 MW in 2015 to date.

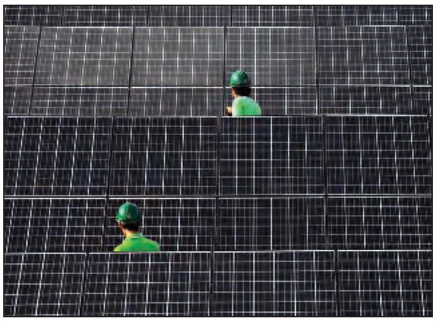
According to the agreement, approximately 188,000 Pieces of Honey modules TSM-PC05A will be installed on two ground-mounted solar power plants in India. The installations are expected to provide an annual output of 81.6 GWh. The shipment will be completed in the first quarter of 2015.

"We are seeing a significant pick up in the adoption of solar power in India this year and we are delighted to be taking part in the growth with our efficient and high-quality modules," said Zhiguo Zhu, COO and President of Trina's module business unit. "India is no doubt a robust and growing emerging market for solar energy. We believe this agreement not only demonstrates our growing brand awareness in India, but also sets a solid foundation for our expanding business in the region in 2015. We look forward to capturing more market opportunities in India with ACME."

Mr. Manoj Kumar Upadhyay, Chairman of ACME, added, "We first started our partnership with Trina Solar in 2013. We are delighted to further deepen our relationship with Trina Solar on these two projects in India.

ACME had delivered many successful projects in the past. Looking into the future, we are also very optimistic about India's solar prospect and are expediting our paces to expand our projects portfolio. We have strong faith in Trina Solar's dedicated team, comprehensive products and superior product quality and look forward to more partnership with Trina Solar in 2015."

JinkoSolar to supply 104 MW of PV modules for project in the US



JINKOSOLAR has announced that it will supply 104 MW of PV solar panels for the Utah Red Hills Renewable Park project. JinkoSolar will deliver over 340,000 of its utility-scale, high-efficiency polycrystalline 72-cell panels to the Utah Red Hills Renewable Park though a contract with Swinerton Renewable Energy. Scatec Solar, the project's developer and a long-term owner, hired Swinerton Renewable Energy to construct the plant and procure the appropriate technologies.

The Utah Red Hills Renewable Park, set to be built on a site with excellent solar irradiation, will generate around 210 million kilowatt hours (kWh) of electricity per year, which will be fed into the grid under a twenty-year Power Purchase Agreement (PPA) with PacifiCorp's Rocky Mountain Power, according to the utility's obligation under the federal Public Utility Regulatory Policies Act. Based on EPA estimates, it will power approximately 18,500 homes and prevent nearly 145 thousand tons of carbon dioxide emissions annually.

"We are thrilled to be a part of this large project," said Nigel Cockroft, General Manager of JinkoSolar (U.S.) Inc. "The Red Hills project is a true testament of the positive progression in the sustainable energy industry, which JinkoSolar is proud to support."

"Swinerton is excited to continue our successful partnership with JinkoSolar--an innovative leader in the Solar Industry--and to bring jobs and years of clean power to the Parowan residents. Utah Red Hills Renewable Park is a great project for the city of Parowan and we couldn't be more eager to work with this team," commented Mr. George Hershman, Vice President and Division Manager of Swinerton Renewable Energy.

"Scatec Solar is proud to bring on experienced partners and proven technologies to build a project that will deliver clean and reliable energy to the residents of Utah," said Mr. Luigi Resta, Managing Director of Scatec Solar North America. "Our team on the ground is excited to be building the first utility-scale PV project in a state with such incredible solar potential."

1366 Technologies and Hanwah Q CELLS partner to commercialise direct wafer technology

1366 Technologies and Hanwha Q CELLS have announced that they have entered into a long-term strategic partnership to jointly advance the efficiency and quality of solar cells while dramatically reducing their costs. The two companies will collaborate on the development of 1366's proprietary Direct Wafer Technology with the intent to commercialize and use Direct Wafers in Hanwha Q CELLS' world-renowned solar cells.

Upon successful commercialisation of the Direct Wafer Technology, the companies expect to expand the partnership. Among others, the potential options include the supply of Direct Wafers from 1366's manufacturing facilities to Hanwha Q CELLS.

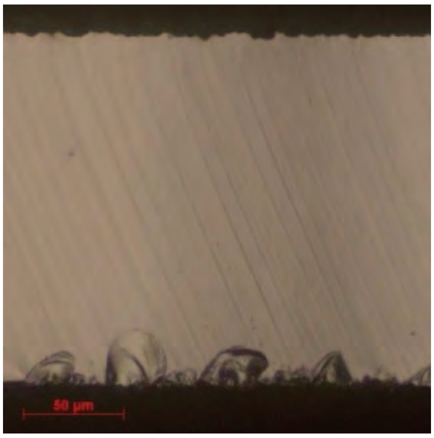
"Our mission at Hanwha Q CELLS is to be at the forefront of photovoltaic technology and to rapidly translate innovation into mass production," said Seong-woo Nam, CEO, Hanwha Q CELLS. "1366's Direct Wafer Technology is innovation at its best. We strongly believe in its potential to be commercialized in order to deliver significant cost reductions and quality improvements at the same time. "

"It is a powerful endorsement of our technology that Hanwha Q CELLS has recognized the high potential of our technology to advance cell performance and drive down the cost of photovoltaics," said Frank van Mierlo, CEO, 1366 Technologies. "Hanwha Q CELLS is recognized globally for its commitment to innovation and quality, setting many technical standards for the industry. We couldn't be more proud to combine our resources with a company that's long stood at the center of the global solar revolution. It's an ideal fit."

1366 Technologies' Direct Wafer forms multi-crystalline wafers directly from molten silicon instead of today's multi-step, energy- and capital-intensive process. The result is a uniformly better wafer, created at one-half the cost. The technology also has the enormous benefit of being a "drop-in" replacement for 60 percent of the photovoltaics market, making it seamless for cell and panel manufacturers to readily adopt the technology without adding a single new piece of equipment.

1366 Technologies remains on track to build a 250 MW commercial facility in the United States. Construction is scheduled to begin in Q3 of 2015. To date, the Company has raised more than $64 million from private investors including The Hanwha Group, which participated in the Company's Series B round in 2010.

3D-Micromac enable half cells



3D-MICROMAC AG plan to introduce the brand-new microDICE OTF system at SNEC 2015. The system uses Thermal-Laser-Separation for cutting of cells into half cells. By using half cell technology the average module power yield can be increased significantly.

Cell separation has become industrial relevant due to the introduction of half-cell modules concepts, which allow a substantial power gain. The standard industrial process of p-type cells is based on a laser scribing and subsequently mechanical cleaving. The disadvantages of this process are the reduction of the cell efficiency, the reduced mechanical strength and the expensive handling due to the combination of a laser process with a subsequent cleaving.

3D-Micromac has overcome these weaknesses with the brand-new microDICE OTF using Thermal-Laser-Separation for splitting PV cells into half cells. The separated cells show a significantly higher mechanical strength, better edge quality as well as a lower power reduction compared to laser scribing and leaving approaches. The productive system achieves a throughput of 3,600 cells per hour of incoming full cells. The optical set-up relies on the on-the-fly technology successfully used at 3D-Micromac's laser structuring tools for processing of PERC cells. The laser processing is realised during the continuous transport of the cells under the laser source, whereby the relative motion of the cells is automatically compensated for. Stops for the positioning of the individual cells are completely eliminated. The continual movement of the conveyor belt results in an almost 100-percent capacity utilization of the laser source. The microDICE OTF is a fully automatic 24/7 production solution and can be offered as stand-alone or inline system.

Thermal-Laser-Separation (TLS) is used in the semiconductor industry's back-end to separate semiconductor wafer in components. The process is based on thermal induced mechanical stress, generated by a combination of aser heating and cooling. The method is suitable for most brittle materials including Si, SiC, Ge and GaAs wafers. Compared to traditional separation technologies, TLS impresses with clean, micro-crack-free edges and greater resulting bending strength. The complete cleaving is a one pass process with a speed of up to 300 mm/s. The relatively low temperature (no material is ablated or melted) in combination with the high cleaving speed are the reason that the electrical properties are not influenced by the separation step.

ZSW boosts efficiency of cadmium-free CIGS solar cells

THE CENTRE FOR SOLAR ENERGY and Hydrogen Research Baden-Württemberg (ZSW) in Germany has managed to boost the efficiency of cadmium-free CIGS thin-film solar cells to 21.0 percent.

The Stuttgart scientists replaced the system of intermediate films consisting of CdS and ZnO with a combination of ZnOS and ZnMgO to achieve this performance. This combination promises to harvest even more light than the material used in earlier CIGS cells. With this improvement, the researchers at Stuttgart relegated their Japanese colleagues, the former record holders, to second place and took the lead in the global efficiency stakes.

The record for conventional solar cells made of CIGS is 21.7 percent. ZSW scientists set this record and have now come very close to matching it with the new cell type. Michael Powalla, ZSW board member and head of the Photovoltaics division, believes the lack of heavy metals in the new cell's buffer layer is an advantage, but not the key benefit. The metal in conventional CIGS modules is chemically bound.

"First and foremost, the buffer layer transmits more light without the CdS. In theory, we could use it to achieve even higher efficiency than with previous CIGS cells. The alternative buffer layer and the CdS buffer are both deposited in a chemical bath, so a transition to manufacturing is possible without requiring additional processes," he said As a buffer layer, ZnOS is more transparent to light in the blue wavelength range. This means more sunlight penetrates to the underlying CIGS absorber layer, which then converts more light energy into electricity. Another innovation in the cell is its improved front contact. The researchers made it with ZnMgO in place of the high resistance, thin ZnO film. Made in a ZSW manufacturing lab, the solar cell has a surface area of 0.5 square centimetres, a standard size for experimental cells. The Fraunhofer Institute for Solar Energy Systems ISE confirmed the results. Alternative CIGS technology is still in the initial stages of development, so a further significant increase in efficiency is possible. ZSW's industry partner Manz AG has already made the first test modules. ZSW researchers expect that the modules made in southwest Germany can be brought to market within a few years.

The Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) is a leading institutes for applied research in the fields of PV energy, renewable fuels, battery technology, fuel cells and energy systems analysis.

M-KOPA Solar lights up 20,000 homes in Uganda

M-KOPA Solar has announced that it has connected over 20,000 off grid homes in Uganda affordable solar power. It is now expanding its distribution nationwide and targeting to add 50,000 more homes by the end of 2015.

M-KOPA Solar is pioneer of 'pay-as-you-go' energy for off-grid customers. Launched in Kenya in October 2012, M-KOPA now provides solar power to over 150,000 Kenyan homes. M-KOPA began pilot operations in Eastern Uganda in mid-2013 and is now scaling up across the country. M-KOPA's rapid growth has been driven by its revolutionary payment plan, which makes high-quality solar affordable, even to those living on low-income. Customers can acquire the company's latest solar system – the M-KOPA III – for a deposit of UGX 99,000 plus 365 daily payments of UGX 1400. The daily price is cheaper than what customers would pay on average for the equivalent in kerosene lighting and charging services.

After a year of daily payments, customers own their systems outright with no further billing. The deposit is fully refundable and customers can receive real-time customer support from M-KOPA's toll free call centre, 7 days a week. All payments are made conveniently over either MTN Mobile Money or Airtel Money platforms. The M-KOPA III comes with an 8W solar panel, a high quality lithium battery, two LED solar lights with switches, a solar rechargeable LED torch, radio and a mobile phone charger. The M-KOPA III is upgradeable to include two additional solar lights – sold separately.

Jesse Moore, Managing Director and Co-Founder, M-KOPA Solar, says, "We are very proud of the M-KOPA III solar home system and our success to date in Uganda. Together we are helping Ugandans get rid of kerosene, improve their standard of living and save money all at once. It's a win-win for everyone.'' M-KOPA Uganda has added more than 20,000 customers in the past 15 months.

According to Anthony Weremaka, General Manager, M-KOPA Uganda: "In Uganda M-KOPA is now connecting over 500 new homes to solar each week, and even bigger growth lies ahead. We have nearly 100 terrific staff and 200 sales agents across the country who earn a good income selling M-KOPA products and services. We'll be doubling in size over the course of this year and so looking for other talented people to join our team, be part of this great company and change people's lives."

Ghana's off-grid households to benefit from pay-as-you-go solar

AZURI TECHNOLOGIES announced at the Solar & Off-Grid Renewables West Africa Event its partnership with energy company Oasis African Resources to bring affordable, pay-as-you-go solar power to 100,000 off-grid homes in Ghana in the next 2 years. The project is supported by the Ministry of Power, and aligns with the Government's current efforts to bring reliable, renewable power to Ghana at scale.

The deployment plan will focus on cocoa farming regions, and be distributed in association with agricultural co-operatives and women-based organisations. The large-scale roll-out builds on previous pilot deployments in Ghana, which have proven the success of this solution for rural Ghanaians over the last 18 months.

While the energy crisis in Ghana has been intensifying, discussion has mainly focused on the business and urban residential populations, who are now experiencing rolling blackouts of 24 hours or more. However, these recent debates obscure the pre-existing challenges for those Ghanaians, predominantly in rural regions, living permanently off the grid. Data available indicates that about 80% of Ghana's population have access to the grid, however there are about 5 million people in rural Ghana most of whom are not likely to be connected in the foreseeable future.

Azuri Technologies' internationally acclaimed home solar systems bring top class European design with high quality components to provide enough clean and reliable power for daily home lighting and mobile phone charging.

The project will deploy Azuri's flagship product Quad, and include 4 high quality LED lamps, mobile phone charging and a Radio/MP3 player. Crucially, instead of an upfront cost, the system can be purchased through a Pay-As-You-Go model. This model allows the customer to use the system while paying for it

incrementally by the regular purchase of top-up credit, typically costing less than the lighting costs and phone charging fees being replaced.

The Minister for Power, Dr. Kwabena Donkor commented, "This initiative supports the Government's commitment to fully incorporate renewable energy into our energy supply mix, as outlined by the President during his State of the Nation's Address.

"The Ministry of Power is pleased to support this project for rural households, and will also explore other avenues with Oasis, Azuri and other renewable energy partners to establish solar as a significant and reliable power source for micro enterprises in both rural and urban communities."

Forging public-private partnerships on rural electrification energy access

150 ENERGY ACCESS STAKEHOLDERS from the public and private sector, as well as from civil society, gathered at the Ministerio de Economia y Competitividad to discuss opportunities in rural electrification markets in a one-day unique business matchmaking workshop.

The Alliance for Rural Electrification (ARE), in cooperation with ICEX Spain Trade and Investment, organised the workshop to further advance cooperation between the public, private and finance sector. This platform, organised by ARE on a regular basis, assists off-grid market professionals and newcomers to learn about upcoming initiatives and projects in the pipeline as well as to create new business opportunities in the sector.

To provide context to the rural electrification situation worldwide, the workshop kicked off with presentations on regional policy developments and business growth options in Africa, Asia and Latin America. The scene was set by speakers from Bloomberg New Energy Finance, the African Union Commission (AUC), Eurochambres/European Business and Technology Centre (EBTC) and Fundacion Accioná Microenergia. During this session, ARE together with the EBTC launched the India Off-grid Electricity Market Brief to serve on the common objective to facilitate rural electrification competence and technology transfer from Europe to India.

The subsequent session showcased opportunities for financing including the upcoming ElectriFI initiative by the European Commission and the tools available to support energy access projects by AECID, FRES and IRENA. This was concretely exemplified by success stories from ARE members Sunna Design and Mobisol who presented successful business models implemented by themselves.

Participants also had the chance to meet with eight key rural electrification experts during the Energy Access Café in the afternoon. This was a unique and informal opportunity for participants to ask any burning questions they had for the experts. The diverse expert tables spanned from the European Commission, Eurochambres, IEC, RECP, EDP - Energias de Portugal SA, Siemens, Phaesun and Generalia.

The workshop ended with an energetic power pitch session from 13 speakers from the public and private sector, including RECP, EIB, Schneider Electric, the Spanish Ministry of Economy and Competitiveness, GIZ, CIEMAT, CLUB-ER, GDF Suez Rassembleurs d'Energie, SunEdison, Trama TecnoAmbiental, Smart Hydro Power GmbH, XANT and PlanetEnergy.

The workshop concluded with a networking dinner courtesy of the European Commission - EuropeAid.

A better method for making **perovskite solar cells**

Researchers at Brown University have developed a new method for making solar cells from perovskite — a faster, more straightforward method that can produce flexible, high-efficiency, thinner cells.

RESEARCH LED BY a Brown University Ph.D. student has revealed a new way to make light-absorbing perovskite films for use in solar cells.

The new method involves a room-temperature solvent bath to create perovskite crystals, rather than the blast of heat used in current crystallization methods. A study published in the Royal Society of Chemistry's Journal of Materials Chemistry A shows that the technique produces high-quality crystalline films with precise control over thickness across large areas, and could point the way toward mass production methods for perovskite cells.

Perovskites, a class of crystalline materials, have caused quite a stir in the clean energy world. Perovskite films are excellent light absorbers and are much cheaper to make than the silicon wafers used in standard solar cells. The efficiency of perovskite cells — the percentage of sunlight converted to electricity — has increased at a staggering pace in just a few years. The first perovskite cells introduced in 2009 managed an efficiency of only about 4 percent, a far cry from the 25-percent efficiency boasted by standard silicon cells. But by last year, perovskite cells had been certified as having more than 20-percent efficiency. That rapid improvement in performance is promising, and researchers are racing to start using perovskite cells in commercial products.

There are a number of different ways to make the films, but nearly all of them require heat. Perovskite precursor chemicals are dissolved into a solution, which is then coated onto a substrate. Heat is applied to remove the solvent, leaving the perovskite crystals to form in a film across the substrate.

"People have made good films over relatively small areas — a fraction of a centimeter or so square. But they've had to go to temperatures from 100 to 150 degrees Celsius, and that heating process causes a number of problems," said Nitin Padture, professor of engineering and director of the Institute for Molecular and Nanoscale Innovation.

For example, the crystals often form unevenly when heat-treated, leaving tiny pinholes in the film. In a solar cell, those pinholes can reduce efficiency. Heat also limits the substrates on which films can be deposited. Flexible plastic substrates, for example, cannot be used because they are damaged by high temperatures.

Production-friendly

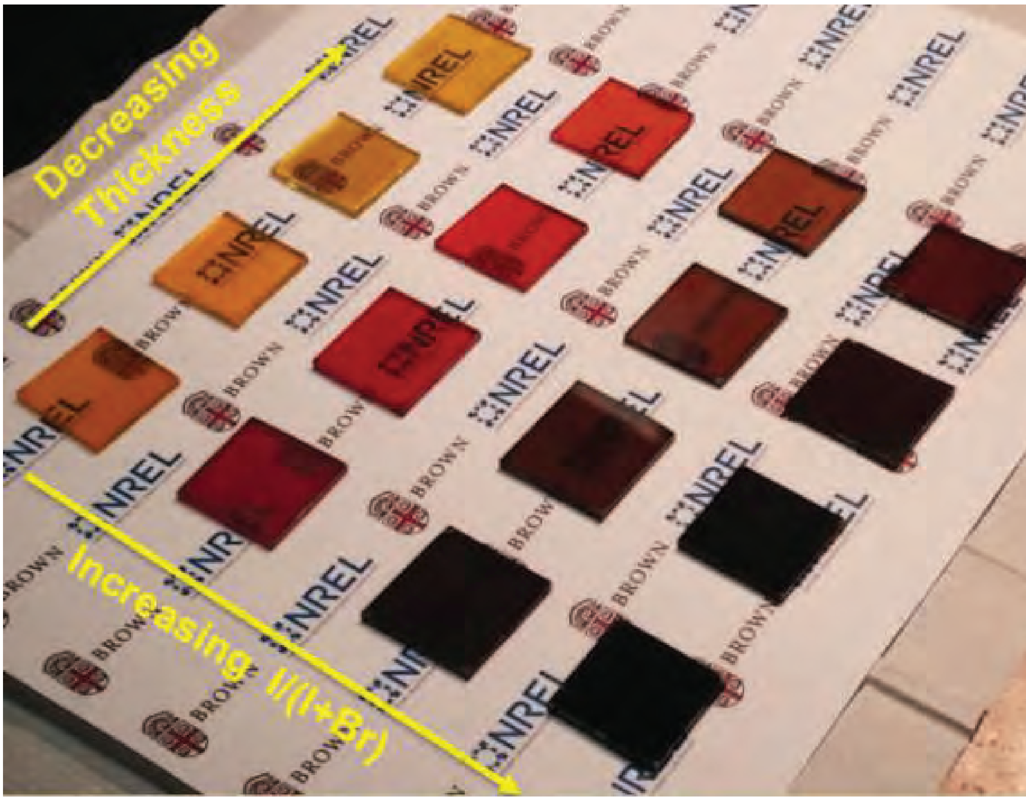
The SSE process takes place at room temperature in less than two minutes, lending itself to mass production techniques.

