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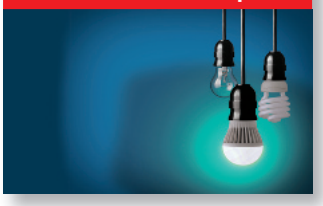
Printing cells to cut CPV costs

Selecting superior phosphors for LEDs

Tunnel junction boosts LED output



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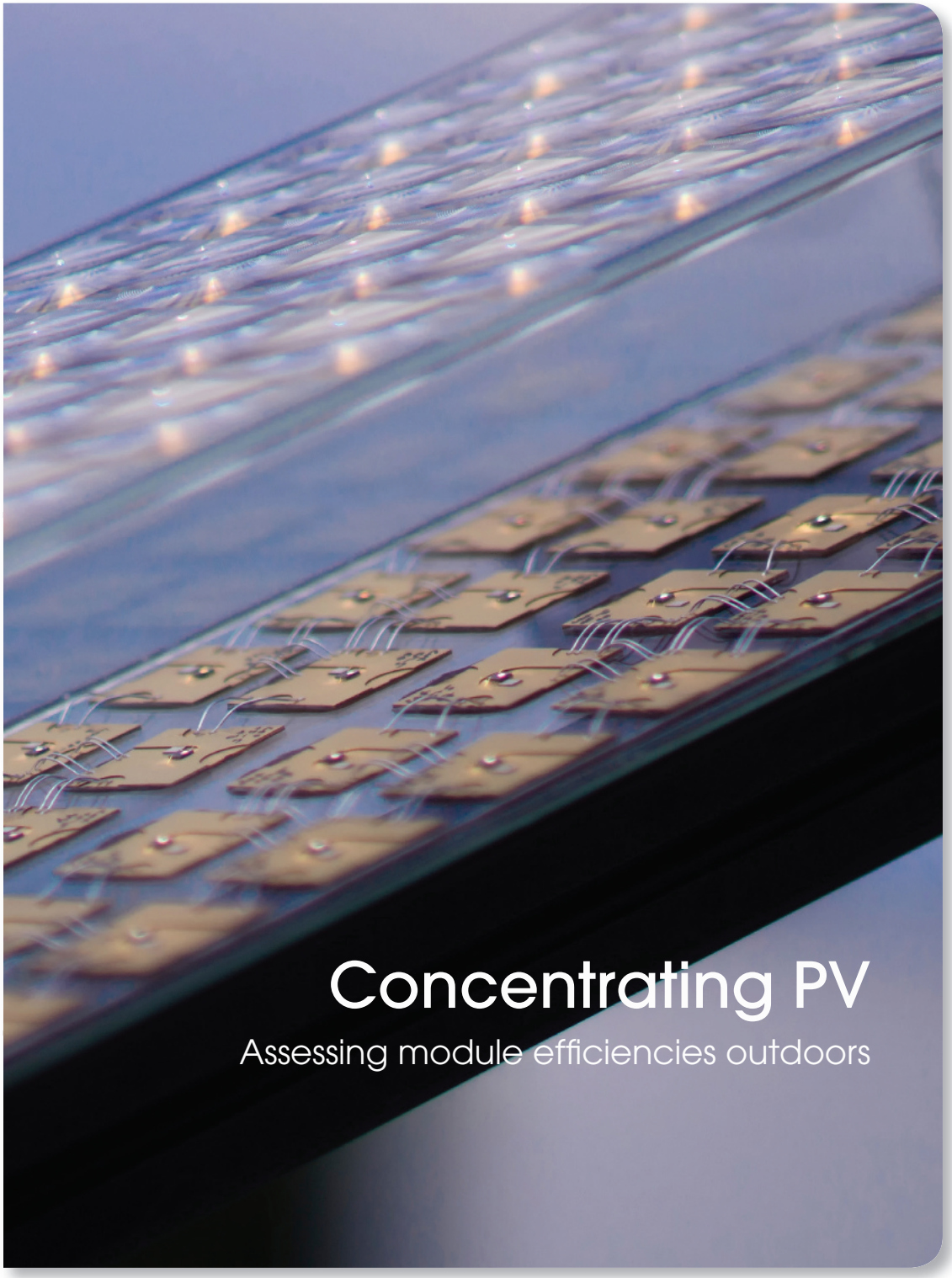

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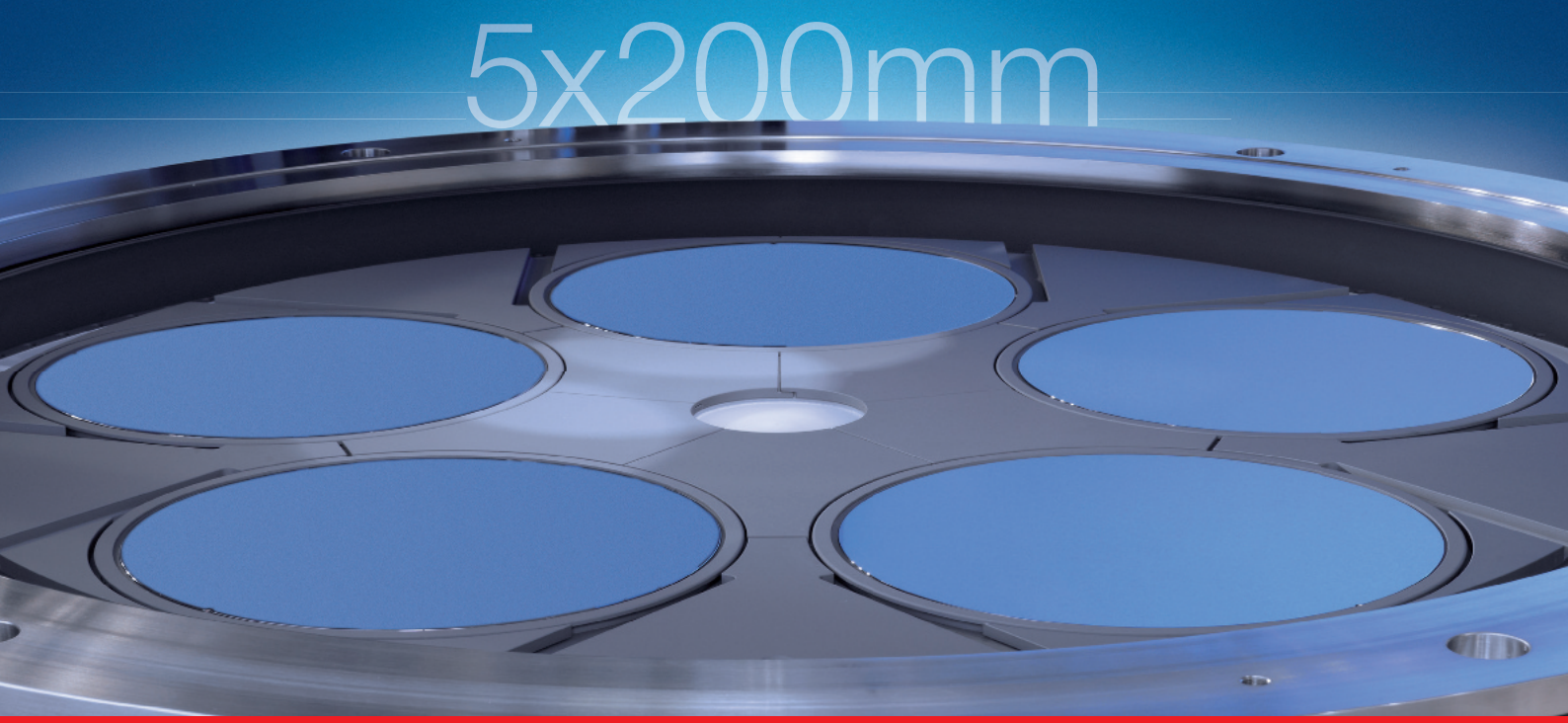

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ALWAYS ONE STEP AHEAD

editorial view

by Dr Richard Stevenson, Editor

Magnificent magnification

WHEN IT COMES TO CPV with III-V cells, you could argue that it ain't what you do, but the way that you do it. After all, all modules focus sunlight onto cells by factors of several hundred or more, and it is the architecture that is used to do this that governs the two most important metrics of all: efficiency and cost.

Efficiency figures don't vary that much between one CPV module maker and another, but design does. And it is this – and the way that the module is put together – that can govern the competitiveness of companies in this field.

One company with a great approach is Semprius of Durham, NC. It works with cells that are far smaller than those used by its peers, and employs surface mount techniques to manufacture light, low-cost modules (see p.34 of this issue for details).

At the heart of the Semprius production is a rubber-stamping process developed at the University of Illionois. This enables simultaneous transfer of a vast number of square cells, with sides of 0.6 mm, from a growth substrate to another platform.

The rubber-stamping process is a great way to handle very small cells. And because they are so tiny, it is possible to pop ball lenses on top of them that combine wide acceptance angles with minimal chromatic aberration and a uniform distribution of light onto the cell. If these cells were of traditional

dimensions, the ball lenses would have to be much bigger, and cost so much more that it would not be acceptable to use them.

Further benefits associated with a switch to smaller chips are: a massive reduction in the heat dissipation per cell, which simplifies cooling requirements and leads to further cost savings; and shorter paths for the charge carriers, trimming sheet resistance.

So the Semprius module has much to recommend it, and it will be interesting to see if it can help to drive uptake of CPV. For several years, this form of solar has been promising to make a transition from a technology under field tests to a serious competitor to the incumbents. Maybe now the latest version of the Semprius module will help to turn the dream of CPV into a reality.