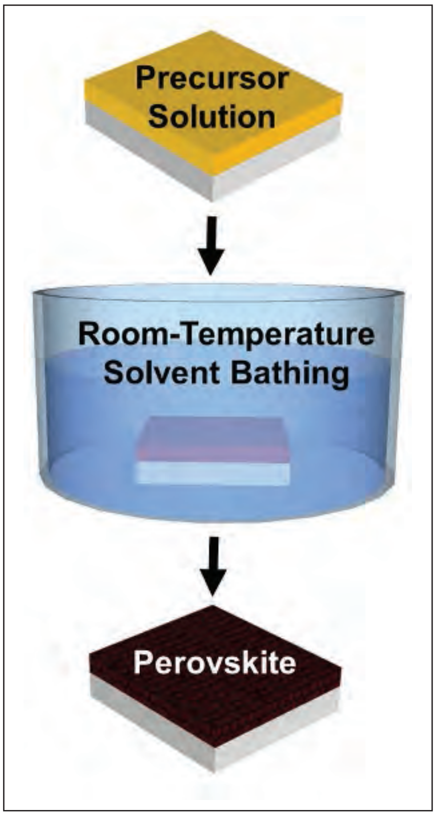
Padture lab/Brown University

Yuanyuan Zhou, a graduate student in Padture's lab, wanted to see if there was a way to make perovskite crystal thin films without having to apply heat. He came up with what is known as a solvent-solvent extraction (SSE) approach.In his method, perovskite precursors are dissolved in a solvent called NMP and coated onto a substrate. Then, instead of heating, the substrate is bathed in diethyl ether (DEE), a second solvent that selectively grabs the NMP solvent and whisks it away. What's left is an ultra-smooth film of perovskite crystals.

Because there is no heating involved, the crystals can be formed on virtually any substrate — even heat-sensitive polymer substrates used in flexible photovoltaics. Another advantage is that the entire SSE crystallization process takes less than two minutes, compared to an hour or more for heat-treating. That makes the process more amenable to mass production because it can be done in an assembly line kind of process.

The SSE approach also enables films to be made very thin while maintaining high quality. Standard perovskite films are generally on the order of 300 nanometers thick. But Zhou has been able to make high quality films as thin as 20 nanometers. The SSE films could also be made larger — several centimeters square — without generating pinholes. "Using the other methods, when the thickness gets below 100 nanometers you can hardly make full coverage of film," Zhou said. "You can make a film, but you get lots of pinholes. In our process, you can form the film evenly down to 20 nanometers because the crystallization at room temperature is much more balanced and occurs immediately over the whole film upon bathing."





Those ultra-thin films are partially transparent (films of standard thickness are black and opaque), so they could be used to make photovoltaic windows, the researchers say. And by tweaking the perovskite precursor solution composition, Zhou has been able to make cells in different colors.

"These could potentially be used for decorative, building-integrated windows that can make power," Padture said. The group plans to do more work to refine the process, but they are encouraged by the early results. Working with scientists at the National Renewable Energy Laboratory in Colorado, initial testing of cells made with SSE films showed conversion efficiency of over 15 percent.

Solar cells based on semitransparent 80-nanometer films made using the process were shown to have higher efficiency than any other ultra-thin film. "We think this could be a significant step toward a variety of commercially available perovskite cell products," Padture said.

Additional authors:
Additional authors on the paper were Mengjin Yang and Kai Zhu of the National Renewable Energy Laboratory; Wenwen Wu, a former postdoctoral research associate at Brown; and Alexander L. Vasiliev of the National Research Centre Kruchatov Institute. The work was supported by a grant from the National Science Foundation (Grant No. DMR-1305913) and the Brown University Graduate School.

Work at the National Renewable Energy Laboratory was supported by the U.S. Department of Energy under Contract Nos. DE-AC36-08-GO28308 and DE-FOA-0000990. Zhou and Padture have filed a provisional patent based on this work.

Solar could meet **California energy demand** three to five times over

Further development of solar energy, is complicated by the need to find space for solar power-generating equipment without significantly altering the surrounding environment.

NEW WORK FROM Carnegie's Rebecca R. Hernandez (now at University of California Berkley), Madison K. Hoffacker, and Chris Field found that the amount of energy that could be generated from solar equipment constructed on and around existing infrastructure in California would exceed the state's demand by up to five times. It is published by Nature Climate Change.

"Integrating solar facilities into the urban and suburban environment causes the least amount of land-cover change and the lowest environmental impact," Hernandez explained.

Just over 8 percent of all of the terrestrial surfaces in California have been developed by humans—from cities and buildings to park spaces. Residential and commercial rooftops present plenty of opportunity for power generation through small- and utility-scale solar power installations. Other compatible opportunities are available in open urban spaces such as parks.

Likewise, there is opportunity for additional solar construction in undeveloped sites that are not ecologically sensitive or federally protected, such as degraded lands. "Because of the value of locating solar power-generating operations near roads and existing transmission lines, our tool identifies potentially compatible sites that are not remote, showing that installations do not necessarily have to be located in deserts," Hernandez said.

This study included two kinds of solar technologies, photovoltaics, which use semiconductors and are similar to the solar panels found in consumer electronics, and concentrating solar power, which uses enormous curved mirrors to focus the sun's rays. A mix of both options would be possible, as best suits each particular area of installation, whether it is on a rooftop, in a park, on degraded lands, or anywhere else deemed compatible or potentially compatible. They found that small- and utility-scale solar power could generate up to 15,000 terawatt-hours of energy per year using photovoltaic technology and 6,000 terawatt-hours of energy per year using concentrating solar power technology.

Overall the team found that California has about 6.7 million acres (27, 286 square kilometers) of land that is compatible for photovoltaic solar construction and about 1.6 million acres (6,274 square kilometers) compatible for concentrating solar power. There is also an additional 13.8 million acres (55,733 square kilometers) that is potentially compatible for photovoltaic solar energy development with minimal environmental impact and 6.7 million acres (27,215 square kilometers) also potentially compatible for concentrating solar power development.

The team's work shows it is possible to substantially increase the fraction of California's energy needs met by solar, without converting natural habitat and causing adverse environmental impact and without moving solar installations to locations remote from the consumers. "As California works to meet requirements that 33 percent of retail electricity be provided by renewable sources by 2020 and that greenhouse-gas emissions be 80 percent below 1990 levels by 2050, our research can help policymakers, developers, and energy stakeholders make informed decisions," said Field, director of Carnegie's Department of Global Ecology. "Furthermore, our findings have implications for other states and countries with similarly precious environmental resources and infrastructural constraints."

New nanowire structure
may be used in solar cells

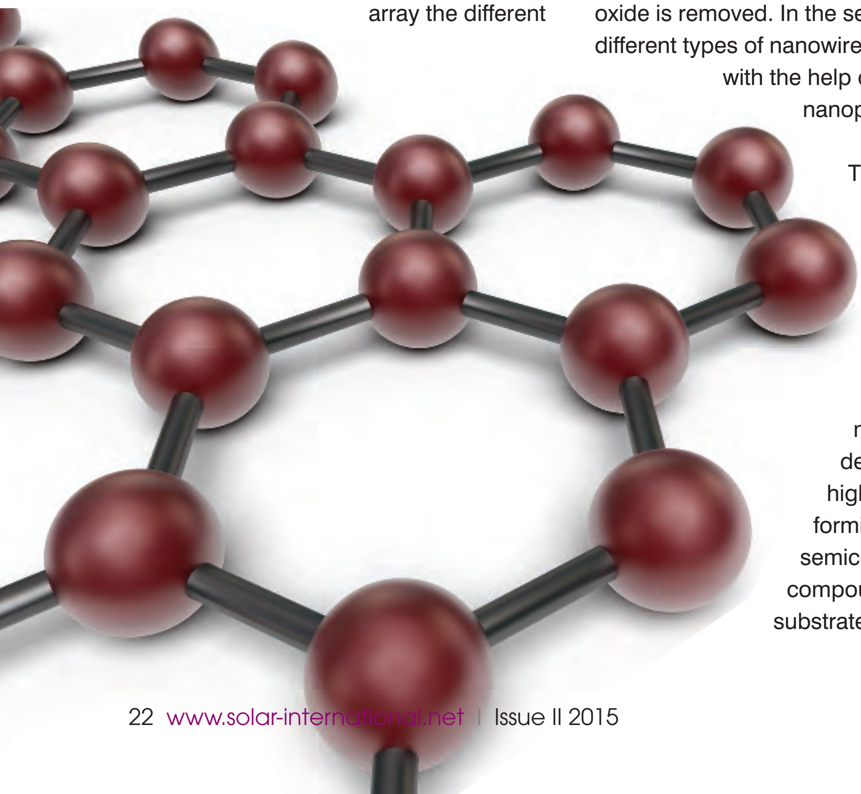
Researchers have developed a new method to implement different types of nanowires side-by-side into a single array on a single substrate. The new technique makes it possible to use different semiconductor materials for the different types of nanowires.

RESEARCHERS at Aalto University have developed a new method to implement different types of nanowires side-by-side into a single array on a single substrate. The new technique makes it possible to use different semiconductor materials for the different types of nanowires.

'We have succeeded in combining nanowires grown by the VLS (vapour-liquid-solid) and SAE (selective-area epitaxy) techniques onto the same platform. The difference compared with studies conducted previously on the same topic is that in the dual-type array the different materials do not grow in the same nanowire, but rather as separate wires on the same substrate', says Docent Teppo Huhtio. The research results were published in the Nano Letters journal on 5 February 2015. The new fabrication process has many phases.

First, gold nanoparticles are spread on a substrate. Next, the substrate is coated with silicon oxide, into which small holes are then patterned using electron beam lithography. In the first step of growth, (SAE), nanowires grow from where the holes are located, after which the silicon oxide is removed. In the second phase different types of nanowires are grown with the help of the gold nanoparticles (VLS).

The researchers used metalorganic vapor phase epitaxy reactor in which the starting materials decompose at a high temperature, forming semiconductor compounds on the substrate.



'In this way we managed to combine two growth methods into the same process', says doctoral candidate Joona-Pekko Kakko.

'We noticed in optical reflection measurements that light couples better to this kind of combination structure. For instance, a solar cell has less reflection and better absorption of light', Huhtio adds.

Initially the substrate is prepared by depositing Au nanoparticles on it and covering it with a hole-patterned oxide. The first nanowires grow from these holes and after the oxide is removed, the other type of nanowires are grown via the deposited nanoparticles.

The resulting dual-type array is presented on the electron micrograph on the right. In addition to solar cells and LEDs, the researchers also see good applications in thermoelectric generators. Further processing for component applications has already begun.

Nanowires are being intensely researched, because semiconductor components that are currently in use need to be made smaller and more cost-effective. The nanowires made out of semiconductor materials are typically 1-10 micrometres in length, with diameters of 5-100 nanometres.

Ultra-high efficiency solar cells similar to those used in space may now be possible on your rooftop thanks to a new microscale solar concentration technology developed by an international team of researchers.

"Concentrating photovoltaic (CPV) systems leverage the cost of high efficiency multi-junction solar cells by using inexpensive optics to concentrate sunlight onto them," said Noel C. Giebink, assistant professor of electrical engineering, Penn State. "Current CPV systems are the size of billboards and have to be pointed very accurately to track the sun throughout the day. But, you can't put a system like this on your roof, which is where the majority of solar panels throughout the world are installed."

High efficiency concentrating solar cells move to the rooftop

Ultra-high efficiency solar cells similar to those used in space may now be possible on your rooftop thanks to a new microscale solar concentration technology developed by an international team of researchers.

Giebink notes that the falling cost of typical silicon solar cells is making them a smaller and smaller fraction of the overall cost of solar electricity, which also includes "soft" costs like permitting, wiring, installation and maintenance that have remained fixed over time. Improving cell efficiency from about 20 percent for silicon toward greater than 40 percent with multi-junction CPV is important because increasing the power generated by a given system reduces the overall cost of the electricity that it generates.
To enable CPV on rooftops, the researchers combined miniaturized, gallium arsenide photovoltaic cells, 3D-printed plastic lens arrays and a moveable focusing mechanism to reduce the size, weight and cost of the CPV system and create something similar to a traditional solar panel that can be placed on the south-facing side of a building's roof. They report their results today (Feb. 5) in Nature Communications.

"We partnered with colleagues at the University of Illinois because they are experts at making small, very efficient multi-junction solar cells," said Giebink. "These cells are less than 1 square millimeter, made in large, parallel batches and then an array of them is transferred onto a thin sheet of glass or plastic."
To focus sunlight on the array of cells, the researchers embedded them between a pair of 3D-printed plastic lenslet arrays.

Each lenslet in the top array acts like a small magnifying glass and is matched to a lenslet in the bottom array that functions like a concave mirror. With each tiny solar cell located in the focus of this duo, sunlight is intensified more than 200 times.

Because the focal point moves with the sun over the course of a day, the middle solar cell sheet tracks by sliding laterally in between the lenslet array. Previous attempts at such translation-based tracking have only worked for about

two hours a day because the focal point moves out of the plane of the solar cells, leading to loss of light and a drop in efficiency.

By sandwiching the cells between the lenslet arrays, the researchers solved this problem and enabled efficient solar focusing for a full eight hour day with only about 1 centimeter of total movement needed for tracking. To lubricate the sliding cell array and also improve transmission through the lenslet sandwich they used an optical oil, which allows small motors using a minimal amount of force for the mechanical tracking.

"The vision is that such a microtracking CPV panel could be placed on a roof in the same space as a traditional solar panel and generate a lot more power," said Giebink. "The simplicity of this solution is really what gives it practical value."

Because the total panel thickness is only about a centimeter and 99 percent of it -- everything except the solar cells and their wiring -- consists of acrylic plastic or Plexiglas, this system has the potential to be inexpensive to produce. Giebink cautions, however, that CPV systems are not suitable for all locations.

"CPV only makes sense in areas with lots of direct sunlight, like the American Southwest," he said. "In cloudy regions like the Pacific Northwest, CPV systems can't concentrate the diffuse light and they lose their efficiency advantage."

The researchers tested their prototype concentrator panel outside over the course of a day in State College, Penn. Even though the printed plastic lenses were not up to specification, they were able to demonstrate over 100 times solar concentration.

Journal Reference:
Jared S. Price, Xing Sheng, Bram M. Meulblok, John A. Rogers, Noel C. Giebink. Wide-angle planar microtracking for quasi-static microcell concentrating photovoltaics. Nature Communications, 2015; 6: 6223 DOI: 10.1038/ncomms7223

Is GaN the future for **Photovoltaics?**

Transphorm ramps up GaN-on-silicon device production as photovoltaic inverter markets drive growth.

FOR GAN DEVICE MANUFACTURE, Transphorm, 2015 is already shaping up very nicely. Mass production of power devices kicked off at Fujitsu Semiconductor's CMOS-compatible 150mm wafer fab in Fukushima in late January. And now, Japan-based Yaskawa Electric has revealed it is using these very same GaN power modules in its PV inverters, currently under mass production for Japanese markets.

As Primit Parikh, president and co-founder of Transphorm tells Compound Semiconductor: "Fujitsu's fabrication line has been qualified for automotive-grade wafers in the past, and while our products have always been reliable, the scale of a large mass production foundry such as this is unmatched."

"Mass production here assures our customers they are getting the highest quality product at an affordable price, and they don't have to worry about scaling in the future," he adds.

Parikh will not be drawn into actual production numbers, but as he points out, Yaskawa intends to produce 34,000 systems every year, with each system containing several GaN devices and modules.

"Volumes are beginning to ramp and we are ready to supply and scale up," he says.

Surprisingly for Parikh, and many in the industry, the PV inverter market is proving to be very lucrative for GaN-based devices. The PV inverters market segment has already widely adopted SiC Schottky switching diodes from the likes of Cree, Infineon and Rohm.
And while industry pundits have speculated GaN transistors could make in-roads into this market, questions over qualification have been raised. Not any more, says Parikh.

"Traditionally, the photovoltaic industry has been associated with 25 years of reliability so many doubted the technology would be adopted here," he asserts. But as the company chairman points out, Transphorm has spent several years sampling and selling 600V qualified devices to PV manufacturers, including Yaskawa and India-based Tata Power Solar, with real results.

"Our customers were not married to any technology so they looked at GaN devices from us and our competitors, as well as SiC devices from leading vendors," he explains. "They chose our technology based on performance, cost and reliability. We beat SiC hands down."
Critically, for this industry, Transphorm's GaN-on-silicon diodes and transistors were JEDEC qualified in 2013 and the company has since demonstrated a high voltage off-state lifetime of more than 10 million hours, at 600V, with these chips.
"This is a first for the GaN industry," highlights Parikh. "Cree has introduced the data for SiC MOSFETs and now we have done it for GaN. Nobody else in the wide bandgap industry has shown this true intrinsic lifetime via systematic reliability testing."

Cost-wise, Parikh points out that device to device, GaN-on-silicon is obviously more expensive than silicon, but adds: "SiC is even more expensive." And as he highlights, his company's GaN platform is diode-free as its GaN transistor serves the function of the anti-parallel or fly-back diode used in conventional approaches, bringing cost, space and energy savings.
"Instead of using two high performance components, such as a SiC MOSFET and SiC diode, the GaN customer can use just one," says Parikh. "So we deliver half the components, half the size and half the cost."

So where next of Transphorm?

Parikh reckons the India-based PV inverter market is going to be huge for Transphorm but points out how the company's discrete and module products have also been designed into kW class 99% Totem-Pole PFC circuits and multi-hundred Watt all-in-one computer compact power supplies.

Transphorm Japan is also collaborating with Japan-based auto-makers and OEMs on the use of GaN devices in electric vehicles. Key applications include inverters in drive trains as well as DC to DC converters in, for example, air conditioning units.

"Using GaN in these applications is more near-term that one would think," says Parikh. "I am hopeful for Transphorm and the entire GaN power industry that we will solve real problems and make a tangible dent to energy use."

Laser processes for increasing solar cell and module efficiency

New laser equipment delivers on-the-fly processing speed to create high efficiency PERC half cells. Mandy Gebhardt and Thomas Kießling, 3D-Micromac AG tell us how.

SOLAR PHOTOVOLTAIC cell manufacturers face pressures to reduce costs even as the PV market is growing globally. A core challenge is cost-reduction pressure from conventional energy sources (0.05 €/kWh [Germany]) compared to photovoltaic (0.13 €/kWh [Germany]) [1]. But even as incumbent manufacturers strive to reduce kWh costs, more competitors are entering the marketplace. These factors drive producers, manufacturers, and suppliers into an 'innovation race' to create products that are more efficient and less costly to produce. Innovation concepts that complement existing plant technology and require only relatively modest new equipment investments are an important strategy to consider once an existing plant's performance has reached its practical optimization limit.

Laser processing of crystalline solar cells

One approach to increasing PV cell effectiveness with moderate additional plant investment is the so-called PERC concept (passivated emitter rear cell) made of crystalline silicon that utilizes improved backside surface passivation to increase efficiency. This is realized by the application and processing of bulk layers of aluminum oxide (AlOx) and silicon nitride (SiN).

Laser technologies can play an important role to further reduce costs during PV cell and module production. Examples include precise laser reopening of backside layers in PERC cells as well as cleaving solar cells into half cells to improve current yield. Lasers can also play a role by replacing other soldering processes in cell-module connections.

PERC technologies as the starting point

PERC technology has entered mass production; early adopters can be found in Taiwan and across the global marketplace. PERC cell efficiency of 21 percent and more has been

A highly efficient PERC solar cell machined by laser equipment from 3D-Micromac

well demonstrated by a number of manufacturers. The essential advantage of PERC technology is the comparatively simple integration of the additional required process steps into existing production lines without costly, large-scale plant upgrades. Existing technology can be used along with PERC-specific steps and previous productivity optimizations can be retained. PERC investments in modern production technology amortizes quickly for manufacturers.

Figure 1 shows the basic structure of a PERC solar cell schematically. The main advantage is the supplementation of electrical surface passivation through the cells' back-sides using aluminum oxide and silicon nitride. Typical layer thicknesses for AlOx can range up to 30 nm while the thickness of SiN layers can range from 80-100 nm. Si wafer surfaces can be both textured and polished. During the course of the subsequent production process, these dielectric passivation layers must be partly reopened without damage to the underlying silicon in order to ensure contact between the exposed metal layer and the silicon.

Using laser ablation to open the insulating layer

Laser technology is outstandingly well suited for microstructuring crystalline solar cells. It enables a high throughput and very good economy; it can be reliably integrated into production lines. Its key advantages compared to masking or electron beam processes are economy and superior throughput. Additional advantages are non-contact energy coupling, flexible beam guidance, high accuracy, and rapid positioning as well as exact control of energy infeed. Material damage is avoided; breakage rates are minimized.

When fabricating PERC cells, a main focus is on selective, non-destructive removal of the AlOx and SiOx or SiN passivation layers (Fig. 1) implemented by either a dot or line pattern. If utilizing the dot pattern approach individual dot sizes range from 80 μm-150 μm, while the separation distance between individual dots is typically 0.4 mm-1 mm depending upon customer requirements.

Using the line pattern approach, widths are typically 30 μm-120 μm and line separation distance should be between 0.7 mm and 1.5 mm for most applications. The wafer's backside is contacted using screen printing after successful structuring. Different laser sources ranging from nanosecond lasers to ultra-short pulse lasers can be utilized in PERC cell manufacturing depending upon the customers' quality, throughput, and investment thresholds. A galvo scanner with a working area greater than 160 x 160 mm^2 is used for processing wafers with a size of 156 mm x 156 mm. Nanosecond lasers score points mainly in terms of throughput and cost efficiency. However, the pulse duration does have a thermal influence on the material being lasered. Processing with both 532 nm and with infrared (1064 nm) ultimately prove successful. In an industrial setting, infrared lasers with high repetition rates are generally preferred since they hold clear advantages in terms of acquisition and maintenance costs as well as power utilization and service life. Processing speeds of up to 15,000 mm/s are achieved with it (Fig. 2).

Depending upon material properties a thermal influence from laser-induced heating is detectable.
This is an important consideration because excessive energy input can lead to melting and damage to the crystal structure, which in turn can influence local dosing ratios. Varying levels of thermal influence can lead to increased recombination of charge carriers and thus to a performance degradation in the solar cells.

The potential for damage and reduced performance must be carefully evaluated by the manufacturer so that optimal opening behaviour can be achieved in the crystal structure without reducing the benefits of rear side passivation. PV cell manufacturers should depend upon laser technologists with years of experience, process understanding, and the ability to conduct process development in close co-operation between both parties to realize desired efficiency gains. Laser ablation with ultra-short pulse durations in

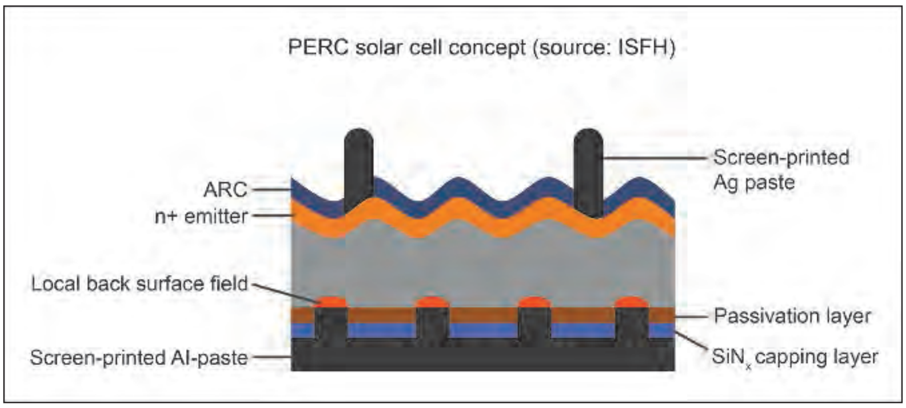


Fig. 1: Schematic depiction of the stack layout of PERC solar cell (source: ISFH)

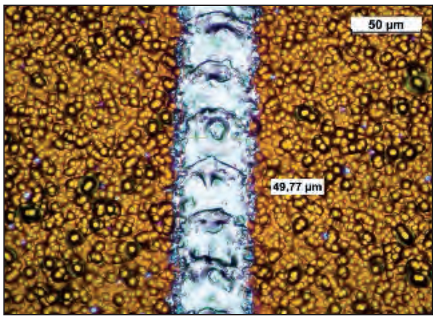


Fig. 2: Ablation of passivation layer with nanosecond laser (microscope image)
Laser ablation with ultra-short pulse

the pico and femtosecond range (10^{-13} s to 10^{-15} s) offers advantages. These lie in the laser's ability to impart all of its energy to the material within a very short time interval. Extremely high power densities up to a few gigawatts per cm² are thereby achieved. This leads to very good absorption of the laser radiation and the associated possibility of processing quasi-"athermal" results with extreme precision. Ultra-short pulse duration can impart qualitatively high-value structures with practically no negative heat influence or contamination of the surrounding material. Ultra-short pulse lasers can be integrated as reliably into fabrication processes as nanosecond lasers; however, they are clearly more cost intensive both to acquire and to maintain.

Ultra-short pulse lasers deliver results that are virtually flawless (visually) as evidenced in Figure 3. The laser also delivers passivation layer processing with extraordinary selectivity; a heat-affected zone is nearly unrecognisable. In contrast to the nanosecond laser, it was also possible to realize processing with significantly less power. These extraordinarily promising results hold out hope for rapidly reducing operational costs by using ultra-short pulse laser sources along with typical PERC cell processing equipment elsewhere along the production line.

From a technical perspective, PV cell production laser equipment is needed that brings about precise surface structuring with minimal crystal damage. From a commercial perspective this optimized processing technology needs to also lower operating costs as a market-entry criterion for PERC technology [2].

Laser source selection currently complies in essential ways with the throughput, geometry, and the stoichiometric framework conditions of the layer to be structured. A robust machine concept is needed that meets the cell manufacturer's specific requirements.

Among these today is realizing throughputs of more than 3,600 wafers per hour. This throughput will need to double within ten years to meet demands projected in the ITRPV roadmap. In addition to high throughput, breakage rates of less than 0.1 per cent must be ensured. Moreover, short maintenance and service cycles as well as high machine availabilities of >95 percent need to apply in standard production. To achieve high-throughput, low breakage and virtually continuous availability, innovative cell handling concepts with effective cost-benefit ratios are needed.

These benefits can be achieved with laser processing on-the-fly (OTF). OTF processing has the advantage of eliminating costly handling and individual positioning of PV cells within the machine. Instead, the wafers are transported on a conveyor belt under the laser source, which renders stops for orientation superfluous. An integrated lens automatically compensates for relative cell motion during structuring of the passivation layer by the laser. The conveyor belt's continuous clocking leads to a nearly 100 percent utilization of the laser source. The implementation of 'non-touch' cell handling can enable an additional production optimization. This handling concept is based upon a technology that avoids mechanical contact between the wafers.

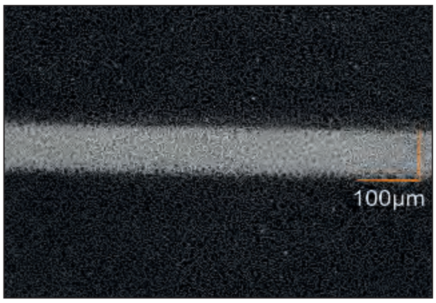


Fig. 3: Ablation of passivation layer with picosecond laser (microscope image)
Laser implementation in an innovative manufacturing system

Gentler, more frictionless wafer transport within the plant is thereby guaranteed during the laser process. Cell breakage or micro cracks (cell damage that can later lead to breakage) are avoided, thus realizing a higher yield. This smoother handling also paves the way for the further reduction of wafer thickness in further cell technologies. Further advantages of non-touch handling result from the system's minimal maintenance cost as well as lower power consumption in comparison to conventional start/stop transport systems.

Half-cell cutting to increase PV module power with TLS-Dicing

Discussing PV cell manufacturing yield, throughout and unit cell performance enhancements would not be complete without considering half-cell concepts. A technologically promising path towards higher module efficiencies without increasing cell efficiencies themselves is central to the concept of a half-cell module [3], [4]. Major benefits supporting the half-cell concept include reduced series resistance loss combined with better light management that occurs when more sunlight reflected from the back-sheet reaches active cell areas [5], [6]. This can lead to an increase in module efficiency of about 3 percent (relative).

However, care is needed throughout the cell separation process because it might induce electrical or mechanical damages to the cells, which either lower the electrical performance of the module or could cause reliability issues. The standard industrial process of p-type cells is based on a laser scribing on the cell rear side (30-100 µm deep,) and subsequent mechanical cleaving. The disadvantages of mechanical cleaving can include reductions in cell efficiency, reduced mechanical strength and substantially greater handling costs due to the combination of a laser process with subsequent cleaving steps.

An alternative process is cell separation based on Thermal Laser Separation (TLS-Dicing/TLS). TLS is used in the semiconductor industry's back-end to separate semiconductor wafers into components. The process is based upon thermal induced mechanical stress, generated by a well-adjusted combination of a laser heating and cooling. Thus, a crack is guided through the entire cell and two half-cells are obtained.

The method is suitable for most brittle materials in the semiconductor industry, including Si, SiC, Ge and GaAs wafers. [7]. Compared to traditional separation technologies, TLS is virtually damage-free; it offers impressive clean, micro-crack-free edges and greater resulting bending strength.

The complete cleaving is a one pass process with a speed of up to 300 mm/s. The relatively low temperature (no material is ablated or melted) in combination with the high cleaving speed are the reason that the electrical properties are not influenced by the separation step. Furthermore, the high throughput and wear-free processing offer great potential for reducing production costs and cost of ownership. It has been demonstrated that cells separated using the TLS process show a significantly higher mechanical strength, better edge quality as well as a lower power reduction compared to laser scribing and cleaving approaches. [8].

Fig. 4: 3D-Micromac's laser processing equipment for machining of high efficiency solar cells (PERC, half cell cutting, selective emitter, EWT, MWT solar cells)

First-class laser system yield and efficiency

3D-Micromac AG has taken the demonstrated potential of the most advanced laser technologies into account and further developed existing production systems for photovoltaics in order to meet cell manufacturers' demands. The microSTRUCT OTF, a highly reliable production tool, was developed and successfully introduced to the market for laser backside opening. The system is characterized by a compact structural form, an innovative handling concept and minimal infrastructure requirements. The mature machine platform is suitable both for new production lines and for equipping existing lines.

The modular structure can be combined with any number of laser sources to match the system exactly to respective process requirements. The complete system encompasses the laser processing station and handling. Throughput amounts to more than 3,600 wafers per hour depending on the contact openings' structuring geometry. The suitability for industrial cell production has been successfully demonstrated and confirmed by customers. 3D-Micromac has adapted its advanced laser technology for cutting solar cells into half cells. The resulting system, the microDICE OTF, also achieves a throughput of 3,600 cells per hour by using on-the-fly technology. It guarantees the highest productivity and an outstanding price-performance ratio. The microDICE OTF is a fully automatic 24/7 production solution and can be offered as a stand-alone or inline system.

All 3D-Micromac production solutions are designed to meet cell manufacturers' demands for achieving maximum throughput rates and yield while cutting cell processing costs. The systems guarantee very high availability through the use of sophisticated concepts and high quality / high efficiency components.

Literature

[1] Kost C. et al., Studie Stromgestehungskosten Erneuerbare Energien, Eigenverlag, Freiburg, 2012.
[2 SEMI, International Technology Roadmap for Photovoltaic (ITRPV) Results 2012, 3 2013. [online].
[3] Schneider J. et al., Solar Module with Half Size Solar Cells. 29th EU PVSEC, Sept. 22 - 26, Amsterdam (Netherlands), p 185 – 189; 2014.
[4] Guo S. et al., Investigation of short-circuit current increase for PV modules using halved silicon wafer solar cells. Solar Energy Materials & Solar Cells 133, p240, 2015.
[5] Turek M., Current and illumination dependent series resistance of solar cells, J. Appl. Phys. 115, p144503, 2014.
[6] Turek M. and Eiternick S., Rapid Module Component Testing and Quantification of Performance Gains. Energy Procedia 55, pp. 369-373; 2014.
[7] Oswald M. et al., Evaluation of Silicon Solar Cell Separation Techniques for Advanced Module Concepts. 28th EU PVSEC, Paris (France), p 1807, DOI 10.4229/28th EUPVSEC2013-2CV.4.51; 2013.
[8] Zuehlke H.-U et al., PV Cell separation by Thermal Laser Separation, 9th SNEC International Photovoltaic Power Generation Conference & Exhibition, 2015

SOLARUNITED emerges from IPVEA to expand its mission

SOLARUNITED Executive Director Bryan Ekus discusses the organization's new focus after the IPVEA moved in 2014 to change its name and expand into new emphasis areas.

CONTRIBUTING EDITOR Mark Andrews met with SOLARUNITED Executive Director Bryan Ekus in March to discuss reasons behind the International Photovoltaics Equipment Association's (IPVEA) decision in September 2014 to change its name and expand its focus. The association, founded in 2008, has seen many changes as solar PV technology matured, markets grew and a host of new competitors entered the international solar energy arena. What is the role of the newly-renamed SOLARUNITED organization and how is it serving its global membership?

Q The IPVEA came into being right at the start of a global recession and represented many industry manufacturers during lean times as well as huge growth periods. Why change the name and mission?

A The original organization grew beyond a concentrated group of manufacturers, many of which had similar backgrounds. You are absolutely right that the world has changed a lot since 2008, and as we said before the September (2014) Board action, those of us working in the organization not only heard requests for activities we were not specifically chartered to deliver, but world economies and the entire solar industry was changing. We needed to be better positioned to address the technology issues, international support for solar and a growing consumer base.

Q How is 'SOLARUNITED' different from the IPVEA?

A Many of the same organizations involved in IPVEA are still involved, but like any association membership changes over time. A fraction of those companies who originally were the core

of IPVEA are still in solar. You're right about facing tough years right after we formed. While some companies didn't survive, others took their places and today the market has increased many times over its size in 2008. Many of the individuals working in one company moved-on and are still in the industry. The main differences between then and now is how the industry itself have evolved, which was a key reason for becoming SOLARUNITED. As a whole, solar is now a significant energy provider in many regions. It's established, not just emerging. So it is also facing challenges that every industry needs to deal with once it moves beyond its pioneering years.

Q What does SOLARUNITED offer that's different compared to the IPVEA?

A We are of course still advocates for our members, but an important change is the focus on three main areas of value: Business, Technology, and Marketing Communications. In essence, the action to become SOLARUNITED is an anticipatory move as we position ourselves to both lead and consolidate the entire solar value chain for the years ahead. We needed a new vehicle to reinforce dialogue, encourage collaboration and address the regulatory and technological environment the industry was and is facing. While we had the basic building blocks already established, we needed a new framework to help a fragmented industry coalesce around common future goals. Technology will always be central to what we do and since it evolves rapidly in this industry, we needed a group dedicated to it. Finally, there's the whole issue of communications within the membership and to outside interests – who speaks for an industry that has so many participants in so many countries? We can, and I believe the changes taken to make us SOLARUNITED are in line with that mission.

Q How are technology changes impacting the way solar power is generated? Has it gone mainstream?

A There are many measures of how big a role solar plays in communities, regions and whole populations. One of the great things about this industry is that there is no 'one-size-fits-all' approach. Innovators are free to pursue what works for them and their customers wherever they see their markets. There are interests that cross borders and we're seeing more of those now. Take for example the fact that as a technology matures there are things we know now that were not known even two years ago, let alone in 2008. Consider how a PV panel functions in long-term service; it's becoming an issue, and that is where quality and reliability emerge as concerns every manufacturer needs to consider. How do our customers recognize valid ways to evaluate products and how can they make the best decisions that benefit them now and long-term? Again, communicating these issues, ideas and seeking solutions are big parts of what SOLARUNITED is about, and its Marketing Communications group will focus on together with members interested in core business issues and technology.

Q How has the role of varying business interests changed and where does SOLARUNITED fit in?

A The strategic committees' key tasks include unifying and encouraging more communication and dialogue between the most important players within the different steps of the solar value chain as well as related industries including energy storage, grid and electric vehicles. We'll definitely be working with key standards organizations that are addressing issues such as safety, best practices and certification of technologies that build confidence with consumers. We have seen the role governments play encouraging renewable resources change over the years, and of course in several cases

governments have encouraged large-scale development of solar PC manufacturing. In other countries the government went from being advocates to actual partners with companies that now compete with other long-established solar manufacturers.

Q Is government interaction with the industry a good reason for becoming SOLARUNITED?

A The need for one unifying solar photovoltaic group is arguably becoming more important. Why now? The industry is preparing to make—and in some cases has already transitioned – from a niche renewables technology to a mainstream source of electricity generation. In Germany for example in 2014, more than 25% of the country's power needs were met at one point with solar. New business models are emerging — such as storage and grid-level systems, while some big technology players have now entered the industry, including Solarcity, Tesla and Google. This is creating new challenges for the solar industry, such as an increasing focus on quality.

Q In the United States, for example, the federal government is planning to cut its Income Tax Credit program from 30% to 10% at the end of 2015. What will this mean for the industry?

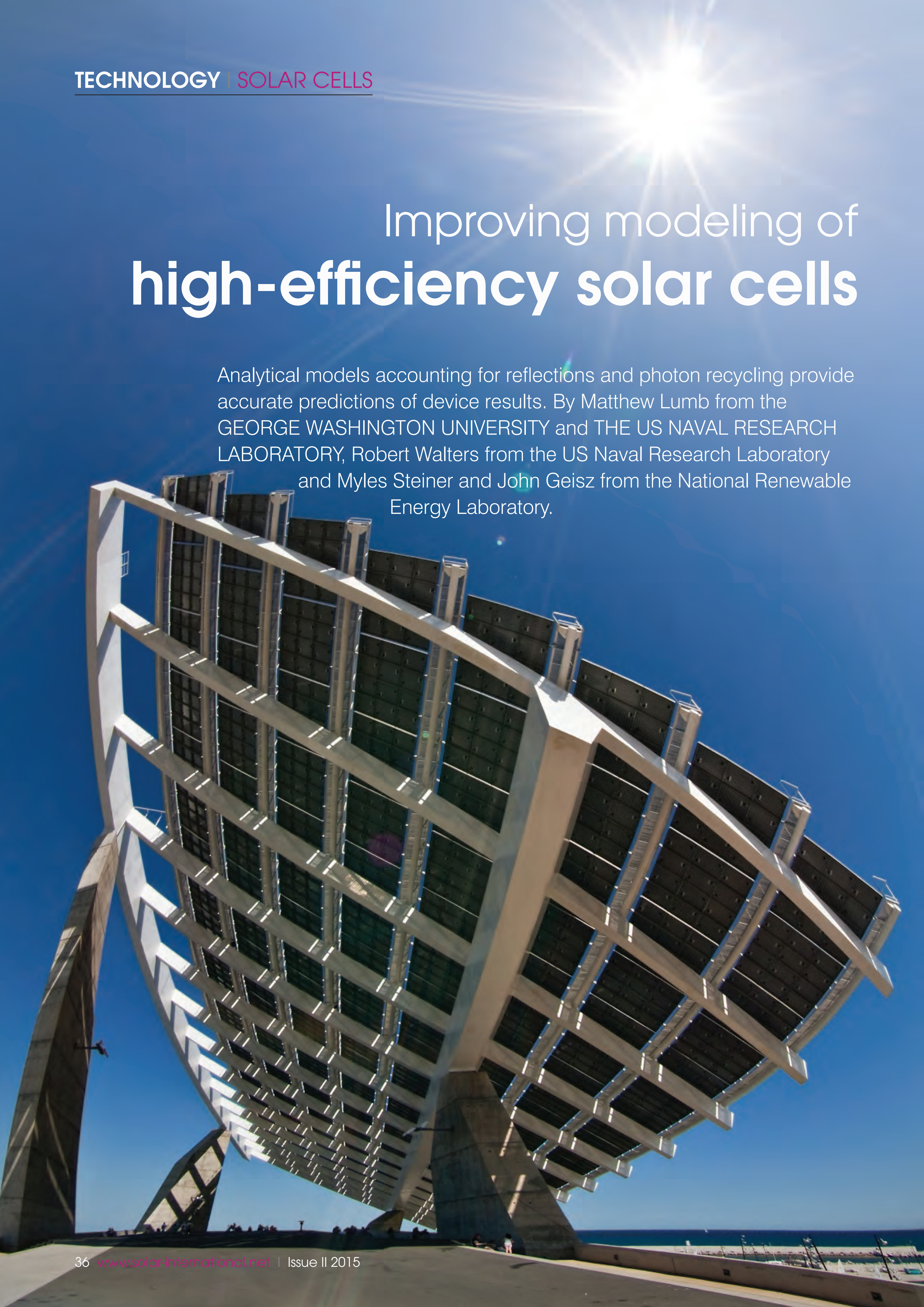
A Governments are tapering off subsidies not just in the US but in other places as well, and in most cases I believe this signals that the industry as a whole has proven its merit and doesn't need the same level of government underwriting that it did years ago. It also places the industry under greater pressure to deliver solar projects at competitive costs and this is making itself felt along the entire value chain — from BOS (balance of systems) component suppliers, to inverter makers, as well as solar cell and module producers. However, a challenge for the global solar industry has been to unify many industry associations representing its various factions and segments. These include regional and national solar and renewables associations, plus other technology-focused groups. So many voices can make it difficult for the solar industry to organize a single, cohesive international business platform, something that the wind industry, for instance, has managed to achieve through its own Global Wind Energy Council (GWEC). At the board meeting, it was decided that SOLARUNITED would temporarily host national and regional associations seeking to develop its own global council, following GWEC's example.