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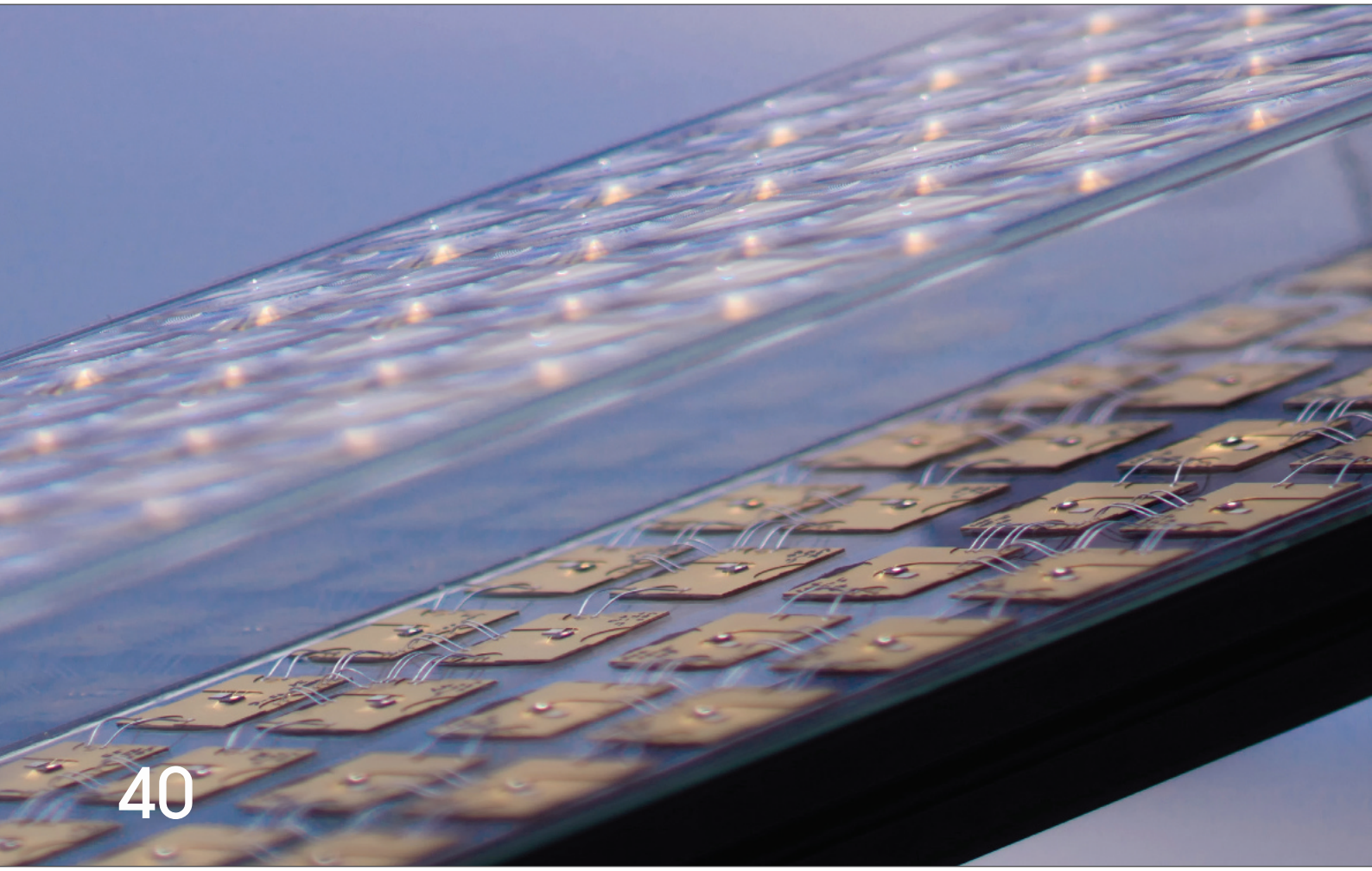

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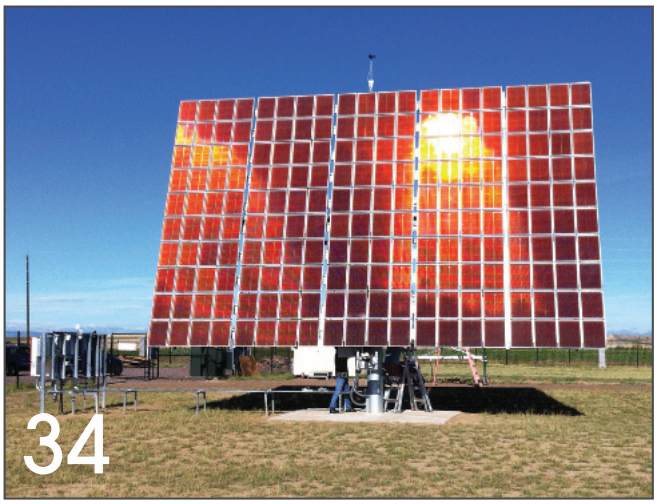


First Chinese supplier makes top 10 LED rankings

CHINA'S MASSIVE INVESTMENTS in light-emitting diode (LEDs) manufacturing capacity are paying off, with a Chinese company entering the top ranks of the global market for the first time ever, according to IHS Technology.

China's MLS Electronics Co. Ltd. in 2013 rose to the No. 10 rank in the worldwide market for packaged LEDs, up from 14th place in 2012. With the other top 10 players based in South Korea, Japan, the United States, Germany and Taiwan, this represents a first for China's burgeoning LED industry.

"Since 2011, most of the new LED production capacity that has been added worldwide has occurred in China," said Jamie Fox, principal LED analyst for IHS. "Because of this, it was inevitable that Chinese companies would eventually penetrate the ranks of the top 10 LED suppliers. MLS was first, having established itself by capitalizing on strong domestic demand."

For the major suppliers, MLS's ascent into the market's upper ranks represents a clear signal that Chinese firms soon will become major competitors in the global LED business.

MLS is one of many Chinese LED suppliers that have sprung up amid the surge in production. However, the other firms do not even rank among the top 20 global suppliers. China's LED supply base is massive and highly fragmented, with thousands of small manufacturers located across the country.

"Despite leading the domestic market, MLS accounted for less than 10 percent of Chinese LED revenue in 2013," said Alice Tao, China LED analyst at IHS. "The next five largest LED suppliers in China represented only about 20 percent of the market."

With the rise of LED manufacturing capacity in China, concerns have risen relating to overcapacity. Some of the equipment purchased for metal-organic chemical vapor deposition (MOCVD) manufacturing—the most important process step in LED production—is now sitting idle in China. Observers have

fretted that the overcapacity could result in the shutdown of some Chinese suppliers.

So far only a few of the smaller Chinese vendors have closed their LED operations. Most of the top companies remain active in the market, with some posting strong profit margins.

MLS and the smaller Chinese suppliers mostly compete among themselves for a share of the large domestic LED market. The international portion of sales for these companies is very small and the extremely low prices in the Chinese market make the country inaccessible to overseas suppliers. Because of this, foreign LED makers don't encounter Chinese competitors very often.

But that situation will change rapidly. IHS expects the LED revenues of Chinese vendors to grow steadily over time, as the country's economy continues to grow strongly. Because of this, Chinese LED suppliers will begin to sell more internationally and come into competition with foreign rivals.

Both intellectual property and quality are concerns for international customers that are considering Chinese suppliers. However, several factors suggest these concerns could be alleviated over time. These factors include patent expirations, China's established history in other industries, the sheer volume of manufacturing capacity in the country and the fact that many LED lamps are assembled in the nation.

Emcore rockets forward with extended contract

EMCORE has entered into a new long-term supply agreement with Space Systems/Loral, LLC (SSL) to manufacture and deliver high-efficiency, multi-junction solar cells for SSL's satellite programs. This new contract follows several other earlier long-term supply agreements between SSL and Emcore.

The solar cells will be designed and produced at Emcore's manufacturing facility located in Albuquerque, New Mexico, USA.

Emcore has been supplying SSL with solar cells for its satellite programs for fifteen years. In early 2013 the firm reached a milestone of delivering its 1 millionth high-efficiency, multi-junction solar cell to SSL, which will ultimately represent more than a megawatt of power delivered into space.

Emcore's long-term business relationship with SSL has been an important component in the growth of the company's Photovoltaics division since 1998.

"After so many years of working together, Emcore is not just a trusted supplier, but also a part of the extended SSL team," says Vivian Mackintosh, Vice President, Supply Chain Management at SSL. "Emcore makes an important contribution to help SSL meet the demand for the world's highest power spacecraft."

"We are proud to continue our long-standing relationship with SSL through renewal of our long term supply agreement and appreciate SSL's continued confidence in Emcore," comments Brad Clevenger, Executive Vice President and General Manager of Emcore's Photovoltaics Division.

"SSL has been a cornerstone of our satellite solar power business and we look forward to contributing to their success for many years to come."

Consortium halves energy loss for power devices

NEW SEMICONDUCTOR MATERIALS could mean 50 percent less energy loss in switched-mode power supplies for PCs, flat-screen televisions, servers and telecommunications systems and could make solar inverters even more compact and cost-efficient.

The partner companies of the research project "NeuLand" have developed highly-integrated components and electronic circuits which made it possible to reduce energy loss in circuits by 35 percent as early as during tests in ongoing research activities. The NeuLand project was funded by the German Federal Ministry of Education and Research (BMBF) with a total of approximately €4.7 million. This project was directed by Infineon Technologies.

The key to reducing energy losses by half is use of the semiconductor materials SiC and GaN-on-silicon, whose electronic properties enable compact and efficient power electronics circuits. Today Infineon already uses the material SiC in its JFETs and diodes for the 600V to 1700V voltage class.

These power semiconductors are primarily used in switched-mode power supplies for PCs or televisions and in motor drives. In the future they may also gain major significance for solar inverters. And after thatt heir use solar inverters could considerably profit. Before NeuLand, SiC was a very expensive wafer material. But NeuLand says its research has shown there are now more SiC vendors and the number of possible applications has grown. The project partners were able to demonstrate that the efficiency of power electronics can be increased by more than a third using SiC and GaN-based components. Solar inverters for example profit from considerable material savings with no change in effectiveness, making them even more cost-efficient.

However, results also showed that the cost of SiC components will have to drop even more for the wide-scale application in solar inverters and that for GaN-based components further intensive research is required on reliability, service lifetime and costs. Aixtron was represented as an equipment provider for semiconductor production, while as a wafer manufacturer SiCrystal was on board for SiC. Semiconductor manufacturer Infineon researched the power semiconductor devices and the production steps for SiC and GaN-based components, while the system technology expertise in the solar sector was provided by SMA Solar Technology.

With NeuLand the project partners were able to further expand their respective proficiencies in future-oriented SiC and GaN technologies along a very wide segment of the value creation chain. NeuLand is an abbreviation from the German for "Innovative power devices with high-energy efficiency and cost effectiveness based on wide bandgap compound semiconductors".

The three-year research project was funded by the BMBF as a part of the call for proposals on "Power Electronics for Energy Efficiency Enhancement" (LES) in the German Federal Government's program "IKT 2020 - Research for Innovation". The objective of IKT 2020 is to strengthen Germany's leading position in electronic technologies.

Philips to merge lighting businesses

PHILIPS has announced plans to combine its Lumileds (LED components) and automotive lighting businesses into a stand-alone company within the Philips Group. The process is expected to be completed in the first half of 2015.

"Philips' strategy in Lighting is to intensify its focus on connected LED lighting systems and services, LED luminaires, and LED lamps for the professional and consumer markets," said Frans van Houten, CEO of Philips.