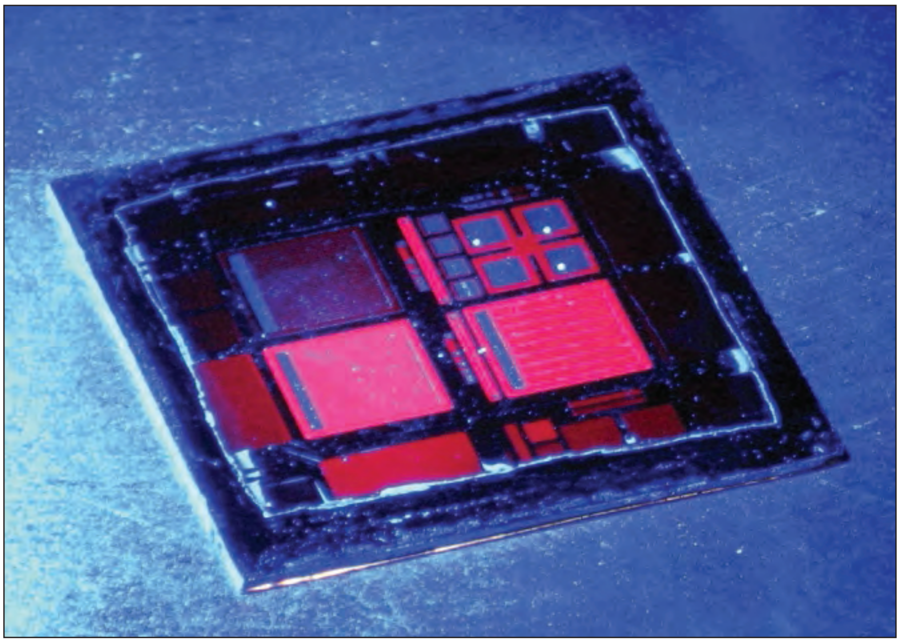
Q What do you hear from consumers, either directly or through SOLARUNITED? What are their interests and concerns?

A That's a big topic. Since we're an industry association most of what we hear we gain through contacts within the organization. One consistent request (from consumers) is for greater transparency so they find it easier to buy solar. The very thing that makes the industry so dynamic—so many choices / so many manufacturers / so many options, can also be daunting for consumers. There may come a time where there are quality seals of approval that emerge, but whatever those may be they'd need to take into consideration that many standards groups (government or independent laboratories) already certify electrical performance and other components. It is yet to be seen whether a group focused totally on solar PV technology will emerge. The regulatory issue is particularly challenging. In the United States there are regulations that can literally change not just from state to state, but even from county to county within a state. That's a challenge. The larger retailers are working to consolidate and be a voice for consumers by demonstrating that they remove some of the complexity of the purchase decision, but again—we are still a young and dynamic industry. It's exciting to have seen such growth over the past six years while we position ourselves for evolving national and global concerns.

Improving modeling of high-efficiency solar cells

Analytical models accounting for reflections and photon recycling provide accurate predictions of device results. By Matthew Lumb from the GEORGE WASHINGTON UNIVERSITY and THE US NAVAL RESEARCH LABORATORY, Robert Walters from the US Naval Research Laboratory and Myles Steiner and John Geisz from the National Renewable Energy Laboratory.





A GaInP cell that is luminescing under blue light, a result of substantial photon recycling enhancement due to the back reflector.

MANY RESEARCHERS IN THE SOLAR SECTOR are pursuing the same goal – to come up with a technology that increases photovoltaic efficiency. It's a worthwhile aim, because if a cell can extract more electrical energy from the sun's rays, solar power may become more affordable, leading to increased sales and better economies of scale.

Several approaches are available for developing higher efficiency cells. One option is to design and evaluate a new architecture in the lab, and an alternative approach is to model new device designs to see if they are superior. In practice, a mix of both these approaches tends to work best, with measurements on real devices verifying the capability of a new cell design that produces promising results in modeling efforts.

Whatever materials are used to build a conventional solar cell, ultimately efficiency is limited by a fundamental process: radiative recombination. It follows from the reciprocity of absorption and emission processes that if all other loss mechanisms are entirely suppressed, the resulting, perfect solar cell would also, in fact, be a perfect LED.

This relationship between a faultless LED and a solar cell has been known for many, many years, and in the 1950s it was employed by Nobel-prize-winning physicist William Shockley and co-worker Hans-Joachim Queisser to derive the efficiency limit for a solar cell. This model, which accounts only for band-to-band radiative recombination of electron-hole pairs, assumes that all other processes are ideal. It is widely used by researchers in the photovoltaics community today, and one of its strengths is that it is able to express the potential of competing technologies in the simplest terms. However, real world solar cells are seldom close to ideal. Efficiency is impaired by optical losses, non-radiative recombination and electrical losses, which usually combine to make the Shockley-Queisser limit a gross overestimation.

Models that can provide a more realistic value for efficiency are highly desired, because they can aid efforts to improve solar cells. This need is particularly acute for III-V cells, which come closer than many other material systems to reaching their fundamental limit, thanks to advances in epitaxy, processing and optical management. In space, these cells are united with those made from germanium to power satellites, and in sunny climes these cells lie at the heart of power generation systems featuring mirrors or lenses that focus the sun's radiation by factors of several hundred or more.

In the 1970s, Harold Hovel and Jerry Woodall introduced a more sophisticated model that is better at capturing the performance of single-junction cells. This pair of researchers, who were working at IBM Research Laboratory in Yorktown Heights, New York, developed an analytical drift-diffusion model that contains all the real world losses (see "The Hovel and Woodall model" for details). However, this approach is far from perfect, because it fails to account for

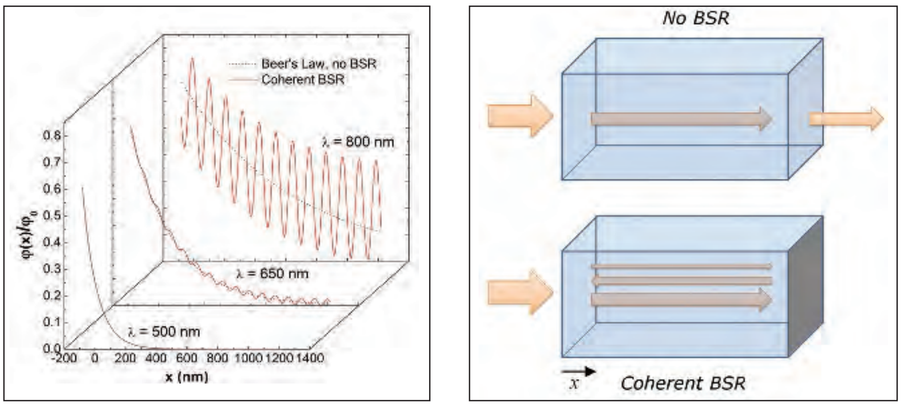


Figure 1. A generation function accounts for optical effects in a cell. A modified form of this function is used when a gold mirror is added to the cell's backside to create a coherent back-surface reflector (BSR).

the contribution to energy generation that occurs in cells employing a high reflectivity back mirror, which increases absorption within the cell and enhances photon recycling. A more complete model would include coherent and incoherent optical effects, such as contributions from back surface reflectors, which increase the probability of photon absorption; and it would account for photon recycling, a process where photons spontaneously emitted by the material through radiative recombination are reabsorbed by it.

Previously, numerical methods have been employed to construct a fully numerical drift-diffusion model that accounts for all these effects. Including them all is essential for accurate modeling of today's best devices, which are coming very close to the fundamental efficiency limit.

Strengths of these numerical models include their flexibility and precision. But these merits have to be weighed against several downsides, which can be addressed by turning to an analytical model that includes the additional optical effects – which is an approach that has been pioneered by our team from the US Naval Research Laboratory, George Washington University and the National Renewable Energy Laboratory (NREL).

One of the virtues of our analytical model is that it avoids the need for advanced numerical techniques for solving boundary value problems on a mesh grid, resulting in a model that is easy to develop. What's more, the analytical model provides an excellent intuitive understanding of the inner workings of a solar cell, due to separate treatment of different regions within the device. All this is possible while delivering comparable accuracy to the numerical model, so long as we can meet the assumptions upon which the model is based.

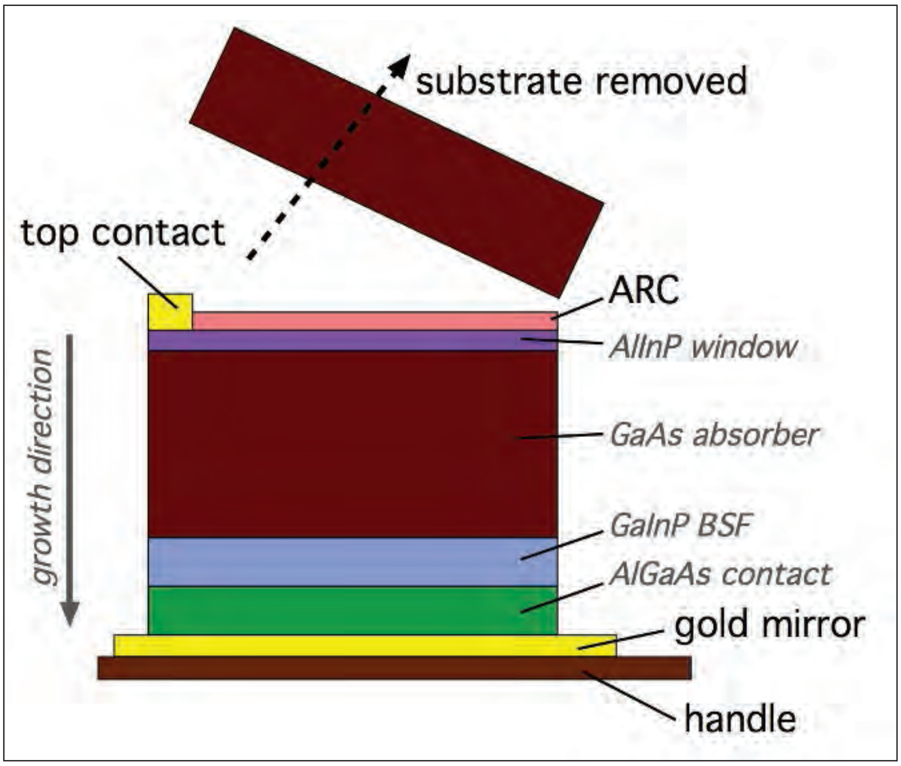


Figure 3. An inverted growth process enables a mirror to be positioned directly beneath the cell, enhancing light absorption. Another benefit of this approach is that it allows re-use of the substrate.

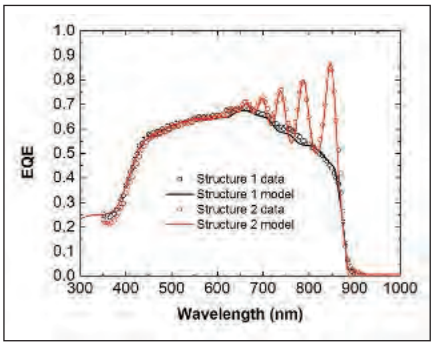


Figure 2: Modeled and experimental values of the external quantum efficiency of two GaAs solar cells of the same 1 μm thickness: structure 1 has no back reflector, whereas structure 2 has a high reflectivity gold back reflector. Note that the external quantum efficiency is a measure of the spectrally resolved probability of an incident photon being captured and converted into an electron in an external circuit.

To date, our work has been restricted to the modeling of single-junction devices. However, it should be possible to extend this effort to multi-junction variants. This will require modification of the model to include luminescent coupling, which occurs when the emission from the top cell generates photons in the cell beneath.

Handling multiple reflections…

To account for the multiple reflections inside the cell when a back mirror is present, we have added a generation function to the drift-diffusion model. It is possible to determine a compact analytical expression for this function at every point in the solar cell by summing the fields of the multiple reflected beams in the absorbing region. This expression can then be incorporated into the drift-diffusion calculations, and solved in an analogous way to the original Hovel and Woodall model. Note that this approach can be applied to both coherent and incoherent reflections from the back surface reflector.

We can illustrate this approach by considering the simple case of a GaAs absorber with a coherent gold back reflector (see Figure 1). At short wavelengths GaAs is strongly absorbing, so the generation function resembles that of Beer's law – this states that as light passes through a substance, its intensity decreases exponentially. For wavelengths near the bandgap of GaAs, this law is not valid, and the generation function deviates significantly as GaAs becomes semi-transparent. In this wavelength region, the solar cell acts like a Fabry-Perot cavity, with the forward and reverse propagating fields interfering to produce an overall enhancement in the photon density absorbed by the GaAs. This leads to an increase in photocurrent.

Adding a gold mirror to the thin GaAs homojunction solar cell leads to a significant increase in its external quantum efficiency (see Figure 2, which shows that modeling can replicate experimental measurements by capturing coherent optical effects arising due to the back surface reflector). However, these demonstration devices were fabricated without a front side anti-reflection coating, leading to losses of approximately 30 percent at the front surface. Therefore, the mirrored cell in this example has not reached the realms of ultra-high efficiency.

Production of these cells begins with MOCVD growth of the epitaxial layers on a GaAs substrate. During post-growth processing, if an external back metal contact is deposited on the rear side of the substrate, the thick absorbing substrate will act as a photon sink to any internally emitted radiation (this is the case for structure 1 in Figure 2).

It is possible to insert a highly reflective back contact by removing the substrate and depositing the mirror directly on the rear side of the epitaxial layers. An innovative way to do this, pioneered at NREL in 2007, begins with the growth of the solar cell in an inverted configuration, with the front layers grown first and the back layers grown last. Layers are then re-orientated during post-growth processing to create a structure where the rear surface of the actual solar cell is immediately accessible. A highly reflective metal or dielectric-metal mirror can then be deposited on the growth surface (this is the case for structure 2 in Figure 2, and the device that results from this approach is shown in Figure 3).

Fabrication of this type of cell is completed by bonding the epistructure to a handle wafer, such as silicon or a flexible plastic, and then removing the native substrate – wet chemical etching is one way to do this, though other techniques have been developed that allow the substrate to be preserved and reused. Epilayers are then processed into individual solar cell devices with front contacts.

… and photon recyling

In addition to multiple reflections, the other significant improvement of our analytical model over that developed by Hovel and Woodall is the inclusion of photon recycling. In a perfect cell, all of the solar radiation that impinges on the front surface will be absorbed. Then, in order to generate power from the device, some radiative recombination must occur. This is an inescapable loss, but in an ideal cell all the non-radiative processes are negligible, and all of photons generated by radiative recombination can only escape the device through its front surface.

When a cell is generating power, there are actually a great number of recombination events happening simultaneously, with photons emitted in all directions inside the absorber. Ideally, most of those photons are recycled into new electron-hole pairs (see Figure 4).

Progress towards this goal is possible with a back surface reflector, which suppresses photon escape through the rear surface of the cell and thus improves the external radiative efficiency.

One of the consequences of photon recycling is a cut in the net rate of radiative recombination. This can also be stated in another way – as photon-recycling increases, the radiative lifetime of minority carriers increases until the external radiative efficiency limit is reached. However, if photon recycling is to deliver a performance improvement, it is paramount that the *internal radiative efficiency* of the material – that is, the fraction of recombination events that are radiative – approaches unity. When this happens, the net lifetime of minority carriers increases due to photon recycling, which leads to an increase in their diffusion length. In III-Vs cell made today, material quality is exceptionally

The Hovel and Woodall model

IN THE 1970s, Hovel and Woodall made an important scientific contribution to solar cell efficiency modeling with the introduction of an analytical drift-diffusion model for single-junction solar cells.

This model capitalizes on the fact that simple *p-n* homojunction solar cells typically operate in the low-injection regime and have carrier populations well-described by Boltzmann statistics. Under these approximations, the diffusion problem for minority carriers in the quasi-neutral absorber regions can be solved analytically.

Optical generation in the cell is described by Beer's law, which is a good approximation for an optically thick homojunction.

By coupling this model with accurate values in the literature for optical constants, semiconductor band parameters, minority carrier transport properties, non-radiative lifetimes and interface recombination rates, it is possible to make remarkably accurate predictions of solar cell performance.

However, the model fails to capture two significant effects related to photon management, both of which are crucial in devices approaching the fundamental limit: coherent and incoherent optical effects, such as back surface reflectors to improve the probability of photon absorption; and photon recycling, where the photons spontaneously emitted by the material through radiative recombination are reabsorbed by the material.

high, enabling cells to operate at very high internal efficiencies. In these devices, the voltage produced by a solar cell provides an excellent indicator of photon recycling, which impacts the recombination rate and therefore the dark current.

Our efforts at capturing photon recycling in our model (see “Including photon recycling in an analytical model”) have helped us to appreciate the importance of maximizing the external radiative efficiency of solar cells. Motivated by this, members of our team at NREL have developed an important modification to conventional homojunction solar cells: the thick emitter concept.

The traditional architecture for a high efficiency III-V cell includes a thin, highly doped *n*-type (emitter) layer atop a thick, lower doped *p*-type (base) layer. Short wavelength light, with a short penetration depth, is predominantly absorbed in the emitter layer and longer wavelength light in the base layer. In contrast, our new design features a thick, moderately doped *n*-type emitter layer atop a thin *p*-type base layer, giving rise to a high external radiative efficiency.

There are several reasons why a thickening of the emitter boosts performance. First, so long as the diffusion length of minority carriers significantly exceeds the thickness of the quasi-neutral regions (which is required for efficient minority carrier extraction in solar cells), a structure with a thick, low doped *n*-type layer can achieve a lower diffusion current than an analogous structure containing a thick, low doped *p*-type layer due to the lower diffusivity of minority holes to minority electrons.

Another reason why our novel architecture increases efficiency is that almost all the photocurrent in the thick emitter structure is produced from the emitter, so device performance is very sensitive to the minority carrier lifetime in this layer. It is possible to optimize the emitter doping concentration to ensure high quality material with a close-to-unity internal efficiency, and a long enough diffusion length to provide efficient minority carrier collection.

When the thick emitter is included in a structure with efficient photon recycling – such as a device with very high internal efficiency and a high-reflectivity, back-surface reflector – this can lead to significant voltage enhancements. In contrast, in a conventional, thin-emitter structure, the dark current and photocurrent contributions of the solar cell are distributed more evenly among the emitter, depletion and base regions of the solar cell, making it more difficult to design a device with both high performance and high sensitivity to photon recycling effects.

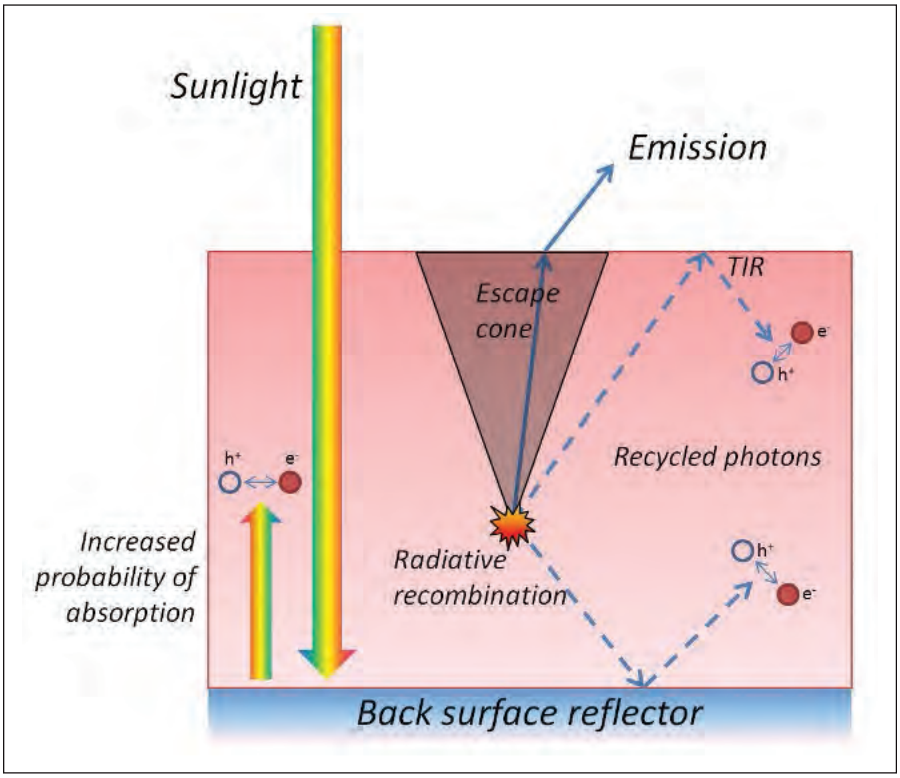
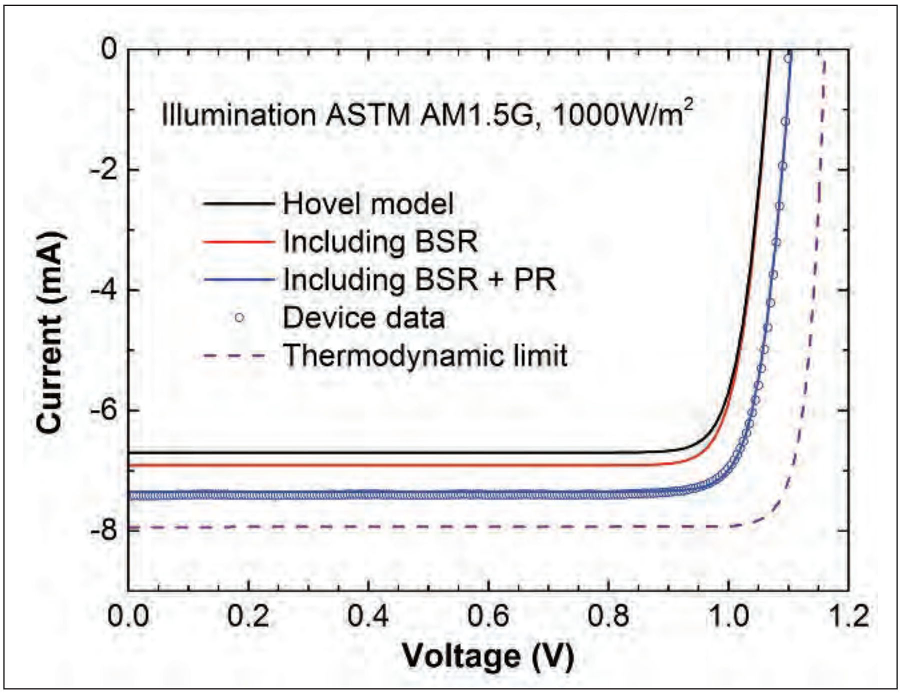


Figure 4. If photon recycling is ideal, the only photons that are able to escape the absorber pass through the front surface; all other photons are recycled to generate new electron-hole pairs. The inclusion of a back surface reflector improves the probability that incident sunlight is absorbed within the device.

Our modeling and experimental efforts have determined the significant increase in voltage output that results from the inclusion of a gold back mirror on our thick emitter GaAs cells (see Figure 5). This device delivers a conversion efficiency of 27.8 percent, within 3 percent (relative) of the current world record for a single-junction solar cell. The performance of this device approaches the fundamental, thermodynamic limit for an ideal GaAs cell.

We have used a variety of models to predict the performance of this thick-emitter, single-junction cell. Calculations based on the model by Hovel and Woodall underestimate performance, due to a failure to capture the optical enhancement that arises due to the multiple reflections from the back surface reflector, and the suppression of radiative recombination due to photon recycling. Slight improvement results from the inclusion of a more realistic generation function that incorporates multiple reflections from the back mirror and the concomitant increase in the short-circuit current density. However, this model still assumes bulk lifetime values with no photon recycling, giving a diffusion length of 4.3 μm for minority holes in the emitter.



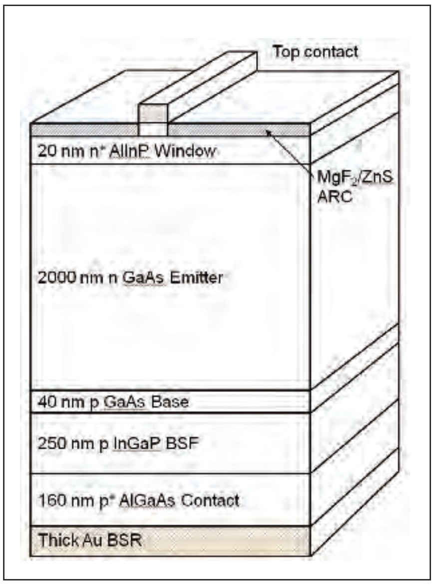


Figure 5. A variety of models have been used to try and capture the performance of the thick-emitter, single-junction cell that incorporates a reflecting gold mirror at the bottom of the device. The model by Hovel and Woodall fails to accurately reproduce the experimental data. Incorporating multiple reflections from the gold mirror, which is also known as a back surface reflector (BSR) improves the calculation, but both BSR and photon-recycling contributions are required to replicate the experimental results.

When photon recycling it taken into account, the diffusion length increases to 17.1 μm and the minority carrier lifetime increases. Our model can then capture the increase in photocurrent extraction efficiency and reduction in dark current. Both these improvements impact the light-current-voltage curves, where it is possible to note increases in short-circuit current density and open-circuit voltage. This voltage exceeds that predicted by the Hovel and Woodall model and highlights the need for modeling that includes photon management strategies, which allow solar cells to get even closer to their fundamental performance limit.

The authors would like to thank Dr. I. Vurgaftman, Dr. A. Hanbicki of the Naval Research Laboratory, J. Adams, V. Elarde, G. Hillier and the R&D team of Microlink Devices Inc., and D. Friedman, I. García and S. Kurtz of NREL for helpful discussions relating to this work. Research at NREL was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 and funded in part by the Foundational Program to Advance Cell Efficiency.

Accounting for photon recycling in an analytical model

BY MAKING A FEW simplifying assumptions it is possible to capture the physics of photon recycling with an analytical model. The key principle that we need to consider is the reciprocity relation linking the absorbed and emitted radiation.

Under voltage bias, we assume that the quasi-Fermi level separation in the device is equal to the applied bias at all points within it – this is a very good approximation for a typical homojunction solar cell under low-injection conditions.

Under this assumption, the rate of radiative recombination is uniform throughout the cell; and the photon current escaping the solar cell, which is related to the internal photon current, is determined from the generalized Planck equation and the absorbance of the structure. The absorbance is the total probability of a photon incident on the cell from outside being absorbed, which is straightforward to compute for a multilayered medium. The fraction of the total photon current in the absorber unable to escape the solar cell is known as the photon recycling factor [see, for example, Asbeck, J. Appl. Phys. **48** 820 (1977)], which determines the average reduction in the net radiative recombination rate for the electron-hole pairs in the cell. This number is a function of the particular geometry of the cell and, in conjunction with the lifetimes of competing non-radiative processes, enables calculation of the overall minority carrier lifetimes in the absorber layers of the cell.

The final simplifying assumption that we make is to assume that the net recombination rate at a given bias in the dark is equivalent to that in the light. This is the often used principle of superposition in solar cells.

Is the US ready for **residential solar?**

Residential solar is growing at a rapid pace, with a 50 percent annual growth rate, yet it still remains at less than one percent of peak demand in the U.S. What is needed to increase the penetration of residential solar in the marketplace? Solar International puts the questions to Neil Auerbach, CEO and Managing Partner from Hudson Clean Energy Partners.

THE IMPRESSIVE GROWTH the residential solar market has experienced over the last few years is due to four factors: the overall decrease in the cost of solar photovoltaic (PV) systems, strong federal and state financial incentives, steadily rising electricity rates and the development of new financing mechanisms such as solar leases and loans.

These factors contributed to a 41 percent compound annual growth rate in the residential solar sector between 2012 and 2014, with the market expected to grow from $4 billion in 2013 to over $11 billion in 2016. As solar PV manufacturers continue to implement technological improvements and streamline manufacturing processes, the cost will continue to decline, providing an added stimulus to growth.

Despite significant reductions in cost, however, the single greatest hurdle for homeowners remains the initial cost required to install a solar PV system. By offering solutions that eliminate upfront cost, solar financing companies are providing a significant incentive for homeowners to go solar. Because of the appeal of ownership, the introduction of simple, affordable loans for residential solar will be a strong driver for the industry, making it as easy to install a solar system as it is to buy a car.

To ensure continued growth, state and federal financial incentives are also necessary. President Obama's proposal to extend the federal Investment Tax Credit (ITC) for solar, which is currently slated to step down from 30 percent of the project cost to 10 percent at the end of 2016, would be an important stimulus for the residential solar market. Maintaining the status quo, i.e., keeping the 30 percent credit intact for homeowners as well as third party system owners, will help maintain nationwide market penetration of residential solar.

Q **Leasing remains the predominant financing mechanism for residential solar. Why and what are the other alternatives? What are the advantages of loans over leases?**

A Solar leases have emerged as an innovative option and remain a popular form of financing due to the elimination of upfront costs and convenient monthly payments. Alternatively, homeowners can also chose a solar power purchase agreement (PPA) or a loan. With a PPA, as with a lease, a third-party investor actually owns the system.

The fundamental difference is that with a lease the homeowner pays a monthly fee, while with a PPA the homeowner purchases the power generated by the system at a set price per kilowatt-hour. In both cases, the cost is less than the homeowner would have paid to the utility. Also, in both cases, all financial incentives for solar, including tax credits, rebates and Solar Renewable Energy Certificates (SRECs), accrue to the third-party investor, rather than to the homeowner.

New solar residential loan products, however, are challenging the popularity of leases. Solar loans have a number of advantages over leases and PPAs, foremost among them being that the homeowner -- not the third-party investor -- owns the system. In addition to the innate satisfaction provided by ownership, ownership also increases property values, increases a home's attractiveness to prospective buyers and -- perhaps most importantly -- allows the homeowner to reap the benefit of financial incentives and property and sales tax exclusions.

Loans allow the homeowner to obtain free electricity from the installed system at the end of the loan term, whereas homeowners need to continue to pay the system owner for the

electricity at the end of the lease term. In addition, loans offer the convenience of fixed payments (although new loan products have been introduced that mimic leases and PPAs, with escalator clauses and references to power prices) and loan terms of similar length to PPAs and leases, which translate to lower monthly payments. Finally, loans generally offer simpler approval process, reducing the paperwork involved in executing a lease of PPA.

Q Do you see loans replacing leases as the main financing vehicle in the near future?

A Ultimately, yes. Just as with automobiles, there will always be a place for leases, but as loan products become more widely available they will overtake loans as the financing model of choice. The most important point, however, is that any type of financing vehicle – be it lease, PPA or loan – can accelerate the adoption of solar by eliminating the upfront cost, thus helping homeowners save on their energy bills and helping the environment by generating electricity from a clean, renewable source of energy. The increased access to low-cost capital offered through solar leases and loans, along with the dramatic declines in the cost of solar PV systems, is allowing solar installers to convert millions of interested homeowners into the happy beneficiaries of solar systems that generate power from an inexhaustible source of energy – the sun!

Q What has been the barrier to adoption of the widespread use of solar loans for residential solar?

A The residential solar sector is growing rapidly, but it is still in its nascent stages, with less than 1 percent residential solar penetration. The main barrier to greater adoption is that the market has not yet developed a range of simple, easy-to-execute, affordable loan products to meet the growing demand. Until recently, the situation was analogous to the time in the automobile industry when consumers had to come up with the cash upfront to buy a car – or borrow it from mom and dad. The good news is that new loan products are now being introduced that make it easy for consumers to make the transition to solar with no money down.

Q Hudson has a long track record of expertise in clean energy investments. In what ways is Hudson helping to promote the investment in solar?

A Hudson Clean Energy Partners is a private equity firm that has been making privately negotiated investments in the dynamic, high-growth clean energy industry for more than a decade. Global in scope, Hudson is dedicated to investing exclusively in renewable power, alternative fuels and energy smart technologies in sectors that include wind and solar energy, biofuels, biomass, geothermal energy, energy efficiency and storage.

Though our investments span the range of renewable energy technologies, solar has been a major focus for us, with our investments including those in solar PV development, solar PV cell and module manufacturing, utility-scale solar power generation, silicon manufacturing, grid integration products and project finance. Our inaugural solar infrastructure investment program, the Hudson Solar Infrastructure Program (HSIP), provides investors access to high-quality solar PV projects that generate a steady stream of long-term cash flows at attractive, risk-adjusted yields. Our latest initiative is Sunlight Financial, a specialty finance company we've organized to help address the market gap in loan products geared to the residential solar market.

Q With the changing energy landscape, what do you see as the fundamental opportunities and obstacles confronting the industry?

A We see tremendous opportunity in the solar industry in coming years. The rapid market growth, combined with significant technological advancements, has allowed module manufacturers and other technology providers to begin tackling issues such as storage, efficiency, O&M and maximizing performance over the lifecycle of the asset. Solar financing will be a major part of the equation in coming years, creating new opportunities not only for consumers, but also for solar financing companies, solar integrators and solar equipment providers worldwide.

To help move solar financing into the mainstream, the Solar Energy Finance Association (SEFA), a non-governmental organization dedicated to advancing the availability of public capital and expanding financing options for the solar industry, recently announced plans to develop and promote the use of standardized financing contracts to reduce the time and complexity of evaluating projects, lower transaction costs in the solar development process and improve transparency to the consumer. We believe efforts to streamline solar financing, along with other innovations such as the incorporation of storage and the use of data analytics to ensure high levels of efficiency and performance, will help solar maintain and even exceed current extraordinary levels of growth. At the same time, new obstacles are arising. The most threatening is utility opposition to the increased penetration of solar. Slow growth – and even contraction – in the utility industry is prompting utilities to fight back in the battle for dominance over local electricity markets, including by changing rate structures, limiting grid connections for renewables, imposing net metering caps and repealing or reducing incentives. For the most part, solar advocates are winning the battle as utility regulators feel uncomfortable protecting utilities against the threat of competition from customers, a clear reversal of their mandated role.

Although cost allocation is a reasonable issue for utilities, regulators, consumers and the solar industry to debate and address, it must be done in a manner that promotes competition, consumer choice and the national interest in increasing access to renewable energy. A more effective strategy for utilities might be to take a "if you can't beat 'em, join 'em" approach by building their own distributed solar PV plants and investing in solar PV portfolios. That is the strategy being pursued by the oil and gas industry. The American Petroleum Institute (API), the foremost big oil lobbying group, recently joined with the Solar Energy Industries Association (SEIA) to produce a report entitled the "State of American Energy," demonstrating how differences can be put aside to cooperate and secure the nation's energy future.

Q What is the government doing to support residential adoption and what needs to change?

A While many have criticized solar incentives, the value of incentives for solar and other renewable energy technologies is dwarfed by those received by the oil, gas and nuclear industries. If solar is ever to make up a significant share of the nation's energy supply, it needs to compete on a level playing field, which is why financial incentives are so important. The federal ITC, which covers 30 percent of the upfront cost of solar, has been a major driver of residential and commercial solar growth.

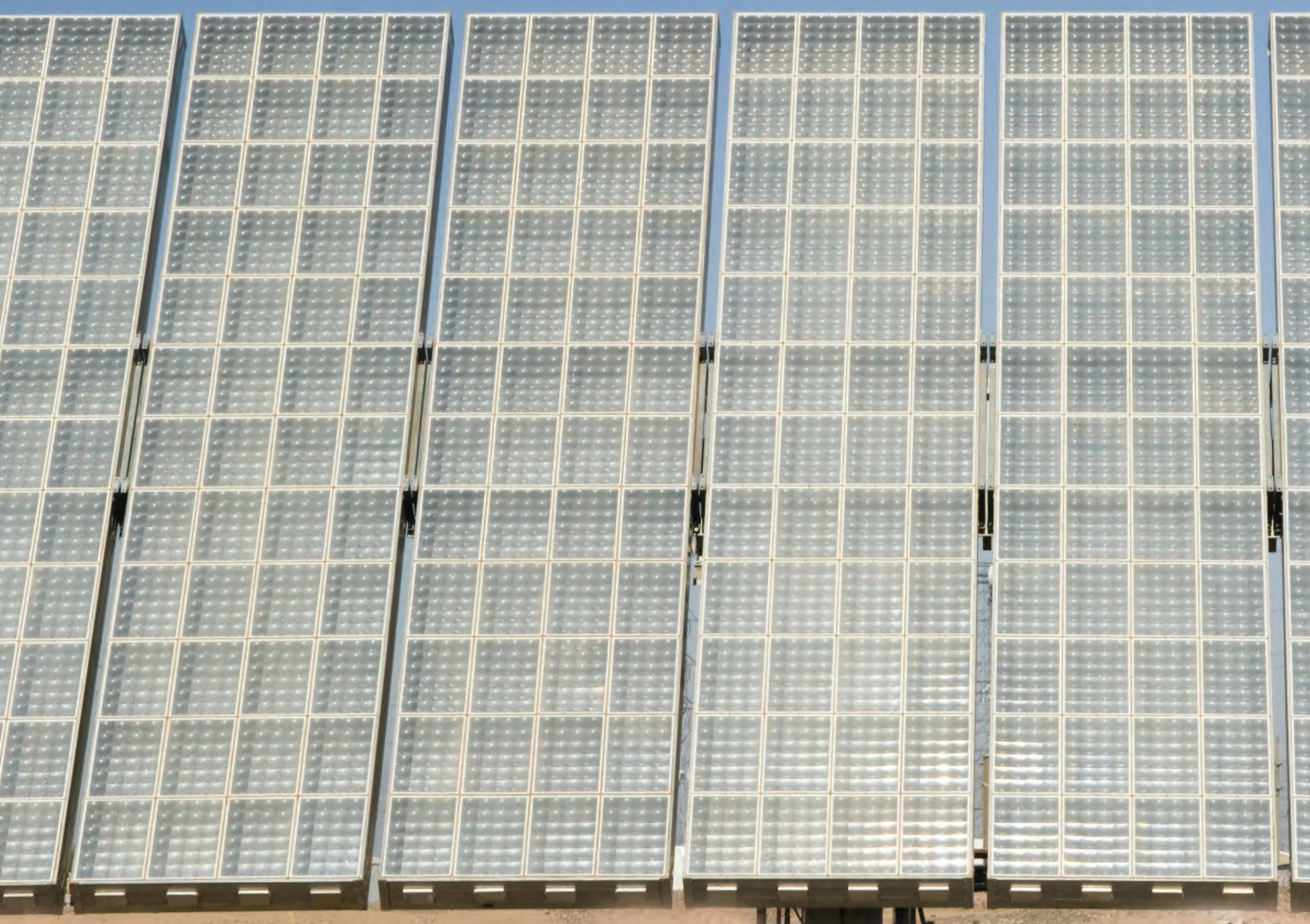
SEIA estimates that since its implementation in 2006, the ITC has helped annual solar installation grow by over 1,600 percent -- a compound annual growth rate of 76 percent. However, the ITC is slated to step down to 10 percent at the end of 2016, which many predict will result in a temporary contraction in the solar industry. As mentioned, President Obama has proposed permanently extending the ITC, which would play a major role in incentivizing homeowners to install solar beyond the end of 2016. Let's be clear though: the ITC step down, if it occurs, will slow down the growth of the industry, not kill it. The solar industry has done a remarkable job of reducing cost. The step down will mean that an industry that is great for American jobs and environmental stewardship slows down, rather than speeds up.

Another important element in incentivizing solar is state programs. While residential solar was competitive in more than 10 states in 2014 without state subsidies, state incentives remain an important driver of solar growth. One important state incentive is SREC (Solar Renewable Energy Certificate) programs. Under such programs, homeowners earn an SREC for the generation of each 1,000 kilowatt-hours of solar energy. SRECs are then purchased by utilities to help them satisfy state mandates requiring them to secure a specific portion of their electricity from solar. The SREC, which is sold separately from the electricity itself, represents the solar aspect of the electricity produced, with the value being set by the market based on supply and demand. The SREC model has been a very effective driver of solar growth and will continue to have a significant impact in years to come. While many states have implemented SREC programs, the expansion of such programs, or similar programs, to the states that do not yet have them would help to further speed the adoption of solar, as would refinements and improvements to existing SREC programs.

HUDSON CLEAN ENERGY is a leading private equity and infrastructure firm based in Teaneck, N.J. making privately negotiated investments in the dynamic and high-growth clean energy industry. Global in scope, Hudson is dedicated to investing exclusively in renewable power, alternative fuels and energy-smart technologies, in sectors that include wind and solar energy, biofuels, biomass, geothermal energy, energy efficiency and storage.

Turning to ultra-high concentrations to increase the competitiveness of CPV

Slashing the cost of CPV will not come from just edging up efficiency: It will also result from introducing ultra-high concentrations and moving to streamlined, high-volume production. By Richard Stevenson.



IN SOLAR CIRCLES, if you want to generate some positive publicity, there is little that can beat the breaking of the solar efficiency record.