"By combining Philips Automotive lighting and Lumileds, the Automotive lighting customers will continue to benefit from a fully integrated end-to-end R&D and supply chain, enabling the adoption of LED technology in automotive applications," said Philips Lighting CEO Eric Rondolat.

Sales of the combined businesses were approximately EUR 1.4 billion in 2013. The chief executive officer of the new company will be Pierre-Yves Lesaicherre, the current chief executive officer of Lumileds.

Costs associated with setting up the combined business are expected to amount to EUR 30 million in the second half of 2014.

Red phosphor brightens white LEDs

WORKING with Peter Schmidt of Philips Technologie GmbH in Aachen, a team of researchers led by Wolfgang Schnick at LMU Munich, has developed a new material for application in LEDs.

The newly developed phosphor enhances the quality of colour rendition by white-emitting LEDs. (Source: Wolfgang Schnick, LMU Munich)

"With its highly unusual properties, the new material has the potential to revolutionise the LED market," says Schnick. The two teams report their results in the latest edition of Nature Materials.

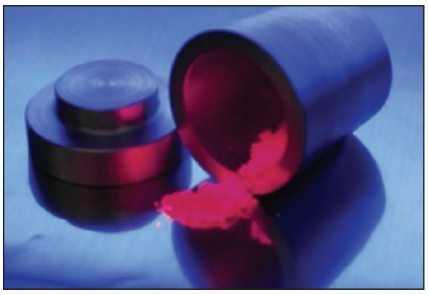
Conventional incandescent light bulbs have a very low energy conversion efficiency, which has led the EU to order their withdrawal from the market. As a result, LEDs have become the light source of choice for the foreseeable future.

The light emitted by LEDs is generated by electronic transitions in solid-state semiconductors. In contrast to so-called energy-saving lamps, which contain toxic mercury, LEDs are environmentally friendly. What's more, they are highly efficient and promise significant reductions in energy consumption.

A single LED can produce light of only one colour tone. However, Schnick and his team had previously achieved a breakthrough by synthesising innovative phosphor materials that allowed the blue light produced by conventional LEDs to be converted into all the colours of the visible spectrum -in particular, those at the red end.

Mixing of the different colours results in high-quality white light and this invention earned Schnick and his colleagues a nomination for the German Future Prize 2013. LEDs that generate blue light can be converted into white-light emitters by coating them with various luminescent ceramics. These materials absorb some of the blue light and re-emit the energy at wavelengths corresponding to all the other colours of the visible spectrum from cyan to red.

The combination of these colour components with the unabsorbed blue



light results in pure white light. The process sounds simple, but its practical realisation is very challenging. It requires phosphors which display extremely high thermal stability and operate with very high efficiencies.

"The problem with commercially available white-light LEDs is that there is always a trade-off between optimal energy efficiency and acceptable colour rendition," says Schnick. The red-emitting phosphor materials so far used are the principal factor responsible for this, because they have a particularly significant influence on the so-called colour rendering index.

There is also a growing demand in the industrial sector for new phosphors capable of emitting in the deep-red region because this would enable the conflicting demands of optimal efficiency and most natural colour rendition to be reconciled.

The new material developed by Schnick, Schmidt and their colleagues is based on the nitride $Sr[LiAl_3N_4]$. When doped with an appropriate amount of europium, a rare-earth metal, the compound displays intensive luminescence over a very narrow range of frequencies in the red band.

Peak emission occurs at wavelengths of around 650 nm and peak width (full width at half-maximum) is only 50nm. The first prototype LEDs incorporating the new material generate 14 percent more light than conventional white-light LEDs and have an excellent colour rendering index. "With its unique luminescence properties the new material surpasses all red-emitting phosphors yet employed in LEDs and has great potential for industrial applications" Schnick concludes.

First Solar to build CdTe 150 MW solar facility in California

TENASKA SOLAR VENTURES has selected First Solar to design and build the 150 megawatt (MW) AC Tenaska Imperial Solar Energy Centre West project near El Centro, California.

First Solar will provide full Engineering, Procurement and Construction (EPC) services on the project, employing its advanced thin film photovoltaic modules and single-axis tilt technology. The project sits on approximately 1,100 acres of previously disturbed land in Imperial County.

Tenaska Imperial West is the second solar project in Southern California's Imperial Valley developed, owned and managed by Tenaska.

In November of 2013, First Solar completed construction on the 130MWAC Tenaska Imperial Solar Energy Centre South power plant for Tenaska. "We are pleased to continue our relationship with Tenaska," says Roger Bredder, First Solar's Managing Director for U.S. Business Development. "This project will provide up to 800 jobs in the Imperial Valley at construction peak, and make a significant economic contribution to the local community. It will also provide the residents of Southern California with a reliable source of clean, renewable energy."

Bredder explains that the local workforce that built Tenaska Imperial South over the past two years will provide a strong pool of experienced workers familiar with First Solar's technology and construction methods.

First Solar has already started engineering and expects to begin construction later in 2014, with full commercial operation anticipated in 2016. San Diego Gas & Electric Company holds a 25-year power purchase agreement (PPA) for all electricity generated by Tenaska Imperial West.

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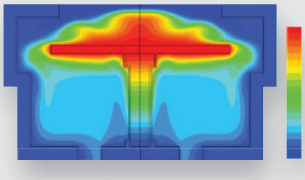

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Despite low revenues GaN power market should boom

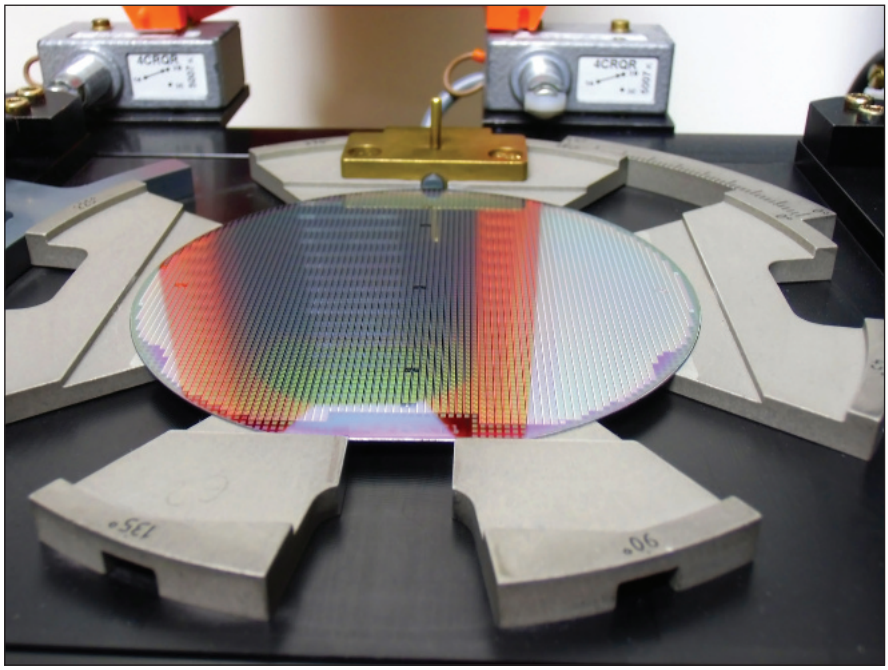
ACCORDING TO THE LATEST REPORT from Yole Développement, the GaN power industry is consolidating in preparation for significant growth Overall, 2020 could see an estimated device market size of almost $600 million, leading to 580,000 x 6-inch wafers to be processed. Ramp-up is estimated to start in 2016, at an estimated 80 percent CAGR through 2020, based upon a scenario where EV/HEV begins adopting GaN in 2018 - 2019.

The power supply/PFC segment will dominate the business from 2015 - 2018, ultimately representing 50 percent of device sales- automotive will then catch-up. In UPS applications, the medium-power segment is likely to be very much in line with the GaN value proposition, and savings at system level will be demonstrated. Yole thinks GaN technology could grab up to 15 percent of market share in this field by 2020. Room for extra cost in motor drive applications is unlikely. Therefore, the incentives to implement new technologies such as GaN have to be serious and strong.

Considering the possible improvement of conversion efficiency, and augmented by a predictable price parity with silicon solutions by 2018, Yole expects GaN to start being implemented in motor control by 2015 - 2016, and reach around $45 million in revenue by 2020.

The PV inverters segment has already adopted SiC technology, and products are now commercially available. It's possible that GaN could partially displace SiC thanks to better price positioning. However, now that SiC is in place, qualifying GaN may be more challenging. Recent announcements show that the GaN industry is taking shape as mergers, acquisitions and license agreements are settled.

The latest Transphorm-Fujitsu agreement, in addition to Furukawa's IP portfolio's exclusive licensing, are positive signs that GaN technology is spreading across the value chain, reinforcing the leaders' market position but likely leaving the weakest players by the wayside.
Yole Développement forecasts that



2014 will only generate $10 million - $12 million in device sales (in addition to R&D contracts and so forth). Such a moderate business means only the strongest will survive, and that several early-birds will see their cash-flow swiftly dissipate. Yole believe that the GaN business will really ramp up in 2016, exceeding the "psychological threshold" of $50M in revenue. The key question is, how can GaN survive the next 1 ½ - 2 years? At the risk of being overly-pessimistic, Yole say some companies will not survive, and will either be acquired or go bankrupt.

Today, the power GaN business is mainly centred on low-voltage DC-DC converters (typically Point-of-Loads, or POL) using available 200V-rated devices. Unfortunately, this business only generates a few million dollars in revenue. However, thanks to the 600V device's introduction this year, GaN will grow quite fast in power-supply and PFC applications where technical added-value and economics are obvious. After simulating several case-studies, Yole have concluded that even though today's market price for GaN devices exceeds the price for silicon devices, efficiency improvements and electricity bill savings can overcome this extra cost in less than one year for a 300W, 24/7 operation power supply (data server type). By 2018, the same power supply could be even cheaper than its silicon counterpart thanks to the reduction in passives (capacitor, self-induction) cost, along with switching frequency increase. Yole see the PFC segment taking off by 2015, and achieving an 80 percent CAGR over 2016 - 2020. Other applications such as PV inverter, and, to a lesser extent, motor control, will see GaN begin capturing market share by 2015-2016.

The next big thing will unquestionably be the EV and HEV segments, where GaN could definitely play a role in power systems such as low-voltage (14V -> 200 - 400V) DC-DC converters, and later for battery chargers (on-board 3.6 & 7.2 kW first, and then off-board 50kW+). However, we don't see any chance for GaN to enter power-train inverters (60kW+) before 2019-2020, due to the current lack of high-current devices and the projected price.

600V-rated GaN devices were announced more than two years ago. However, only a few select customers have had access to 600V for qualification purposes. The majority of the power electronics community has been unable to source such devices. This has probably affected GaN technology's credibility, and opened the door for its main competing technology, SiC, to continue expanding its industry presence.

GaN Systems expand in Canada

GAN SYSTEM, a developer of power switching gallium nitride semiconductors, has moved into its new headquarters and R&D facility in Ottawa, Canada. Located at the heart of Kanata's high technology community, the move was necessitated by the company's expansion over the past twelve months and plans for continued rapid growth as GaN devices replace legacy silicon-based semiconductors in power conversion and control applications worldwide.

"We are committed to long term, fast-paced growth, and these new facilities will provide the resources and capabilities we need as we move rapidly from R&D to commercialisation this year." said Jim Witham, CEO. The new HQ and R&D facility is three times larger than GaN Systems' previous premises, with a tenfold increase in laboratory space. The labs have dedicated power and cooling, which is crucial, as Girvan Patterson, co-founder and President explains: "When you produce devices that can switch 200 Amps or more, it calls for some highly specialised facilities to fully test them.

"The power available in this location and our custom-designed labs will enable us to fully explore higher power applications and substantially accelerate the long term reliability testing of our devices."

Headcount has already increased significantly over the past six months and GaN Systems has expanded its global team as its power conversion devices, based on its proprietary Island Technology, are commercialized. GaN Systems is believed to be the first company in the market with a wide range of parts already available for sampling.

MA/COM introduces GaAs based LNA

M/A-COM TECHNOLOGY SOLUTION has launched a new three-stage low noise amplifier for point to point applications. The MAAL-011111 is a low noise amplifier covering 22 - 38GHz in a small and low cost 3 x 3 mm QFN package. It offers 19dB of gain and less than 3dB of noise figure.

The LNA is self-biased requiring only a single 3.3V voltage supply and there is no need for any external components. It is claimed to be easy to implement and takes up a small board area. The high gain and low noise figure makes it well suited as a first stage LNA in receiver applications covering multiple bands simultaneously.

"The MAAL-011111 offers excellent performance across the full band up to 38GHz in a small fully molded QFN package," says Amer Droubi, Product Manager, MACOM.

"The low noise amplifier has an integrated ESD protection and by-pass capacitors and requires a single positive bias supply, making it an idea low cost and easy to implement solution for a wide range of applications."

Mitsubishi Electric touts GaAs-based laser diode for projectors

MITSUBISHI ELECTRIC has developed a GaAs based 638nm wavelength red laser diode (LD) offering an output power of 1.8 W at continuous-wave operation. The company says this is the world's highest level among 638nm LDs in this package size used as light sources for projectors.

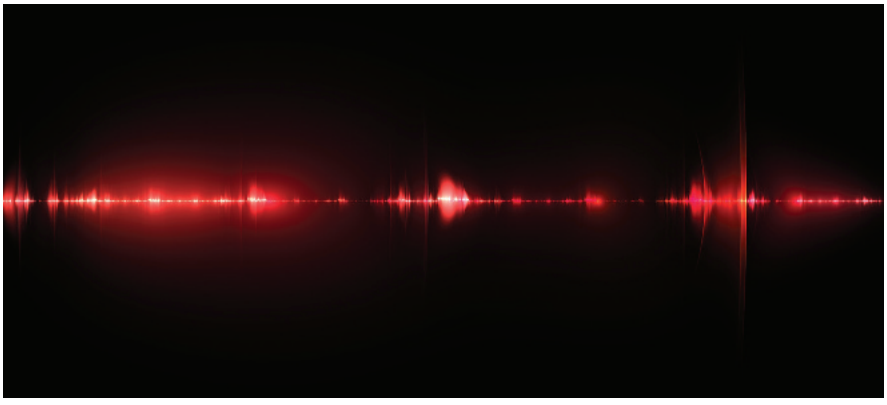
A commercial launch is targeted for the fiscal year ending in March 2016 at which time laser light sources for projectors are expected to take off.

638nm wavelength red laser diode
Light sources for colour projectors, conventionally lamps, are being replaced with solid-state light sources offering higher energy efficiency, higher colour reproduction and longer life. LDs deliver high output power while consuming low power because of their high power-conversion efficiency.

Mitsubishi Electric says that previously, the output power of red LDs with wavelengths shorter than 640nm was not sufficient for high-brightness projector applications at high temperatures.

As a first step to overcome this limitation, the firm applied specialised window-mirror structures and epitaxial growth technology to develop an LD capable of 0.5W power output at continuous-wave operation, which is packaged in a 5.6mm diameter transistor-outline can (TO-can).

After that, it applied a new LD structure in a 9.0mm TO-can package to achieve an output power of 1.8W at a 638nm lasing wavelength at continuous wave operation within an operating range of 0 to 45°C. The device is also capable of emitting 1.3 W at continuous wave operation above 55°C and should meet the demands for bright projector systems. Luminosity as a red light source exceeds 220 lumens due to lasing at a short wavelength and electrical conversion efficiency is 38 percent at 1.8 W at 25°C, helping to reduce power consumption.



Finisar buys Aixtron MOCVD system

FINISAR expands capacity for new tunable lasers and PICs. Finisar Corporation, the designer and manufacturer of optical communications components and subsystems, is expanding its capacity for making tunable lasers, high speed modulators, and photonic integrated circuits (PICs) with an AIX 2800G4-TM MOCVD system from German firm Aixtron SE.

To be used in Finisar's Swedish facility in Järfälla, near Stockholm, the new MOCVD deposition system will also support the company's focus on developing new, more highly integrated indium phosphide products, according to Patrik Evaldsson, Vice President and General Manager of Finisar Sweden. Finisar Corporation already uses Aixtron's Planetary Reactor technology production for lasers and photodetectors.

Wireless infrastructure drives RF power

SPENDING on RF power semiconductors for the wireless infrastructure markets took another jump in 2013.

Other markets are seeing some moderation in growth as the global economic picture and political factors come into play but some sub-markets are showing a nice upside.

Also, according to a new study from ABI Research, gallium nitride - long seen as the likely promising new "material of choice" for RF power semiconductors - is continuing its march to capture share, especially in wireless infrastructure.

"Gallium Nitride is delivering increasing market share in 2014 and is forecast to be a significant force by 2019," notes ABI Research Director Lance Wilson. "It bridges the gap between two older technologies, exhibiting the high-frequency performance of Gallium Arsenide combined with the power handling capabilities of silicon LDMOS. It is now a mainstream technology which has achieved meaningful market share and in future will capture a significant part of the market."

The vertical markets showing the strongest performance outside of wireless infrastructure in the RF power semiconductor business are the defence oriented segments, which Wilson describes as being now "a significant market" in total. Despite the poor press for defence oriented electronic hardware the actual performance in 2013 was better than originally thought for some sub-segments.

"RF Power Semiconductors" examines RF power semiconductor devices that have power outputs of greater than 4 watts and operate at frequencies of up to 3.8 GHz, which represent the bulk of applications in use today.

MicroSense ships LED measurement tool

MICROSENSE, LLC has announced multiple shipments of its new, next-generation automated sapphire wafer metrology tool, the MicroSense UltraMap C200. Designed specifically for high throughput dimensional measurement of sapphire wafers for LED manufacturing, the UltraMap C200 provides throughput of ninety 6" diameter sapphire wafers per hour.

The UltraMap C200 utilises MicroSense's novel two sided capacitive sensing technology to measure sapphire wafer geometry including thickness, TTV (total thickness variation), bow, warp, and LTV (local site thickness variation).

"LED manufacturers typically don't make their own sapphire wafers, so incoming quality control has become a requirement for LED chip makers as the industry continues to migrate from primarily 2" wafers to 4", 6" and 8" wafers," according to David Kallus, Director of Dimensional Wafer Metrology at MicroSense. "LED manufacturers have found high sapphire wafer bow strongly correlates to LED yield loss. The UltraMap C200 utilizes our proprietary capacitive sensing technology and advanced high density wafer mapping algorithms to provide world leading measurement repeatability and throughput."

"Sapphire has become a break out substrate material, and sapphire factories are scaling to capacities unheard of before, driven by the LED and smartphone component markets," continues Kallus. "In order to improve sapphire wafer yields and drive down wafer cost, wafer manufacturers need to measure at more steps in the wafering process.

Unlike metrology tools based on optical methods, the MicroSense UltraMap C200 measures sapphire wafers and substrates with any surface finish - as cut, lapped, ground, polished, textured and patterned sapphire substrates (PSS) - without sacrificing wafer throughput or measurement repeatability. Wafer surface condition has no effect on measurement performance."

The UltraMap C200 is available in three versions including tools with robotic loading, robotic loading with cassette sorting and a bench top tool. The UltraMap C200 handles wafers ranging from 2" to 8" in diameter.

IQE wins new multi million pound manufacturing agreement

IQE PLC has entered into a new multi-year volume manufacturing agreement expected to be worth in excess of £1million a year for epitaxial wafers for use in optical communications applications.

The new supply agreement is with an existing key strategic customer that already has a significant presence in the Asia Pacific region and includes the rapidly growing market for photonics in China. The new contract increases IQE's share with a guaranteed minimum of 80% of the customer's business, which is expected to be worth more than £1m in additional annual revenues to IQE's photonics business unit. Customers are increasingly seeking to ensure security of supply through entering into long-term supply agreements to support products and devices for LTE backbone communications for base stations, Gigabit Passive Optical Networks (GPON) and Fibre to the Home (FTTH) at 2.5G and 10G, migrating to 100G over the coming years.

The agreement also includes scope for adding new products which are currently undergoing qualification, such as Avalanche Photo Detectors (APDs) for high-speed, long-reach detectors.

The new contract takes the form of a "Vendor Managed Inventory" (VMI) agreement which enables IQE to optimise production efficiency and manage any short-term fluctuations in demand. Dr Drew Nelson, IQE CEO, said:"IQE provides the key enabling technology that is helping to meet the ever increasing demands on optical communications driven by trends such as 'Big Data' and 'The Internet of Things.'

"As the importance of photonic applications continues to grow, customers increasingly need to ensure security of supply to meet the needs of their technology roadmaps and are seeking to enter into volume manufacturing agreements.

"IQE is the global leader in wafer outsourcing and is seen by its customers as their key strategic partner to support this rapidly growing industry sector."

Semiconductor quantum dots with single-atom precision

SCIENTISTS AT NTT Basic Research Laboratories in Japan, the Paul-Drude-Institute in Germany, and the Naval Research Laboratory in America have developed quantum dot and combined artificial molecules with single-atom precision in terms of position and configuration. This was achieved on a clean surface of semiconductor single crystal thin film manufactured by MBE using a low-temperature Scanning Tunneling Microscope (STM) to integrate atoms one-by-one.