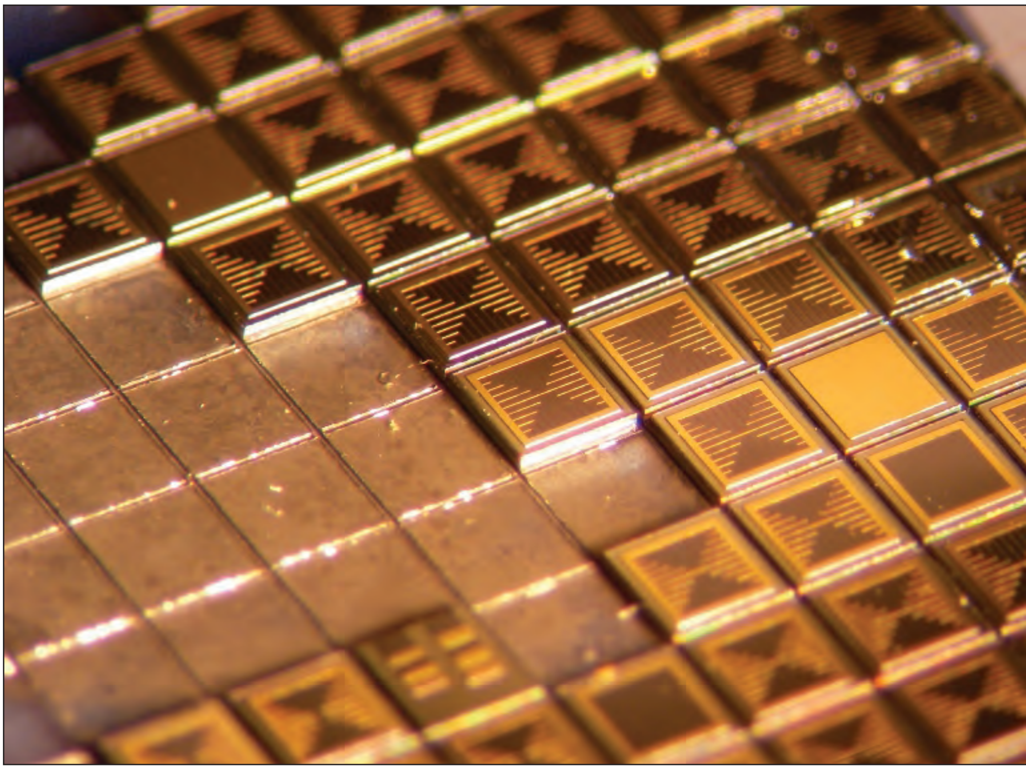
It is easy to understand why such success can hit the headlines. It is partly because the breaking of a record is a clear success story – and it is also because solar technology is rather pricey, and gains in efficiency promise to allow it to be far more competitive with the likes of coal, oil and gas.

However, boosting efficiency is not the only way to bring down the cost of solar energy generation, and in the case of concentrating photovoltaics (CPVs), there are two other levers that can deliver far greater gains. One route for slashing costs is to move to ultra-high levels of concentration – that is, 1000 suns or more – and the other is to increase manufacturing volumes and streamline production.

Championing the adoption of both these approaches is Carlos Algora, Head of the III-V Semiconductors Group at the Solar Energy Institute of the Technical University of Madrid (IES-UPM). Thanks to the efforts of him and his team, those working in this field can benefit from calculations for determining how the cost of electrical generation for CPV systems depends on efficiency, the level of concentration, and a factor that Algora refers to as 'learning'.

The latter factor, 'learning', encompasses a variety of cost-reducing mechanisms. They include the fall in costs that occurs as manufacturing ramps up, and engineers involved with this introduce new approaches for cutting costs – and learning also includes the trimming of costs that result from the use of mass production plants and the negotiation of attractive discounts from suppliers.

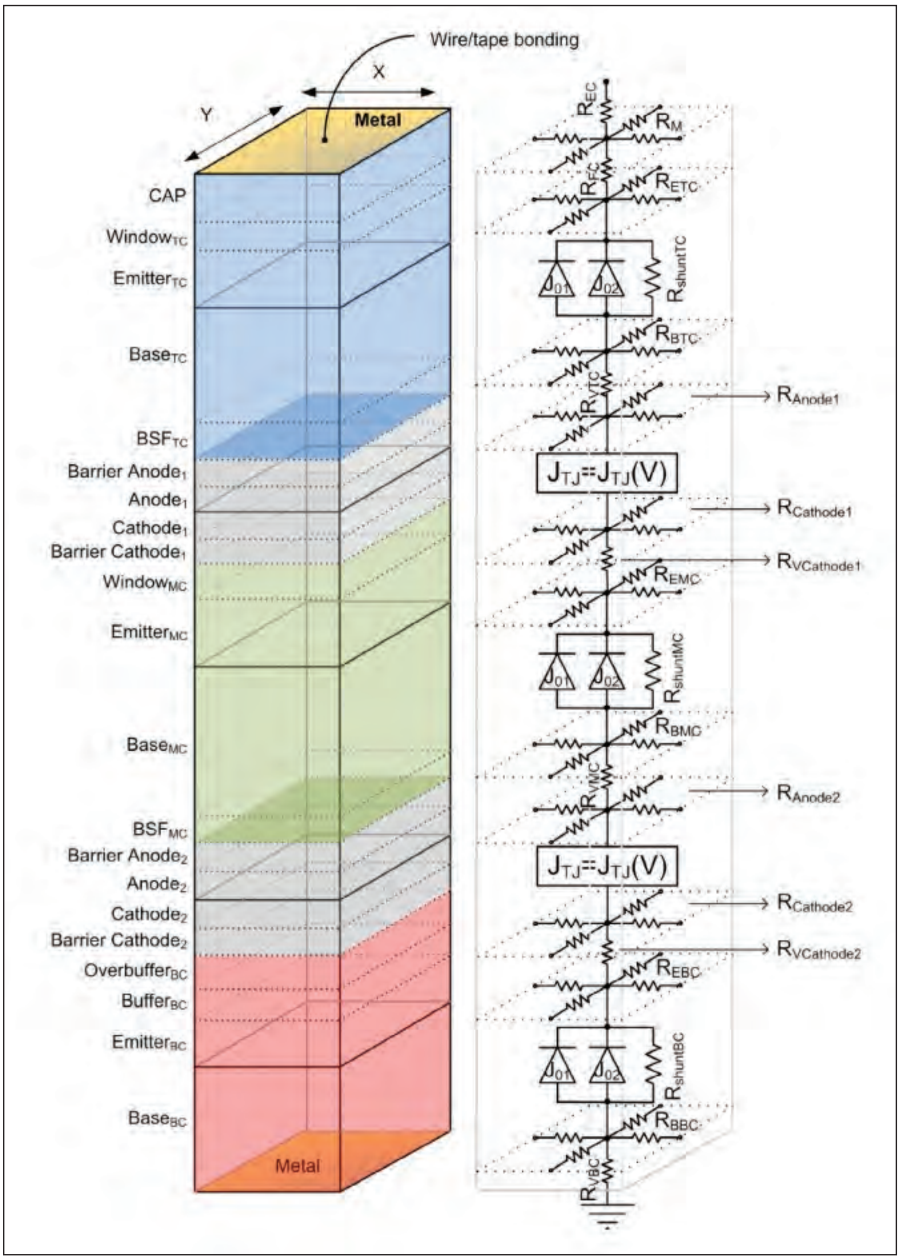
Calculations including all of these factors are carried out by considering a starting



1 mm2 GaInP/GaInAs/Ge triple-junction solar cells developed by the III-V Semiconductors Group of IES-UPM. Calibrated efficiency of these devices is 39.2 percent.

point of low-volume production, such as 1 MW, and efforts are made to determine how far costs will fall as production climbs to far higher values, such as 1 GW.

"What is important is that we apply different learning coefficients depending on the components of the CPV system," argues Algora. This means that learning associated with optoelectronics is applied to secondary optics, while the learning of motors and related components is used for trackers. The most recent set of calculations by Algora and his co-workers have determined the dividends paid by learning, higher concentrations and increasing efficiency. To judge the level of cost reduction, keep in mind a baseline figure – installation costs of 2.40 Euro-per-Watt-peak for a 500 suns CPV plant of one megawatt employing 36 percent efficiency cells. Increasing cell efficiency will obviously bring this installation cost down, but even raising efficiency to a jaw-dropping 50 percent – 4 percent above today's efficiency record – will only deliver a fall in costs to 1.75 Euro-per-Watt-peak, according to the calculations. Such gains are possible just through learning, however, and if concentration is increased to 1000 suns, it is possible to do even better, reaching Euro-per-Watt-peak values of 1.30-1.45. But most encouraging of all, if the three levers of efficiency, concentration and learning are pulled in unison, it is possible for post-learning generation costs to nudge 0.8 Euro-per-Watt-peak at 1000 suns.



The structure of a triple junction solar cell unit under the front contact (left figure) and the corresponding 3D distributed model (right figure) developed at IES-UPM.

Look carefully at these calculations and you will find a hierarchy of factors influencing the cost of CPV: first learning, second the level of concentration, and third efficiency. But the bad news is that the factor that can deliver the biggest benefit, learning, cannot be the initial driver to lower costs. That's because it will only be possible to draw on the benefits of learning by first increasing demand for CPV, which must be spurred by moves to higher efficiencies and concentrations.

Rebuffing the critics

Although the benefits of moving to higher concentrations are clear from these calculations, naysayers may argue that there are many reasons why greater focusing of the sunlight is not a great idea. They might point out that ultra-high concentrations would make it very tricky to construct a stable multi-junction cell that would not overheat and would provide a sufficiently low series resistance. And they might also claim that increasing the level of concentration would place very challenging demands on the pointing accuracy for the focusing of the sunlight – after all, the most widespread CPV system built by Soitec, which operates at 500 suns, has an acceptance angle of about 0.5 degrees.

Algora and his co-workers are rebuffing these criticisms by designing and manufacturing new cells that work better at high concentrations. They are designed to work with already available high-performance focusing elements for ultra-high concentrations, such as those developed by LPI. "The market is dominated by the classical Fresnel lens, which is not specifically developed for CPV," argues Algora.

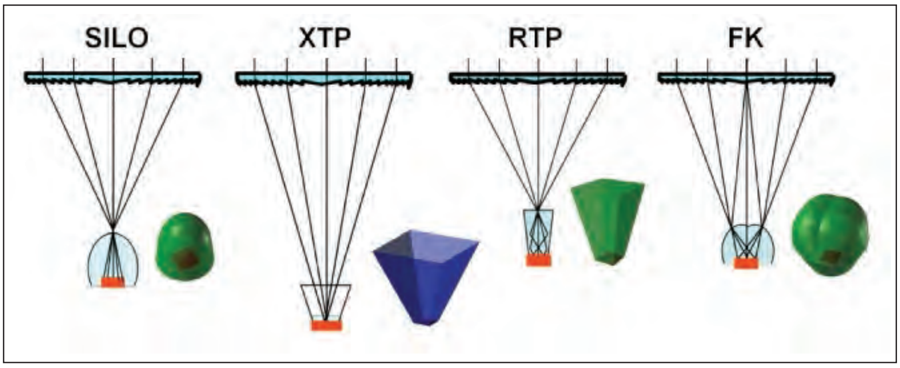
With more appropriate optics, an acceptance angle of around 1 degree at concentrations of 1000-2000 suns is possible. The rub is a move to two-stage optics, but even this has an upside: With secondary optics, an optical element covers the cell, protecting it from the environment, so reliability is further increased.

Another advantage of introducing a new optical design is that it can improve the level of uniformity of concentration impinging on the cell. Algora says that about ten years ago the situation was terrible, with non-uniformity (peak-to-average) factors of typically four or five at ultra high concentrations. Currently, this situation has improved with peak-to-average factors of now about 1.5-2.0. This means that when optics are purchased today for building CPV modules operating at 1000 suns, at the centre of the cell the level of concentration can be 1.5-2.0 times this. And that is a problem, because many of the cells designed to operate at 1000 suns have an efficiency that drops off a cliff, rather than slowly decreasing at higher values.

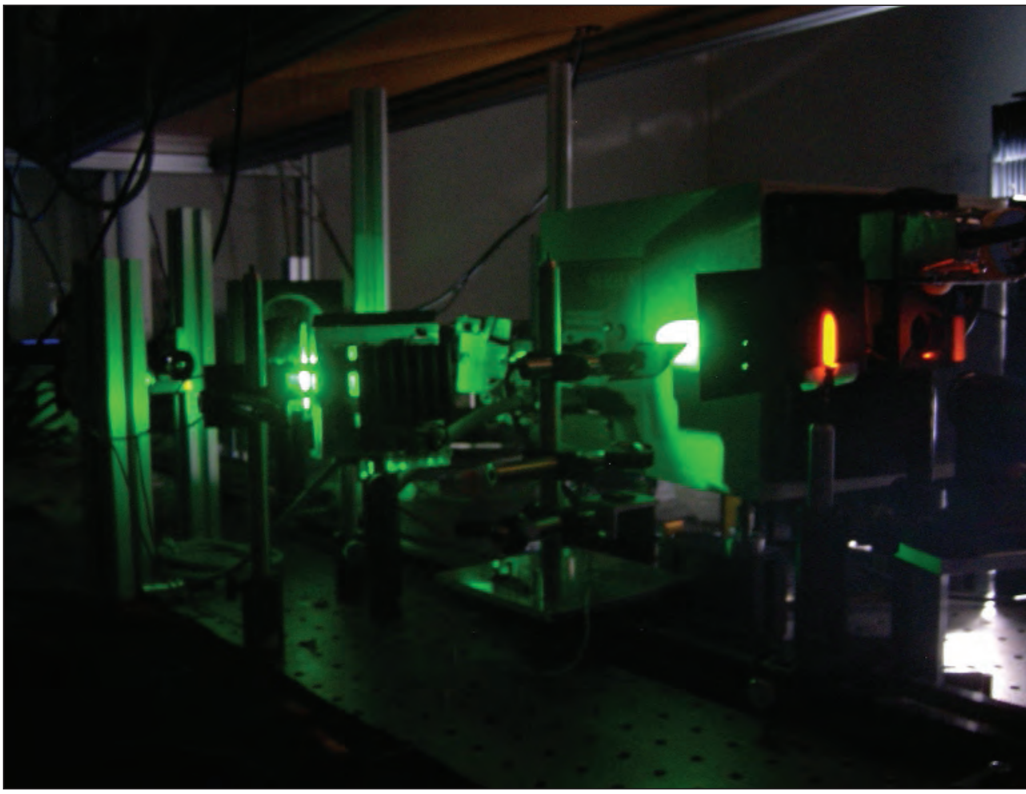
What's more, champion cells rarely give their best at 1000 suns: Soitec's 46 percent efficiency four-junction, wafer-bonded cell produced its best performance at 508 suns, while Sharp's inverted metamorphic structure delivered its peak efficiency of 44.4 percent at 302 suns and Spire's device topped out at 42.3 percent at 406 suns. However, a peak efficiency at higher concentrations is possible.

For example, the West-coast start-up Solar Junction has produced triple-junction devices delivering 44 percent efficiency at 947 suns, and the IES-UPM team has produced even higher values for concentration at peak efficiency with cells sporting fewer junctions: it has reported 26.2 percent efficiency at 1004 suns for a GaAs single-junction solar cell and 32.6 percent efficiency at 1026 suns for a GaInP/GaAs dual-junction solar cell.

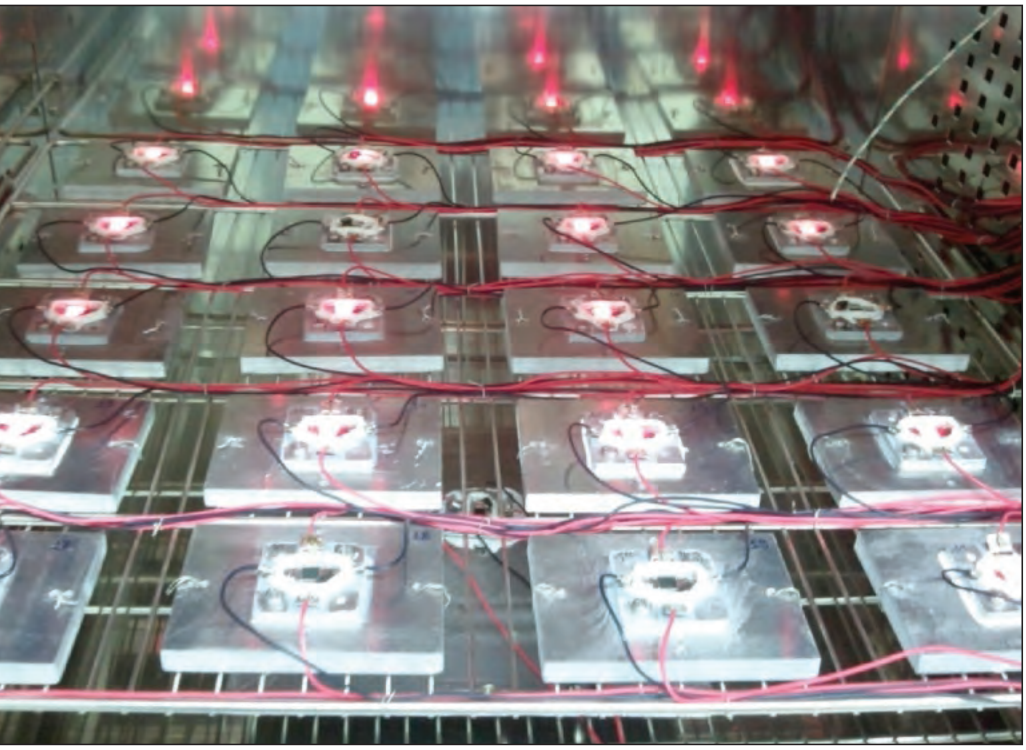
To those that believe over-heating of the cell could be a concern at ultra-high concentrations, Algora counters by pointing out that if the cell is small enough, there isn't even the need for active cooling. According to him, at 1000 suns the light power density impinging on the cell is 1 MW/m^2, so for a cell with a surface area of 1 mm^2, incident power is just 1 W. If 40 percent of this energy is converted into electricity, that



Diagonal cross sections of different CPV systems with secondary optics elements. From left to right: Secondary lens producing Köhler integration with 1-fold (SILO), truncated inverted pyramid mirror (XTP), truncated inverted pyramid glass (RTP) and secondary lens delivering Köhler integration with 4-fold (FK). All the elements have been simulated with the 3D distributed model of IES-UPM.



The characterization setup at IES-UPM for measuring the electro-optical properties of multi-junction solar cells



A temperature-accelerated life test of commercial triple solar cells carried out at IES-UPM to assess the reliability of the devices.

leaves 600 mW generating heat, which is easy to extract.
With small cells, one big issue today is laying hands on product. Algora says that in the brochures of the main solar cell manufacturers, the smaller solar cells are 5 mm by 5 mm or 3 mm by 3 mm. Such cells are designed to operate at 500 suns, which represents the biggest market for CPV, and in this realm thermal management is not such an issue. However, as more CPV system makers move to ultra-high concentrations, availability of smaller cells should rise.

Carrying currents

Moving to concentrations of 1000 suns or more places additional demands on the tunnel-junctions connecting the cells. These current-carrying bridges must not limit the flow of charge through the cells, so they should ideally have a peak current density in excess of 30 A cm^{-2} – this capability can accommodate currents associated with concentrations of up to 2,000 suns.

While offering this level of performance, the voltage drop across the tunnel-junction should be as small as possible, in order to realise as high an efficiency as possible. Orchestrating efforts to develop a high-quality tunnel junction is Algora's colleague, Enrique Barrigón. He explains that the material used to make the tunnel-junction governs the peak current density. "In order to have high peak current densities, you should use low bandgap materials, but that introduces a limitation into your design." That limitation is light absorption, which drags down cell efficiency of the subcell beneath the tunnel junction.

It is possible to overcome this conundrum with a special tunnel junction designed by the IES-UPM team that is built from the pairing of *p*-type, heavily doped AlGaAs and *n*-type, heavily doped GaInP. "It has a very high peak current density, and at the same time it is transparent for the light going into the middle cell."

To reach such a high current density – it is initially 996 A cm^{-2}, and falls to 235 A cm^{-2} after a thermal annealing step that simulates the growth of additional sub-cells – traps must be present in the structure. "If you try to simulate the behaviour of your tunnel junctions, it is impossible to get such high peak current densities unless you introduce some trap defects that enable the tunnelling," explains Barrigón.

Optimisation of the multi-junction solar cell also requires optimisation of other aspects of the device, such as the contacts. Algora and his team have been active in this area, developing a three-dimensional distributed model that simulates the operation of the solar cell at real conditions.

"It is compulsory to go towards a distributed model, because inside a concentrator the solar cell experiences unhomogeneous illumination in terms of intensity, chromatic aberration, etc," explains Algora. Due to these differences, there are variations in voltage losses and photocurrents, but with the distributed model it is still possible to optimise the design of the front metal grid, current matching among the subcells and the solar cell dimensions. "It is a very useful model when you go towards the real world," claims Algora.