This technology has made it possible to implement quantum dots with identical properties, like natural atoms, and do this flexibly at the semiconductor substrate for the first time at this level of precision. It could be possible to manufacture quantum devices with atomic-level reproducibility e.g. a single photon source with a uniform wavelength, or an array of quantum bits with uniform functions, which has not been possible before. Results were published in the *Nature Nanotechnology* on the 29 June.

If the fabrication and characterization of quantum structures with atomic precision is possible at the semiconductor substrate surface, this will be a major leap toward being able to make a new types of integrated circuits that combine wafer-level semiconductor technology and atomic and molecular electronics. For the base of the atom manipulation, the team used an (111)A-oriented surface of indium arsenide crystal. The (111) A surface has periodic hollow sites caused by a specific atomic structure of compound semiconductors. The structure formation can be exactly controlled by placing each atom at each hollow site. The high quality InAs thin film has been grown at NTT-BRL on the (111)A-oriented substrate with atomically controlled thickness. After the grown InAs surface was covered by a protection film (amorphous As), the sample was transferred from NTT to PDI.

When the sample was loaded into STM instruments at PDI, the protection film was removed in an ultra-high-vacuum to recover the clean (111) A surface, on which it is feasible to perform atom manipulation. The indium atom is self-ionized at the InAs surface to be +1 charged ion with releasing an electron. By using the low-temperature STM, we can observe surface atomic arrangement and also form nanostructures by atom manipulation of these ions as building blocks. Artificial atoms ($6 \leq$ the number of atoms ≤ 25) have been manufactured by arranging each In atom one-by-one in a line at the (111)A surface. The row of such ions behaves as a 'core' of an artificial atom and electronic states at the semiconductor surface are confined to the induced local potential well. The team expect achievements to open the door to developing electronic technology by combining atomic and molecular electronics with semiconductor thin film technology.

Publication information: Quantum dots with single-atom precision by S. Fölsch etc al, Nature Nanotechnology (2014). DOI: 10.1038/NNANO.2014.129

Plessey orders metallisation tool

FERROTEC CORPORATION has confirmed that the first Temescal UEFC-4900 will be delivered to Plessey Semiconductors.

Plessey's proprietary MaGIC process produces a unique, thin layer of GaN-on-Silicon and the UEFC-4900 offers the benefits of the Auratus deposition process to attain near-perfect uniformity and reduction in material consumption.

"At only 2.5 μm for both buffer and epitaxial layer, our MaGIC process uses a much thinner GaN layer compared to the 8 μm thickness typical on most other LED processes," says Mike Snaith, operations director at Plessey.

"When you're working with this level of precision, the uniformity and efficiency that you can achieve with a Temescal system is essential. The UEFC-4900 will be an excellent upgrade from our FC-2800 platform with its Auratus enhancements such as increased capacity, faster throughput and reduced cost of operations."

"Plessey is making tremendous inroads into reducing the cost of high brightness LEDs with its unique GaN-on-Silicon process. By producing high performance GaN LED structures on standard silicon substrates, Plessey is able to deliver industry-standard performance at a dramatically reduced cost of manufacture," Gregg Wallace, managing director of Ferrotec's Temescal division, comments.

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Toyota reveals SiC power semiconductor

TOYOTA MOTOR CORPORATION, in collaboration with Denso Corporation and Toyota Central R&D Labs., Inc. (Toyota CRDL), has developed a SiC power semiconductor for use in automotive power control units (PCUs).

Toyota will begin test driving vehicles fitted with the new PCUs on public roads in Japan within a year. Through SiC power semiconductors, Toyota aims to improve hybrid vehicle (HV) fuel efficiency by 10 percent under the Japanese Ministry of Land, Infrastructure, Transport and Tourism's (MLIT) JC08 test cycle. The company also aims to reduce PCU size by 80 percent compared to current PCUs with silicon-only power semiconductors. SiC power semiconductors have low power loss when switching on and off, allowing for efficient current flow even at higher frequencies. This enables the coil and capacitor, which account for approximately 40 percent of the size of the PCU, to be reduced in size.

PCUs play an important role in hybrids and other vehicles with an electrified powertrain: they supply electrical power from the battery to the motor to control vehicle speed, and also send electricity generated during deceleration to the battery for storage.

However, PCUs account for approximately 25 percent of the total electrical power loss in HVs, with an estimated 20 percent of the total loss associated with the power semiconductors alone.

Therefore, a key way to improve fuel efficiency is to improve power semiconductor efficiency, specifically by reducing resistance experienced by the passing current. Since launching the Prius gasoline-electric HV in 1997, Toyota has been working on in-house development of power semiconductors and on improving HV fuel efficiency.

As SiC enables higher efficiency than silicon alone, Toyota CRDL and Denso began basic research in the 1980s, with Toyota participating from 2007 to jointly develop SiC semiconductors for practical use. Toyota has installed the jointly developed SiC power semiconductors in PCUs for prototype HVs, and test driving on test courses has confirmed a fuel efficiency increase exceeding 5 percent under the JC08 test cycle.

In December last year, Toyota established a clean room for dedicated development of SiC semiconductors at its Hirose Plant, which is a facility for research, development and production of devices such as electronic controllers and semiconductors.

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QMC starts mass production ahead of schedule

QUANTUM MATERIALS CORPORATION (QMC) has received its increased capacity equipment and is launching mass production of advanced materials several months ahead of schedule.

QMC specialises in CdSe tetrapod Quantum Dots (QDs). As an emerging provider of quantum dots, nanoparticle materials and related platform technologies, Quantum Materials Corp.'s (QMC) production phase equipment is capable of producing 250 kilograms of quantum dots per annum.

The company's proprietary high volume process technology produces quantum dots with superior uniformity to those created via manual processes.

Additionally, QMC is executing its strategic plan to broaden the product line to a variety of tetrapod quantum dots including cadmium and previously announced Cadmium-Free Non-Heavy Metal Quantum Dots and size-optimised nanoscale metallic compounds including metal oxides. QMC recently added thick shell technology to its product offerings that possess many optoelectronic and photovoltaic advantages.

Looking beyond this achievement, Quantum Materials Corp. Chairman and CEO Stephen B. Squires stated that "Quantum Materials' next larger system, expected to be rapidly deployed later this year, will place us far ahead of the competition in the ability to supply reliable industrial quantities of quantum dots. We plan to quadruple production output by January 15th, 2015, and have engineered plans in place to deploy short-lead-time parallel systems to meet ever increasing market demand."

David Doderer, Vice President of Research and Development for QMC, further detailed, "mass production affords the ability to quickly negate cost constraints and enable quantum dot penetration into newer applications such as security, defence, filtration, and product-ID packaging as well as our immediate opportunities in the display, lighting and energy sectors."

"With this accomplishment, our team has taken a significant step toward our goal of evolving quantum dots from an esoteric technological novelty to a core component commodity." Explaining his vision of the technology market, Squires continues, "The consumer expects the 'next big thing'.

Our quantum dots are a strong part of technological innovations that enable products that can be simply incredible. We are very focused and highly motivated to provide these key building blocks to a wide range of product innovators so that their dreams become reality in superior next-generation products for these markets."

In addition to manufacturing Tetrapod Quantum Dots (TQD) engineered to specific lighting, display and medical applications for leading manufacturers worldwide, QMC is also developing TQD-infused films for medical devices, solid state lighting applications, electronic displays and quantum dot solar cells.

European supply chain for advanced GaN technologies

A FOUR-YEAR RESEARCH project guided by the European Defence Agency (EDA) has succeeded in establishing the entire supply chain for making GaN power components within Europe. The supply chain ranges from the availability of SiC substrates for the epitaxial growth of GaN, to the industrial manufacturing of HEMTs.

Project MANGA (Manufacturable GaN-SiC-substrates and GaN epitaxial wafers supply chain) was set up to ensure production of GaN devices for military applications without relying on international suppliers. Their high efficiency and robustness means GaN-based power electronic components are fast replacing established technologies in a broad spectrum of defence applications from advanced radar and communication antennas to electronic warfare.

As such, the technology is regarded as critical.MANGA involved research institutions, universities and defence companies from Germany, France, Italy, Sweden and the UK, working with the EDA. In the scope of the project, GaN-based transistor layers were grown epitaxially on newly developed, high quality SiC-substrates. Applying established foundry processing, these transistor layers were finally used to make state-of-the-art hemts.

In future projects, the EDA aims to further reduce the European defence industry's dependence on international trade regulations.

In a follow-on project, the partners want to achieve the qualification of an industrial European wafer supplier for state-of-the-art hemt structures.

Cree readies GaN for low-cost markets

Is this the transistor that could trigger a telecoms industry shift from silicon to GaN? Rebecca Pool talks to Jim Milligan of Cree, to find out more.

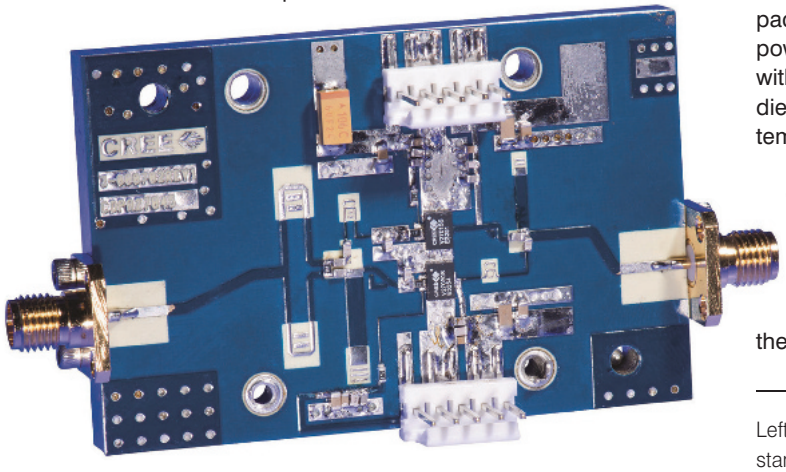
LATE LAST MONTH, US-based LED lighting and power device pioneer Cree unveiled its latest family of high-power transistors, specifically targeting wireless telecoms infrastructure markets.

Housed in a so-called 'innovative plastic package', the GaN-on-SiC devices include the industry's first 300 W plastic-packaged transistor operating at 2.7 GHz. Operating frequencies scale to 3.8 GHz and P_{sat} efficiency is a nice 65 percent, but critically, device costs look set to hit the low price points the telecoms industry needs to move from industry incumbent silicon LDMOS to GaN transistors.