While undertaking all this work, the Spanish academic has been a vehement campaigner for improving the manufacturing process. Since 1997 he has been advocating a move to an LED-like approach to making CPV cells and modules that will allow a trimming of the cost of this technology. He holds a Spanish patent related to this that was granted in 2000, and he and his team have collaborated with Semprius, a pioneer of ultra-high concentrations that employs 1,111 suns on cells with sides of 0.6 mm (see *Compound Semiconductor*, July 2014, p. 34).

Algora believes that the LED industry can offer some insights into multi-junction reliability. Both species of device may incorporate similar III-V materials, and

> "Giving rise to further optimism, current densities in LEDs are higher than those in multi-junction cells operating at ultra-high concentrations. However, there is good reason for caution at this stage: Since CPV systems need to operate for 30 years or more, the cells must have lifetimes around two times that of LEDs"

with lifetimes of 50,000-100,000 hours, the reliability of the LED is encouraging for the future of CPV.

Giving rise to further optimism, current densities in LEDs are higher than those in multi-junction cells operating at ultra-high concentrations. However, there is good reason for caution at this stage: Since CPV systems need to operate for 30 years or more, the cells must have lifetimes around two times that of LEDs.

Looking ahead

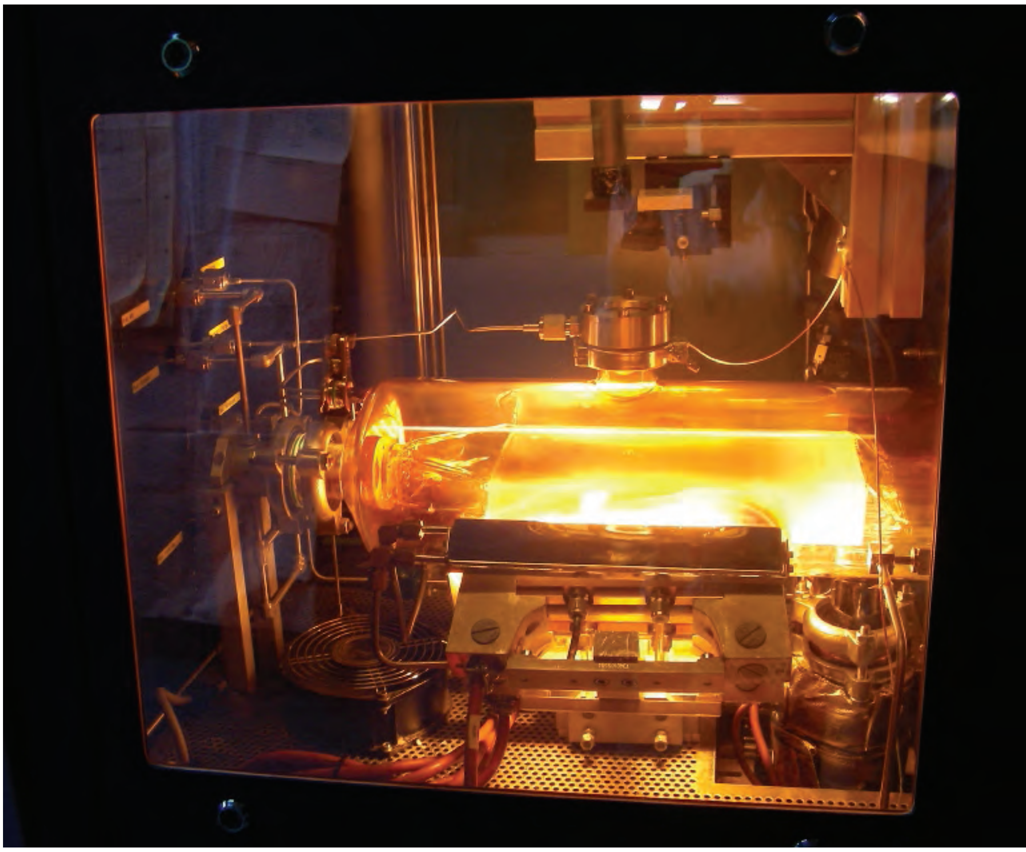
While there are compelling arguments for strong growth of a CPV industry sporting ultra-high concentrations, Algora believes that will not happen overnight, with success hinging on both the future of the PV industry at large, and the CPV industry operating at more modest concentrations. "We have the technology in the main components – solar cells, optics, trackers and modules – and we have a very brilliant future regarding improvement in all of these aspects, mainly solar efficiency," argues Algora.

However, for sales to rise, he believes that the cost of the technology must drop to less than that associated with silicon flat-plate technology (he says that today the cost of CPV should be as little as 20-30 percent more expensive than silicon if installed in places with 20-30 percent higher direct irradiance than those usually used for silicon systems).

The fastest way for CPV to close the gap with silicon is learning, and according to Algora, learning means production of close to half a gigawatt, or a gigawatt. At present the only companies able to do that are Soitec and Suncore, so for the benefits of learning to materialise, shipments of CPV systems from these companies must climb over the next years.

If Soitec and Suncore are successful, this will allow companies with different approaches to CPV to make an impact, including those pioneering ultra-high concentrations. "These new actors will benefit from a lower price of trackers and a low price of optics," says Algora.

"But now, CPV is in the hands of these two biggest companies, so we would very much like the success of these two companies."



The MOCVD reactor at IES-UPM.

Will the solar rooftop lease model ever take off in India?

Affordability has always been a bottleneck to the large scale adoption of solar in India. Akhilesh Magal tells Solar International why there have been roadblocks to success.

SUNEDISON was perhaps the earliest example of the solar lease model – a model where rooftop owners did not have to own the system by making a onetime upfront payment. The lease model allowed consumers to pay-as-you-go.

The model has been very successful among customers, especially in America. According to industry reports, the solar leasing model accounted for 10 percent of all solar systems sold in California in 2007. This number shot up to 75 percent by 2012. Many other states across the U.S. are witnessing a similar boom in the solar leasing (or third party ownership) market.

Why should India be any different? Affordability has always been a bottleneck in India. With good radiation and high electricity prices in certain pockets, the 'Third Party Ownership' (TPO) model appears to be the perfect solution for consumers who want to shift to solar at no upfront costs. The question remains, why has the market not taken off? I think there are three key reasons:

1.No clear regulations on third party ownership

Although several states in India have announced net metering benefits, there are only a handful of states that allow third party ownership. This means that Feed-in Tariffs (FiT) and other energy banking incentives cannot be passed on to the investor. This complicates the tri-party agreement between the consumer, the investor and the government agency and these states are not clear how to handle this. In most other states, third party ownership is simply not officially recognized.

As of now, 12 Indian states have announced rooftop policies with some incentives - only four recognize third party ownership. Most importantly, Maharashtra – the state with some of the highest consumer prices for electricity in India – and therefore the largest market for rooftop solar – does not have a net metering policy (although the draft order is in the pipeline). Connecting to the grid is fraught with regulatory risk. Nobody exactly knows if such models are legally allowed or not. Often, it is left to the discretion of the utility engineer to approve or disapprove of these models. The solution to this regulatory mish-mash should be a central regulation on net-metering by India's central electricity regulator (CERC) that formally recognizes such third party ownership models and clearly marks out the incentives and the money flow among the parties involved.

2. Long-term leases

This is perhaps the biggest challenge in India. Many commercial clients (such as IT companies in special economic zones) rent building space rather than own it. This means that such clients

do not own roof rights. This means that the agreement now needs to involve the building owner. Most building leases in India are between three to five years, which is too short a time for a profitable solar PPA.

What's more, India is in a dynamic phase of its economic development. Cities change rapidly and buildings are pulled down or frequently altered. In such a dynamic condition, no consumer wants to commit to a 25 year lease. Price predictability or energy security is often undervalued in India. People have an overexposure to change – and seem to be comfortable with it.

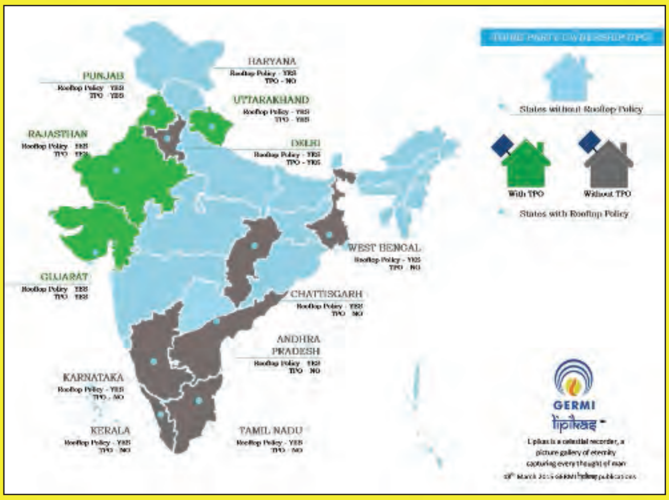
3. False promise of subsidies

The Government of India used to offer a one-time capital subsidy of 30 percent for rooftop systems (now reduced to 15 percent). Although this was meant to promote the rooftop market, it ended up hindering the market in the long-run. Once budget allocations ran out, consumers went on a wait and watch mode. Many installers, promised to 'arrange' for the subsidy – which never happened.

A much cleaner way of incentivizing the market is to announce tax incentives – in the form of income tax rebates for investments in solar energy. India's income tax rate is at 33 percent and allows tax deductibles up to INR 100,000 (this was raised to INR 440,000 in the recent financial budget).

To promote third party ownership, investors can be incentivized with tax breaks. Accelerated depreciation is already being allowed, where 80percent of the asset value can be depreciated in the first year. This is however useful only to investors that already have fat pockets from other businesses. Investors (especially foreign investors) that are looking to fund projects on a Special Purpose Vehicle (SPV) basis cannot use the AD benefit. The government could consider, giving a further discount on the Minimum Alternate Tax (MAT) for solar companies.

India needs to make a transition from a government driven market to a market driven by consumers and suppliers. This



can only be possible when developers and consumers connect directly to each other to forge a vibrant rooftop solar market. I believe that the Third Party Ownership (TPO) model is crucial in the link to this transition – and all the more reason why governments across India need to get their act together to eliminate the barriers that I discussed above.

Akhilesh Magal is the Head Advisor – Solar Energy for the Gujarat Energy Research and Management Institute (GERMI), an institute dedicated to research in the fields of, solar energy, energy efficiency, environment and petroleum research. He is an environment engineer from Carnegie Mellon University and is an expert on solar policies and grid integration of renewable energy. He can be reached at akhilesh.m@germi.res.in or @ akhileshmagal

Cost reduction in the solar industry

Andrew Barron discusses new processes as a route to attaining cost reduction targets for photovoltaic manufacturing.

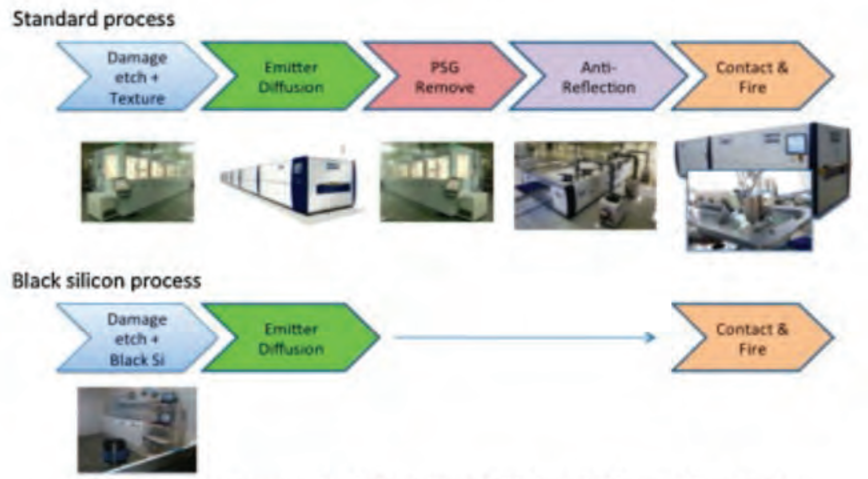
FOR SOLAR ENERGY to become cost-competitive with energy derived from fossil fuels, we must either increase their efficiency or significantly reduce the cost of manufacture. In other words we need to consider the cost/kW hour as we do with coal, oil, gas, and nuclear power, rather than just quantum efficiency under ideal laboratory conditions.

One area that has been focused on with regard to reduced manufacturing costs is to move away from silicon photovoltaic (PV) technologies to thin film (e.g., CIGS, CdTe) and 'third generation' solar (e.g., DSSC, OPV) devices. While it is clear that these will remain intensely researched PV technologies, the infrastructure of the solar industry remains irrefutably based on the production of 'first generation' silicon cells. Irrespective of the adoption of potentially disruptive next generation PV manufacturing technologies, with 85–90 percent of a global PV market share worth ca. $100 billion, Si-based PV will continue as an increasingly prolific component of the World's energy security. Government tariff incentives and low prices for PV have accelerated demand in China and the USA, while similar drivers across Europe and industry overcapacity have seen prices for silicon solar modules drop to around $1 per watt without undue negative impact on manufacturers' operating margins. Advances in wafer, cell and module manufacturing, lower electrical conversion losses and improvements in cell efficiencies have also driven cost reduction. Despite these advances, both the US and China have a stated goal of further reducing the cost of solar-generated electricity. If we consider the manufacturing process of the cell alone (rather than the panel and the instillation) then there are two areas in which cost reduction could occur: raw materials and consumables or the process steps. It turns out that research into higher cell efficiencies may be the key to reducing the number of process steps and hence manufacturing costs.

A key requirement for an efficient solar cell is a low surface reflectance to maximize the amount of incident photons absorbed by the semiconductor to convert the incident light into electrical energy. The use of an anti-reflection (AR) coating is used to suppress the reflection of the solar cell surface by forming destructive interference of incident light. The most common AR coating for Si PV is plasma-enhanced chemical vapor deposition (PECVD) silicon nitride (SiNx), which has a reflectance of about 2 percent as compared to 40 percent for a polished silicon wafer. Since their functionality is based on a quarter-wavelength coating, traditional AR layers are limited in use because reduction of the reflection occurs for only a narrow range of light wavelength and incident angle.

A potential replacement for the conventional AR coating, so-called “black silicon” (b-Si), was first reported by Jansen et al. Black silicon is a type of porous silicon whose surface morphology provides a graded refractive index between the silicon surface of the device and air, that results in a low reflectivity (~1 percent) and a correspondingly high absorption of visible light.

Black silicon has been successfully fabricated by several different methods including: laser chemical etching, pulsed electrochemical etching, reactive ion etching, and fast atom beam etching. However, these techniques need either expensive instruments with high energy consumption or complicated fabricating processes, making them unfavourable for industrial applications. As an alternative, metal-assisted chemical etching (MACE) methods were developed which generally includes two steps: metal deposition and electroless chemical etching. In the metal deposition step, a metal, such as Au, Ag, and Pt is deposited on the Si surface usually as nanoparticles (NPs). The metal NPs attract electrons from the silicon surface promoting the oxidation to SiO2 in the presence of an appropriate oxidant. In the electroless chemical etching step, the as-formed SiO2 is etched away by HF and a pit is produced under each NP. The remaining Si substrate forms b-Si that consists of a highly porous structure.



Schematic of the process flow for a traditional SiNx based AR coated Si cell and a b-Si equivalent.

To further simplify the fabrication process of b-Si, one-step MACE methods based on the two-step method have been developed. However, developing a lower cost alternative metal precursor for the metal-assisted chemical etching method to further cut down the fabrication cost of b-Si is of interest. Cu NPs have been utilized for fabricating porous Si with a two-step Cu-assisted etching method, but instead of the desirable nanopores only shallow pits were formed on the Si surface limiting the effectiveness of the surface as an AR layer.

Based upon results with the one-step Ag-catalysed system it appeared that the shallow pit morphology was due to the lack of a component in the etchant solutions to reduce Cu_2+ ions to Cu0 and thus increase/maintain the size of the NPs. This is readily overcome by the replacement of H2O2 in the typical MACE system with H3PO3 as a reducing agent in a $Cu(NO_3)_2/H_3PO_3$/HF/H2O system. The result is the formation of b-Si surfaces using low cost chemicals. Furthermore, if a b-Si process is used in combination with the phosphosilicate glass (PSG) films formed during doping to form the active n/p junction within the solar cell, then there is potential for the removal of several steps in the production process. Figure shows a comparison of the process steps used in present Si cell manufacturing versus those that would be needed for a b-Si functionalized cell. As may be seen the number of steps can be decreased. It is in the removal of multiple steps in the manufacturing process and the associated costs of the chemicals, equipment and energy.

Thus, b-Si could eliminate a lot of complexity and significantly reduce costs. Using a detailed, bottom-up manufacturing cost estimating methodology, as used by National Renewable Energy Laboratory (NREL), which takes into account materials, labor and energy costs, an approximate cost for traditional processing (excluding the wafer substrate) can be made of $0.17/watt.

Through the replacement of PSG removal step and the typical SiNx antireflective coating a cost of $0.135/watt is estimated. While this difference may sound small it represents approximately 20 percent cost reduction saving. It is this type of cost saving through the development of new materials processes that offer the best route to grid parity of solar with traditional carbon based energy sources.

Previously published in Materials Today.

The truth behind the numbers
a warning to the PV community

Professor Ravi Silva, Director of the University of Surrey's Advanced Technology Institute discusses the importance of accurate measurements in solar cells which would form the basis of green energy in future smart cities and to power the internet-of-things.

IT IS NEARLY 40 years since the discovery of electrically conducting polymers by Professor Alan Heeger, Nobel Laureate in Chemistry, and nearly 30 years since the first organic heterojunction photovoltaic device was reported (Tang 1986). Given the subsequent vast concentration of research activity undertaken around the world, organic (including organic-inorganic hybrid) solar cell technology is now a maturing technology. PV advancements in the last decade have gathered breakneck pace, with academic breakthroughs seemingly progressing in increasingly rapid timescales.

The drive for cost-effective, clean technology has resulted in a 'race to the top' for the PV research community. There have been innumerable headlines recently that point to 'hero' devices which seemingly deliver 'miracle' discoveries. Whilst the industry is inclined to look towards the positive, there are issues in giving the 'benefit of the doubt' to these reports. The reporting of OPV device and material performance has mirrored that of a number of other technologies in recent years, where discovery is hyped by researchers and, after initial intense interest, consequently becomes undervalued and even ridiculed by industrial and commercial representatives.

This is an issue that has been undermining the solar cell research community, particularly in relation to solution-processed organic and inorganic photovoltaics. Based on a study by Zimmerman et al, carried out on 375 publications in peer-reviewed journals, the authors identified (by comparing the short-circuit current density obtained through the current–voltage sweep versus quantum efficiency measurements) that a significant fraction (over 37 percent) of publications overestimated device performance.

This 'race to the top' has uncovered not only major breakthroughs, but an industry issue - that robust reporting methodologies and measurement protocols are not being adopted by a large fraction of the organic as well as organic-inorganic photovoltaics research community. This may be as a result of the fact that during the initial stages of PV development and discovery there was no clear understanding on the measurement protocols for this new technology. Over the last decade, a better understanding has emerged on how the performance of an OPV cell can be more accurately measured.

It is now nearly a decade since Shrotriya and co-workers described the accurate measurement procedures for characterising organic photovoltaics. Despite these guidelines, it is clear that the proposed methodology and protocols are not being adopted by a large fraction of the photovoltaic research community. With the ever-increasing focus on obtaining higher device power conversion efficiencies (PCEs) for organic photovoltaics (OPV), there is a need to ensure devices are measured accurately. Reproducible results are required to compare data across different research institutions and countries and translate these improvements to real-world commercial production. Typically, the devices reported within this 'race to the top' are single devices with little evidence of repeatability or simple statistical analysis of a sample population. This gives an overestimate

of the current performance capabilities, which consequently undermines the technology in the eyes of industry that would ultimately take up the development and manufacturing of OPVs for the open market.

National measurement institutes do offer standardised measurement facilities for ascertaining PV device performance, but these are invariably expensive as well as time consuming. Given that a researcher may change the formulation of their OPV layers on a weekly basis, the process is

not cost effective for researchers working on new ideas. This causes research groups to report their new discoveries against similar reference devices fabricated in their laboratories, with all the associated variation in production and measurement quality. Furthermore, in order for such a certification to be achieved, the researchers must be able to adequately protect the device from degradation in between the period of fabrication and measurement by the certifying institute.

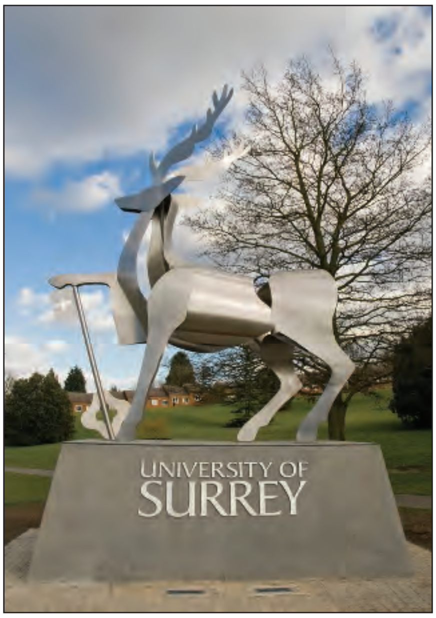
Additionally, although the architectures of organic photovoltaics can be complex, small changes to one part of the device can have an effect on performance which is not always beneficial. There needs to be a framework for researchers to benchmark their results against one another to ascertain the effects of incremental changes to a device architecture. The consequences of not being able to deliver on performance targets when devices are scaled or under prototyping can result in expensive and decisions later in the development cycle.

Clearly, the research community should be very careful when making claims, as any incorrect belief formed in the development of the technology inevitably lead to a lack of faith and confidence in the field and everyone working in it. Similarly, policy makers and funders need to note the time spans required to deliver real-world products and examine any proposed shortcuts to the cycle with a critical eye from a manufacturing perspective. Take the case of crystalline silicon, a technology that took more than two decades to mature. Expecting solution-processed photovoltaic products to be purchased over the counter within a timescale of few years enters into the realm of fantasy, unfortunately headlines and expectations all point to this as reality.

Such problems may be overcome with greater involvement of interested PV manufacturers early on in the research cycle, bringing their experience in the targeted development of commercially applicable products, and the development of Europe-wide and global research networks in which standardised measurement and reporting procedures are defined, promoted and encouraged.

Furthermore, each institute should also ensure where possible that best practices are followed in completing measurements so that the status of the field and the research community is not undermined.

It is encouraging to note that this issue has also been picked up one of the pioneers in the field of silicon photovoltaics, Professor Martin Green who annually produces solar cells efficiency tables in the journal Progress in Photovoltaics for individual cells and



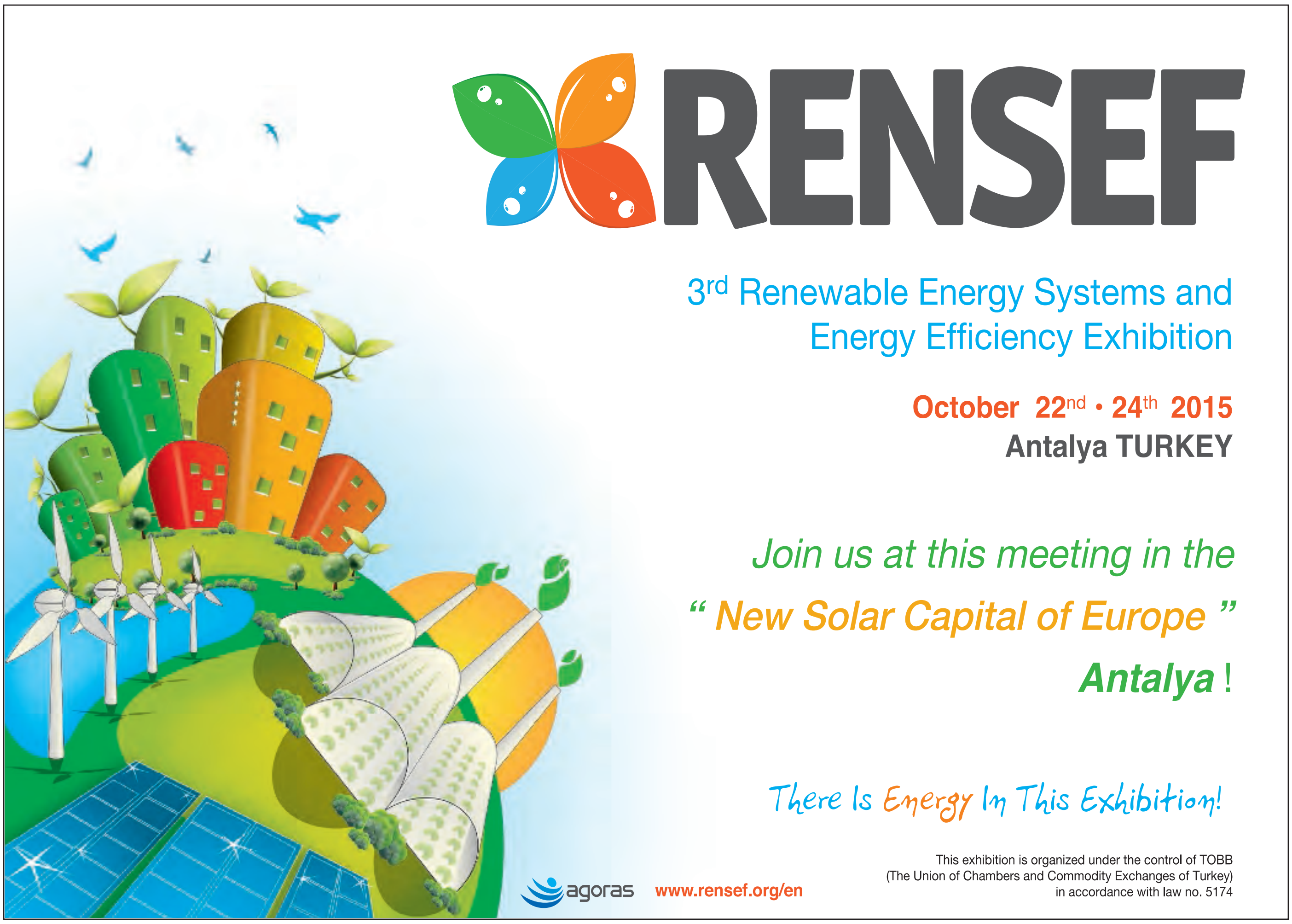
modules. The strict criteria followed by Professor Green (and co-authors) in producing these tables involve the need to verify the performance from an accredited certifying body such as the National Renewable Energy Labs in the USA as well as a minimum device area for specific solar technologies.

While certification may be a difficult practice for most labs, researchers should adhere to strict protocols in reporting ground breaking results to ensure that the reputation of the field remains untainted. Solar cell technology has been a focus of the UK's Advance Technology Institute, at the University of Surrey since its inception in 2002. Its work, alongside industrial partners such as E.ON has focussed on the application of inorganic nanotubes and nanoparticles in organic PV devices. For example, working directly with industry has resulted in the integration of carbon nanotubes that act as additional charge generation sites which help increase the current extracted and improve overall device performance. Furthermore, the industrial collaboration has also ensured that the researchers at the Advanced Technology Institute focus on devices whose performance values are more realistically achievable during the transfer of knowledge from lab scale processes to the manufacturing plants.

Such practices have led to the participation of the ATI in the European Union funded SMARTONICS program which aims at developing a pilot plant for fabrication of organic photovoltaic modules. The concept of inorganics-in-organics was introduced to the PV community in 2013 by the group as 4G solar cells. This concept introduces a framework to form solution processable organic-inorganic multicomponent architectures for fabrication of high efficiency flexible devices. It might be that OPV will be an indispensable technology of the future, as ubiquitous in our cities as the materials used to build our homes and office blocks but, for that to be the case, we must be realistic in our performance estimates for those that will commercialise the technology and endeavour to accurately report and benchmark results with our competing colleagues.

Although the ultimate aim is a need to contribute to finding a solution to the renewable energy problem, it is imperative that the performances reported for photovoltaic technologies become aligned with a 'best practice' so that we can build on the excellent work carried out in laboratories around the world towards a greener and more sustainable future. In this regard, the researchers in the Advanced Technology Institute are looking forward to working closely with the 5G Innovation Centre at the University of Surrey to develop the first generation of energy harvesting components for the Internet of things with the aim of expanding the developments for application in future smart cities.

This article is based upon correspondence from the Advanced Technology Institute in the journal Nature Photonics, published April 9 2015.

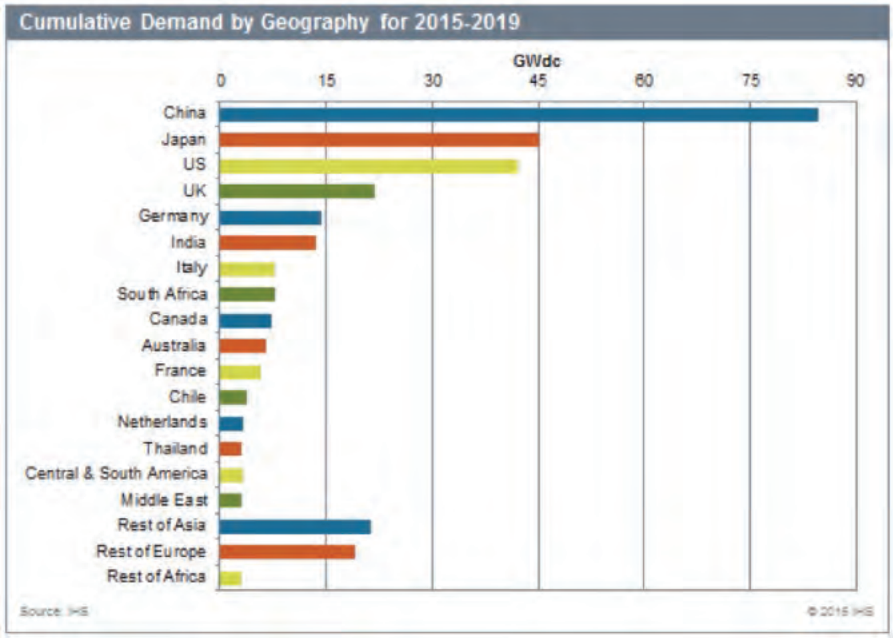

RENSEF
3rd Renewable Energy Systems and
Energy Efficiency Exhibition
October 22nd • 24th 2015
Antalya TURKEY
Join us at this meeting in the
" New Solar Capital of Europe "
Antalya !
There Is Energy In This Exhibition!
agoras
www.rensef.org/en
This exhibition is organized under the control of TOBB
(The Union of Chambers and Commodity Exchanges of Turkey)
in accordance with law no. 5174


Submit your Lab & Fab article
Research is the foundation for the growth of the solar industry.
If you want to highlight the important breakthroughs that you make, submit your latest research stories to either:
jackie.cannon@angelbc.com
It is imperative that Solar International remains a timely resource for this industry, so we are interested in highlighting recent work reported in academic papers.
Therefore, only consider writing a short piece highlighting your work if you have a journal paper that has been accepted and about to appear in press, or a paper that has been published within the last two months.
www.solar-international.net

IHS: Global solar PV capacity to reach nearly 500 GW in 2019

While global PV demand is projected to grow steadily, the increasing number of country markets at the gigawatt level will help to reduce demand volatility.

TOTAL GLOBAL solar photovoltaic (PV) capacity is forecast to reach 498 gigawatts (GW) in 2019, which is 177 percent higher than 2014, according to IHS. While total global solar PV demand is projected to grow steadily, the large number of discrete country markets at the gigawatt-level will help reduce demand volatility.



Source: IHS Marketbuzz, 2015.

"Last year, the market began to shift toward a more supply-driven market, characterized by high utilization rates, following the more demand-driven market that led to PV manufacturing consolidation," said Susanne von Aichberger, solar industry analyst for IHS Technology, formerly Solarbuzz. "This trend is expected to continue through to 2019, when the utilization rate at module production is projected exceed the peak utilization rate reached in 2010, when the global market experienced explosive growth."

Based on findings of the latest IHS Marketbuzz report, global solar demand is expected to reach 75 GW in 2019, which is 66 percent higher than in 2014. Last year, the largest global markets were China and Japan, which together accounted for half of total demand. The United States, U.K. and Germany together accounted for another quarter of total demand.

"In the five years between 2015 and 2019, IHS expects that 11 global markets will exceed the average annual demand level of 1 gigawatt," von Aichberger said. "This large number of country markets reduces the risk of another explosion in the global PV market and of an overly strong capacity build-up. An increasing number of markets are entering the post-feed-in-tariff phase and embracing the integration of PV into the electricity market, which will help the market to avoid boom-and-bust situations."

Average selling prices (ASPs) of standard c-Si modules (i.e., c-Si excluding Super Mono) are forecast to decline by 27 percent between 2015 and 2019, reaching $0.45 per watt (W). The share of thin-film modules produced is projected to decline from 8 percent in 2014 to 7 percent this year -- the lowest share recorded since 2010, when c-Si module shortages opened the door for thin-film technology to reach a production share of 15 percent.

Due to the expected supply-driven market situation, the share of thin film is projected to remain at 7 percent through 2019. Within the thin film category, growth is likely to be driven by cadmium telluride (CdTe) and copper indium gallium selenide (CIGS). By 2019, annual production of a-Si modules is projected to fall to less than half of its 2014 level.

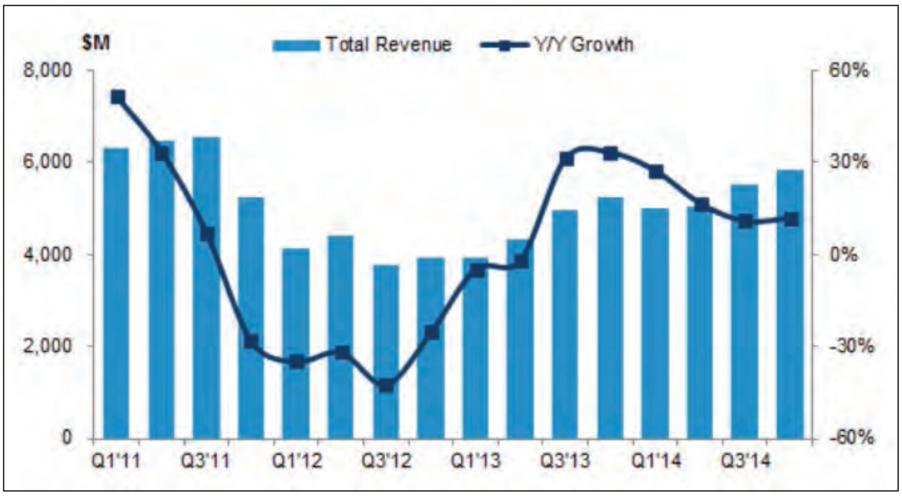
Revenue for leading solar PV module suppliers reached three-year high in Q4 2014

Total module revenue of the top 20 global solar PV suppliers in the fourth quarter reached its highest level since 2011, despite the effect of negative exchange rates on average selling prices.

IHS has announced that quarterly solar photovoltaic (PV) module revenue (excluding processing service revenue) by the 20 leading global suppliers increased to $5.9 billion in the fourth quarter (Q4) of 2014.

According to findings in the company's latest Module Tracker Quarterly report, due to a sharp decline in module prices, quarterly revenues have not been higher, since the third quarter (Q3) of 2011.

Compared to Q4 2013, quarterly module revenue of the 20 leading suppliers increased 12 percent, driven by strong growth of their total module shipment volume, which reached 8.8 gigawatts (GW) in the fourth quarter of 2014. Full year 2014 module revenue by these suppliers also grew to $21.4 Billion.



Quarterly Solar PV Module Revenue of 20 Leading Suppliers
Source: Module Tracker Quarterly report, IHS, Inc.

"To fund their capacity expansion or acquisition, PV module suppliers must continuously increase their revenues," said Ray Lian, principal analyst for IHS Technology, formerly with Solarbuzz. "As these companies gain more market share, we can expect to see further industry consolidation."

Total module shipments from the 20 leading suppliers were the equivalent of 68 percent of global PV module demand in 2014, compared to only 60 percent in 2011. Both Trina Solar and Yingli Green Energy shipped more than 3 GW of modules in 2014. During Q4 2014, the average selling price (ASP) for modules was negatively affected by the strong appreciation of the U.S. dollar against most other currencies, as well as by the elevated share of modules shipped to China and other low-ASP regions. The blended ASP of the 20 leading suppliers decreased 4 percent in Q4, compared to the previous quarter.

Continuous cost reduction efforts, including module efficiency improvements, helped to mitigate declining ASPs. The blended module cost-of-goods-sold of the top 20 suppliers fell below $0.6 per watt for the first time, reaching just $0.58 per watt in the fourth quarter of 2014. Blended gross margins only slightly increased to 14 percent.

"PV module revenues of the 20 leading suppliers will continue to grow, as they benefit from both robust global PV demand growth and increasing market share," Lian said. "We expect them to reach historic revenue heights, as early as the fourth quarter of 2015."

Researchers enable solar cells to use more sunlight

Scientists report an improved component that will create a higher current.

SCIENTISTS of the University of Luxembourg and of the Japanese electronics company TDK report progress in photovoltaic research:they have improved a component that will enable solar cells to use more energy of the sun and thus create a higher current. The improvement concerns a conductive oxide film which now has more transparency in the infrared region. Attempts had been made before, but this is the first time that these films were prepared by a one-step process and, at the same time, stable in air.

"The films made at the University of Luxembourg have been exposed to air for one and half years and are still as conductive as when they were fresh prepared," says Prof. Susanne Siebentritt, head of the laboratory for photovoltaics at the University of Luxembourg. "It is a fantastic result, not only for solar cells, but also for a range of other technologies," she adds. Collaborators of this study were Dr. Mat j Hála, research associate in the laboratory for PV and Shohei Fujii and Yukari Inoue, visiting scientists from TDK.

Transparent conductive oxides are used in any device combining electronics and light, like LEDs, solar cells, photodetectors or even touch screens. They have the particularity to combine the properties of metals, which are the best electrical conductors known, with those of oxides, which usually are transparent but not conductive, as for example glass. In solar cells the film has to be conductive because it constitutes the upper electrode. At the same time it has to be transparent in order for sunlight to reach the layer underneath, where the current is formed.

The oxides forming this film can be made conductive by deliberately adding impurities. Zinc oxide with aluminium added is a widely used example. In this case, the aluminium adds free electrons to the zinc oxide which are responsible for the conductivity. However, these free electrons also absorb infrared light. That means that less sun energy can pass through.

The team of the University of Luxembourg and TDK have modified the process used to make the film in order to make pure zinc oxide more conductive. "Our

multidisciplinary team, benefitting from the exchange of knowledge across countries, had the idea to add an additional component -- another gas plasma -- in the so called sputter process. This makes the material conductive even without aluminium." explains Prof. Siebentritt.

This method enables to have less but faster moving free electrons. "With this result, the conductivity is similar to the one with aluminium, but it enables a much better transparency in the infrared region as less free electrons cause also less absorption. That makes solar cells more efficient," adds Dr. Mat j Hála. The findings are now published in the journal Progress in Photovoltaics.

solar INTERNATIONAL

Director & Editor of Solar Publishing Jackie Cannon
T: +44 (0)1923 690205 E: jackie.cannon@angelbc.com

Sales Manager Shehzad Munshi
T: +44 (0)1923 690215 E: shehzad.munshi@angelbc.com

Director of Logistics Sharon Cowley
T: +44 (0)1923 690200 E: sharon.cowley@angelbc.com

Design & Production Manager Mitch Gaynor
T: +44 (0)1923 690214 E: mitch.gaynor@angelbc.com

Circulation and Subscriptions
T: +44 (0)1923 690200 E: circ@angelbc.com

Directors:
Bill Dunlop Uprichard – CEO
Stephen Whitehurst – COO
Jan Smoothy – CFO
Jackie Cannon, Scott Adams, Sharon Cowley, Sukhi Bhadal, Jason Holloway

USA Representatives: Tom Brun, Tom Brun Media,
T: 724 539-2404, E: tbrun@brunmedia.com
Janice Jenkins, Tom Brun Media.
T: 724 929-3550, E: jjenkins@brunmedia.com

Japan Representative: Katsuhiro Ishii,
Ace Media Services Inc.,
T: 81-3-5691-3335 E: amskatsu@dream.com

China Representative: Parker Xu, Unionbandy Limited,
T: 86-755-83753881, E: xp@unionbandy.net

Published by: Angel Business Communications Ltd (London Office), Hannay House, 39 Clarendon Road, Watford, Herts WD17 1JA, UK

Registered Office: Angel Business Communications Ltd (Coventry) UK, Registration Number: 1972952

Angel BUSINESS COMMUNICATIONS PPA recycle When you have finished with this magazine please recycle it.

Solar International is published six times a year on a controlled circulation basis. Non-qualifying individuals can subscribe at: £96.00/€110 (UK & Europe), $140 pa (USA). Cover price £5.50.

Printed by: Pensord Press Ltd. ISSN (Print) 2040-8714 (Online) 2040-8722. © 2015.

To promote your Products and Services contact:
Shehzad Munshi
T: +44 (0)1923 690 215
E: shehzad.munshi@angelbc.com

CORPORATE PARTNERS

High Throughput Production Equipment for Laser Processing of Crystalline Solar Cells

- Powerful Laser Structuring of PERC Solar Cells
- Half Cell Cutting with TLS-Dicing™ to Increase PV Module Power

3D-Micromac AG
Phone: +49 371 40043 0

Technologie-Campus 8
E-Mail: info@3d-micromac.com

D-09126 Chemnitz, Germany
Web: http://3d-micromac.com