"Telecoms is a cost-driven market and the cost of GaN relative to LDMOS has certainly paced its rate of adoption," says Jim Milligan, RF business director at Cree. "We know that GaN offers significant performance advantages over LDMOS, but cost has prohibited its rapid adoption for all but the more niche applications."

"But with a cost-focus, we've slashed the price of the packaging to get to a [packaged device] price comparable with LDMOS," he adds.

Milligan won't be drawn on exact figures, simply saying costs vary according to a device's operating frequency. But as he highlights, a GaN transistor packaged in a ceramic air cavity package would cost twice as much as the LDMOS equivalent. Meanwhile the latest plastic-packaged GaN device is nearly half the cost of a traditionally-packaged GaN transistor.



So price-wise, Cree is getting close, and as Milligan adds: "It's also a lot harder to impedance match LDMOS at frequencies above 2 GHz, so you don't tend to see silicon in a plastic package at these power levels, and that's how we're fundamentally able to compete."

Compatibility counts

So how exactly has Cree managed to safely package a high-performance GaN transistor in plastic? Again, Milligan will not be drawn on details. However, he does reveal that the packaging is non-standard with Cree researchers 'engineering the die attach process, materials and plastic over-mould system to be compatible with a high power, high frequency GaN transistor die'.

The packaging platform is compatible with the various die peripheries used in telecommunications applications with the materials system also being compatible with current plastic overmould practices. As Milligan points out, Cree will use the same high-volume manufacturing processes already used for standard plastic overmould transistors.

"But we think our approach is fundamentally different to other GaN vendors whose products in standard plastic overmould packaging are only capable of servicing lower average power applications," he adds. "Instead, we have worked with partners to engineer both the mould compound and die-attach processes to be compatible with much higher temperature operation."

Cree has already sampled early prototypes to 'strategic' customers, with positive feedback and will be sampling this month, with parts being available in production quantities by the end of this year. Milligan also points out how the company fabricates most aspects of the product, from SiC substrate manufacture and epitaxy to die

Left: Cree claims its new high power GaN RF transistor sets a new standard in performance and price.

fabrication, thanks to its vertically integrated structure and so the supply chain is ready for volume production.

"We have a growing LED lighting business and we share the same manufacturing line with our growing SiC power business," he says. "We're in a unique position to take advantage of our corporate scale to be very competitive."

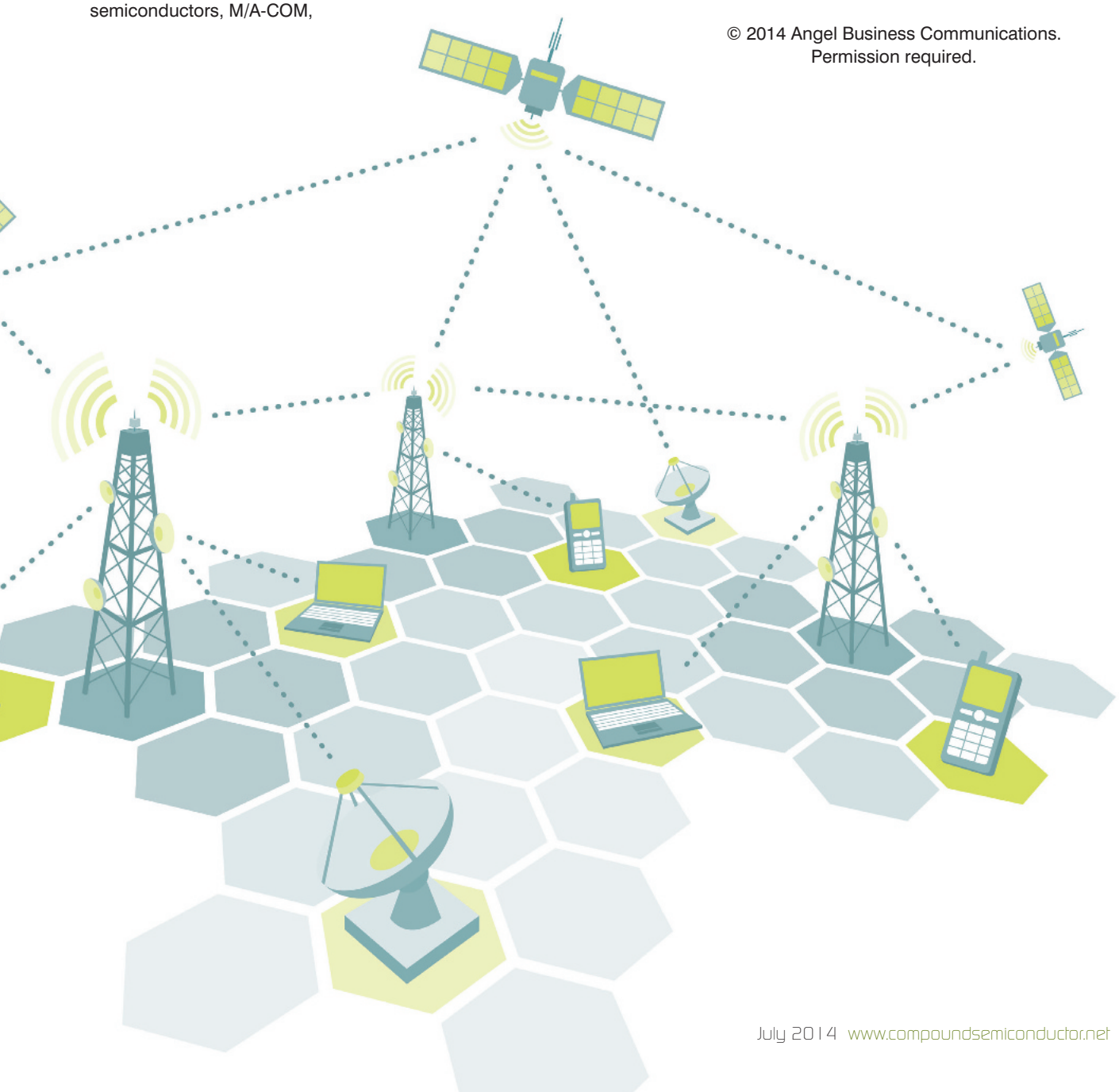
Initial adoption is expected in high frequency, high power systems where silicon can't meet performance demands, and Milligan expects GaN will gain significant traction at lower frequencies as pricing continues to fall.

"There's going to be new system deployments up in the 3.5 GHz band and we'll likely see GaN there from the start, but it is reasonable to assume that there will be many low frequency applications that will continue to use LDMOS for quite a few years to come," he asserts.

But silicon LDMOS aside, what about up and coming GaN-on-silicon transistors? For example, in February this year, US provider of high performance semiconductors, M/A-COM, bought long-time GaN RF semiconductor developer, Nitronex, later joining forces with UK-based wafer maker IQE to produce 4-inch, 6-inch and 8-inch GaN-on-silicon epiwafers. M/A-COM claims to be in 'active discussions with select companies' to license out its IP, just one recent development that signals the rise of GaN-on-silicon technologies. Milligan concurs GaN-on-silicon will gain market share in RF cell applications, but believes the technology will still remain niche, being used in lower power and frequency applications.

"GaN-on-silicon is a tough materials system to manufacture with the epiwafer subject to strain and cracking particularly on the larger wafers that are often touted as a price advantage," he says "In addition to thermal challenges, considerable engineering and yield improvements are required for it to be a viable alternative."

"But given the rapid growth and cost reduction we've seen in GaN-on-SiC – we're currently selling millions of transistors per year – and further expected price reductions as we migrate to six inch wafers in the next few years, it's likely this will remain the incumbent GaN technology platform," he adds.



Crystal IS primed to seize UV LED market

As UV LED markets gather momentum, Crystal IS has launched the first commercial AlN-based LEDs. Will LED makers choose these over existing sapphire-based alternatives? Rebecca Pool investigates.

IN A BID TO CAPTURE ULTRAVIOLET LED market growth, US-based manufacturer of AlN substrates and UV LEDs, Crystal IS, recently launched its so-called Optan UVC LEDs. Described as the first commercial semiconductors based on native AlN substrates, the devices emit light between 250 nm and 280 nm, perfect for disinfecting water, sterilising surfaces, monitoring chemicals in pharma-manufacturing and other analytical applications. Hari Venugopalan, director of global product management at Crystal IS, anticipates strong industry demand.

"Customers have told us that they've found the performance of sapphire-based LEDs to be somewhat limited," he told *Compound Semiconductor*. "[Here] significant lattice mismatches introduce defects, limiting performance and lifetime."

"But with our native AlN substrate, we've reduced defect density by five orders of magnitude, so our products provide light output that is five times higher and with significantly longer lifetimes," he adds.

Indeed, at a maximum drive current of 100 mA, Venugopalan reckons a typical LED lifetime comes in at 3000 hours. "But you know, we deliver so much light that drive currents can come down to 20 mA and lifetimes will exceed 7000 hours," he says. Meanwhile, sapphire-based UVC LEDs struggle to match the 2000 hour lifetimes typically provided by today's well-used deuterium and xenon flash lamps, depending on the specific application. And crucially the company claims its LEDs are actually cheaper than these broad spectrum UV lamps.

As Venugopalan explains, UV lamps supply light at multiple wavelengths, requiring band pass filters and optics to suppress unwanted wavelengths. This approach raises overall system cost, and can also reduce the intensity of the desired wavelength, reducing measurement accuracy.

In contrast, UVC LEDs offer a light source where light is emitted at, or close to, the required wavelength; so no need for extra optics. And according to Venugopalan, Crystal IS' devices offer better light stability during measurements, compared to sapphire-based alternatives.

"In instrumentation, this is really important and our LEDs have excellent spectral quality," he says. "Customers tell us that when they benchmark our LEDs against a sapphire LED, they see a narrow peak far superior and without the secondary peaks they see with sapphire alternatives."

Cutting costs

Crystal IS now claims its LEDs can cost 50 percent less than broad spectrum UV lamps, given the ancillary equipment demanded by these systems. But clearly another key way to cut costs is to grow epi-layers on larger diameter wafers.

As Venugopalan confirms, his company is currently using 1-inch wafers but is transitioning to 2-inch bulk AlN. "We are quickly scaling up to a larger optoelectronic grade AlN substrates to reduce the manufacturing cost," he says. "There are not so many manufacturers of commercial-grade or optical-grade AlN wafers, which could raise [supply chain] concerns in the industry, but we are now supported by a larger parent company [Asahi Kasei]," he adds. "This company is set up to handle demand from our customers and we will be establishing a stable, large-volume AlN manufacturing output."

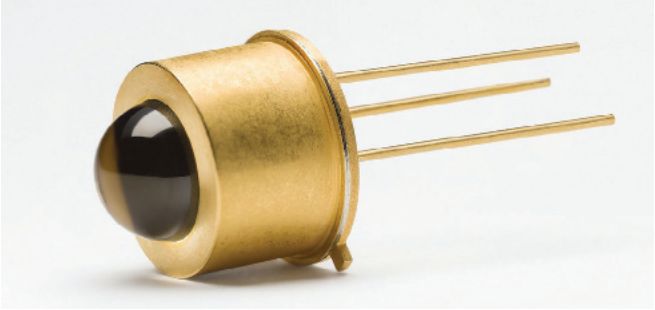
Indeed, chemical manufacturing heavyweight, Asahi Kasei – which acquired Crystal IS in late 2011 – is currently building a trial production line to manufacture the UVC LEDs in Fuji, with all production materials being purchased from Crystal IS.

Venugopalan says the company is already seeing demand for its UVC LEDs in analytical instrumentation and environmental monitoring but expects growing demand from disinfection applications. "We have enough performance right now to replace UV lamps in niche markets within water disinfection and we shall see this soon, starting early next year," he says. "We're qualifying the LEDs, and doing lifetime and reliability tests, and once that's complete we will be able to go after this market."

"You know, this market is so much bigger than instrumentation, so even just addressing the niche sectors will be very significant for us," he adds.

And of course, this makes the move from 1-inch to 2-inch, and eventually 4-inch, AlN wafers, all the more critical.

"The larger substrate sizes will open up more and more sectors of the water disinfection market," says Venugopalan. "Whoever makes the optoelectronic-grade AlN in scale will be the winner, and we believe we are on track to do that."



Optan LEDs target analytical instrumentation applications [Crystal IS]

Analog Devices and Hittite: what next?

As Analog Devices buys Hittite, Rebecca Pool talks to Strategy Analytics analyst, Eric Higham, to find out what lies in store for RF players.

JUST AS INDUSTRY PUNDITS were getting used to the RFMD-TriQuint merger, US signal processing heavyweight, Analog Devices, swoops in and buys RF, microwave and millimetre wave IC designer, Hittite, US, for a hefty $2 billion.

Described as the industry's biggest acquisition of a US IC manufacturer so far this year, the deal saw Hittite's shares rise by 29 percent and Analog's increase by 6 percent shortly after its announcement. And for most, the move makes a lot of sense.

As Analog chief executive, Vincent Roche, emphasised again and again in his post-announcement investors call: "The addition of Hittite increases our presence across the entire frequency spectrum... The timing is good and there's a lot of growth left in all these markets."

Analog Devices is well-known for its signal processing chips used in consumer products including automotives, mobile phones and tablets. Meanwhile, Hittite manufactures high frequency chips for military and satellite communications. Consequently the acquisition clearly fulfils the former's aspirations to offer high frequency chips and other signal processors in a broader range of applications.

As Strategy Analytics analyst, Eric Higham, puts it: "Analog Devices has been talking about getting into the RF space, and now with Hittite, it has definitely become a RF company."

As many in the industry have highlighted, Analog can now add Hittite's high performance RF and microwave products to its existing range of RF products, and draw on its own and Hittite's established partnerships to boost combined market share.

"Where each company has least market strength, the other can step in and should have the relationships to at least get products reviewed," says Higham.

The analyst now expects Analog to start offering more products in 'bundles'. "The company will be saying: 'not only can we provide you a component in that frequency, but we can talk about the signal processing and systems as well'."

And crucially, the deal also outlines an interesting industry trend. "This is the last frontier for integration that everyone is looking at," adds Higham. "It's starting to pull... the low signal processing functions through to the high radio frequencies. Analog Devices isn't a Qualcomm, but this is a start."

But it's not all about expanding the company's reach across the entire frequency spectrum; Analog's acquisition of Hittite also strengthens its financial performance. According to Higham, Hittite has long been the 'darling of the RF industry' due to its consistently high gross margins and operating income. "Plug the company into Analog Devices and this expands all of those financial metrics," he says.

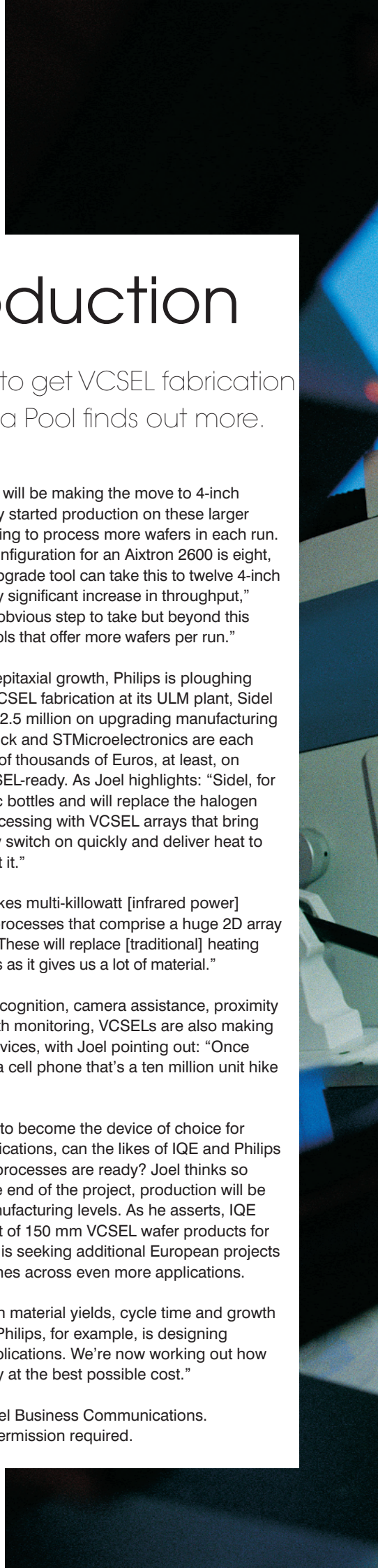
What's more Hittite's high price tag – stock was already trading at a premium prior to the acquisition – can only send positive signals to other businesses in the RF industry. "If any other companies are entering negotiations to be acquired, this has to re-set the bar," says Higham. "Negotiations probably won't get too far before the company says, 'Hittite just went for [$2 billion], that sets our price."

And looking to the future, more industry consolidation is to be expected. Businesses in either the RF or baseband space,

but not both, must surely face concerns over what the likes of Analog Devices will do next with its broad design capabilities. And as Higham highlights, the cost of entering either one of these established markets would likely prohibit expansion from a single company. "If you are a baseband player, it suddenly becomes very expensive to become an RF company in a mature market with established players. And it's the same if you are an RF player, probably more so."

"The latest acquisition has got to make people think long and hard about what their response should be," he adds. "So it wouldn't surprise me if we start to see more consolidation around the non-handset space."

Right: Analog chief executive, Vincent Roche, is confident acquiring Hittite will 'position ADI well to grab more market share'. [Analog Devices]



Perfecting VCSEL production

IQE has joined a €23 million pan-European project to get VCSEL fabrication ready for volume production in three years. Rebecca Pool finds out more.

FASTER DATACOMS, gesture recognition and industrial production are just a few of many up and coming applications that cannot function without the GaAs VCSEL. Integrated with other photonics and electronics devices, these III-V components will enable the high speed interconnects of tomorrow's data centres, heat future industrial manufacturing lines and more.

But there's a problem. While VCSELs are fabricated in a way that resembles LED or CMOS processing – growth of epitaxial layers, lithography, metallisation, packaging and optics integration – manufacturing is relatively slow. Fabrication may well be transitioning to 4-inch wafers, but substrates are still largely 3-inch, process control is limited and some production steps are still manual. However, a recently launched pan-European €23 million project could soon change this.

VIDaP – VCSEL pilot line for infrared Illumination, Datacom and Power applications – aims to bring VCSEL manufacturing on par with LED and CMOS manufacturing in just three years. The project is the latest of some fourteen pilot line projects supported by ENIAC – a European Commission-driven public-private partnership – that aim to boost European competitiveness in nanoelectronics.

This consortium comprises epitaxial material pioneer, IQE, and lighting manufacturing heavyweight, Philips, as well as a host of partners – Sick, STMicroelectronics, Mellanox Technologies and Sidel – each determined to better integrate VCSELs into its chosen application. And a prime focus is the growth of epitaxial layers. As Andrew Joel, commercial director at IQE puts it: "VCSELs are perhaps the most epitaxially demanding of products. The thickness control requirement is a fraction of 1 percent from wafer to wafer and run to run, so yields are lower than traditional high-volume products, and this has been due to the capability of the equipment."

So, with support from the EC ENIAC programme and the Welsh government, the company is to spend nearly €6 million on its VCSEL growth processes, driving up VCSEL throughputs and yields to where LEDs are today. Key priorities include moving to 'state-of-the-art' tools with, for example, *in-situ* monitoring as well as carrying out more off-line SPC analysis to better understand trends in VCSEL growth processes.

"These devices are typically characterised between runs, so you need to get a fast turnaround in the assessment here," says Joel. "So we're streamlining this process to increase run rates."

Crucially, the company will be making the move to 4-inch wafers. IQE has already started production on these larger wafers and is now looking to process more wafers in each run. "The current reactor configuration for an Aixtron 2600 is eight, 4-inch wafers, but an upgrade tool can take this to twelve 4-inch wafers, which is a pretty significant increase in throughput," says Joel. "This is one obvious step to take but beyond this there are even more tools that offer more wafers per run."

And as IQE optimises epitaxial growth, Philips is ploughing some €9 million into VCSEL fabrication at its ULM plant, Sidel is spending just over €2.5 million on upgrading manufacturing lines while Mellanox, Sick and STMicroelectronics are each contributing hundreds of thousands of Euros, at least, on getting production VCSEL-ready. As Joel highlights: "Sidel, for example, makes plastic bottles and will replace the halogen lamps used during processing with VCSEL arrays that bring efficiency gains as they switch on quickly and deliver heat to exactly where you want it."

"Meanwhile Philips makes multi-killowatt [infrared power] systems for industrial processes that comprise a huge 2D array of VCSELs," he adds. "These will replace [traditional] heating lamps... and we like this as it gives us a lot of material."

And be it for gesture recognition, camera assistance, proximity sensing and even health monitoring, VCSELs are also making in-roads into mobile devices, with Joel pointing out: "Once you get designed into a cell phone that's a ten million unit hike immediately."

So with the VCSEL set to become the device of choice for such high-volume applications, can the likes of IQE and Philips guarantee production processes are ready? Joel thinks so and is certain come the end of the project, production will be at LED and CMOS manufacturing levels. As he asserts, IQE recently launched a raft of 150 mm VCSEL wafer products for such applications, and is seeking additional European projects to set up similar pilot lines across even more applications.

"We have a big drive on material yields, cycle time and growth processes," he says. "Philips, for example, is designing VCSELs for its own applications. We're now working out how to grow these efficiently at the best possible cost."

IQE has joined forces with Philips, STMicroelectronics and other Europe-based partners to get VCSEL production ready for volume applications. [IQE]

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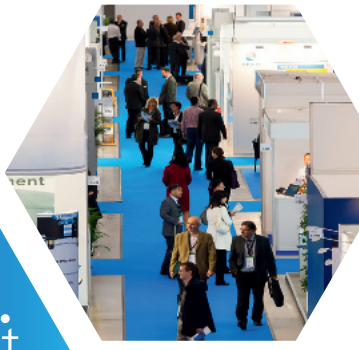

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Understanding imperfections in GaN HEMTs

Concerns over reliability testing and material quality are tempering the success of the GaN HEMT

RICHARD STEVENSON REPORTS

GaN has some great characteristics: It has a very high electric field strength, which allows the construction of devices operating at very high voltages; it has a high thermal conductivity, so chip overheating is not a big issue; and it has good carrier transport properties, which enable the construction of transistors operating at high frequencies.

Thanks to all these attributes, the GaN HEMT has a very promising future. It is tipped to wrestle market share from silicon in the power electronics industry, and in the RF arena it is expected to replace GaAs devices and vacuum tubes, due to its combination of robustness and high output power.

Success is not a given, however. Instead, there are still some weaknesses to address, which are related to material quality and reliability.

Many of these concerns over the capability of GaN HEMTs were highlighted at this year's CS Mantech conference, which was held in late May in Denver, CO. At this gathering Glen David Via from the Air Force Research Laboratory (AFRL) discussed the weaknesses associated with the existing approach for reliability testing; Feng Goa from MIT unveiled an electrochemical degradation mechanism in GaN HEMTs; Petra Specht from the University of California, Berkeley, exposed defective regions within the transistor; and Yutaka Tokuda from Aichi Institute of Technology in Japan reported the results of a comprehensive study into electron and hole traps in GaN epilayers grown on GaN, sapphire and SiC substrates.

Assessing reliability

Via argued that the accelerated lifetime tests applied to GaN HEMTs might fail to give a true picture of their reliability.

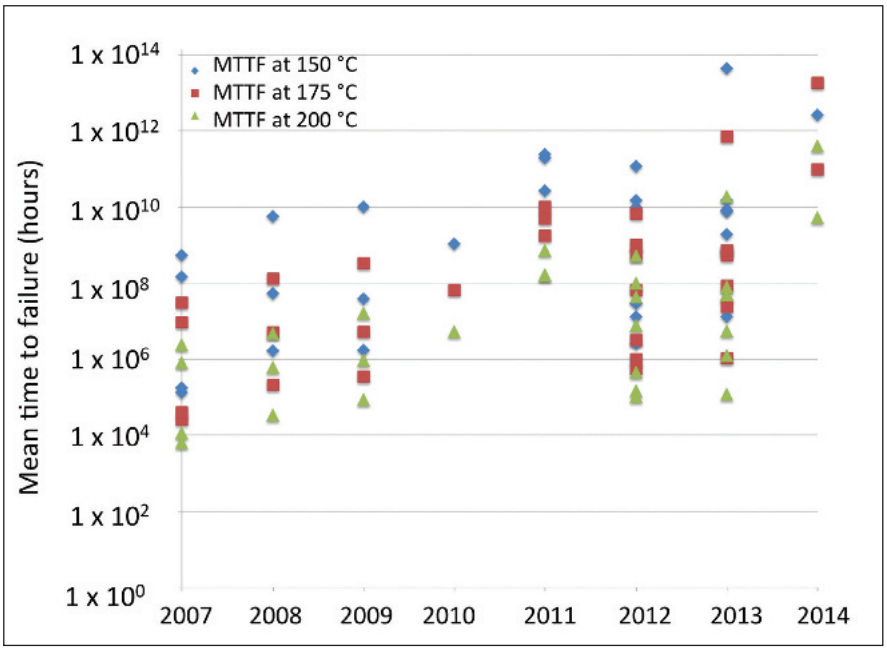


Figure 1. A survey of the literature by Glen David Via from the US Air Force Research Laboratory indicates a steady increase in the mean-time-to-failure of GaN HEMTs.

That's because lifetime estimates are often obtained by taking data over relatively short time frames, and then performing extrapolations by several orders of magnitude. This means that lifetime derived by this approach could shift significantly if inaccurate estimates for channel temperature are employed, or there are errors in the temperature dependence of a material's thermal conductivity.

"My recommendations for increasing user confidence in lifetime tests are to conduct longer term, lower-temperature testing," says Via. "This will aid in reducing the risk of not uncovering a buried, low-activation energy failure mechanism."

He pointed out that another weakness associated with reliability testing is that the data reported is based on accelerated life tests of relatively small sample sizes. "In addition, population statistics are not commonly described, thus confidence bounds on extrapolated lifetimes cannot be determined."

What Via would like to see is a shift from studies that focus on the mean time-to-failure (MTTF) – that is, the time when 50 percent of devices have failed – to predictions of the time to first or one percent failure. "[These figures] will determine insertion readiness for mission critical systems."

At the meeting in Denver, Via presented a survey of industrially reported or published results for AlGaN/GaN HEMTs grown on SiC. He excluded devices formed on silicon from this study, because he only wanted to consider GaN HEMTs employed for mission critical and military applications. These types of applications require a MTTF of 100 years, which equates to a million hours, while commercial applications require a lifetime of just 20 years.

Via's study considered multiple-temperature DC and RF accelerated life tests with channel temperatures ranging from 250 °C to 400 °C, and drain voltages spanning 20 V to 65 V. Values for MTTF varied from less than 100 hours to more than 10,000 hours, and the vast majority of data predicted a MTTF in excess of a million hours for standard operating, which involves a channel temperature of 150 °C. "Given the available lifetime data, there should be little concern with reliability for commercial applications," argues Via.

To predict lifetimes, researchers employ Arrehenius plots, which include an activation energy – it is the slope of a line that is fitted to the MTTF.

"Ideally, the activation energy should correspond to documented failure mechanisms, as with silicon and gallium

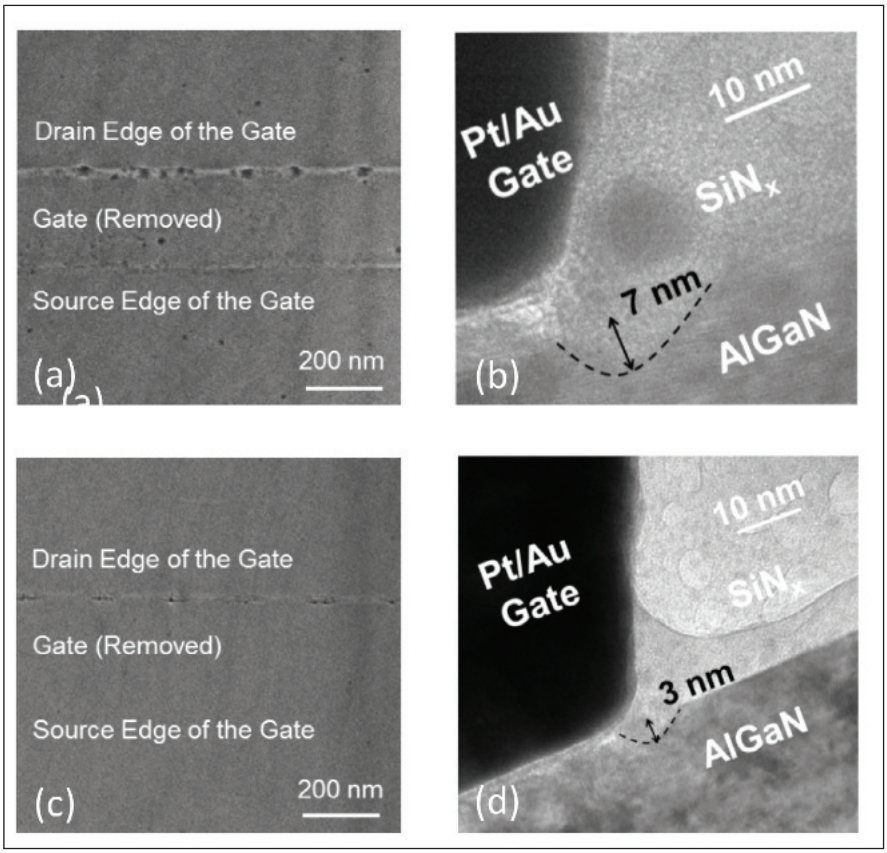


Figure 2. Experiments by Feng Gao and co-workers from MIT show that water is to blame for the creation of pits in GaN HEMTs. Under water-saturated argon gas ((a) & (b)), larger, more numerous pits form than in a dry argon environment ((c)&(d)).

arsenide," says Via. However, at present, the GaN community is yet to agree on the dominant failure mechanisms associated with the activation energy. "The crack or pit that has been observed by many groups has been associated with activation energies ranging from 1.05 eV to over 2.2 eV."

To illustrate how many failure mechanisms have been proposed, Via presented the results of a survey of the literature by his colleague Eric Heller. This study uncovered reports of more than a dozen different explanations for GaN HEMT failure, including diffusion, defect percolation, surface barrier oxidation and trapping.

One interesting trend found by Via in his work is that the activation energy determined in lifetime tests is increasing, and it is now around 2.5 eV, compared with just 1.5 eV in 2007 (see Figure 1). He attributed part of this increase to improved material and processing, and he believes that this approach to lifetime testing is also leading to increases in activation energy values. " As the technology has matured, it has been more and more difficult to accelerate degradations in a reasonable amount of time, so harsher and harsher conditions have been applied." One major flaw resulting from this is that the induced failures are not representative of the 'use' wear-out mechanism.

"There is also the complication that as GaN technology has become more rugged, life tests are not taken to failure," adds Via. Instead, engineers carry out the test for a fixed period, and times to failure are extrapolated to find a MTTF for the population. With this approach, lifetime estimates and values for the activation energy are then generated from an extrapolation of an extrapolation, increasing uncertainty.

Via has looked into possible correlations between activation energy and various device characteristics. The periphery of the device appears to have no impact on activation energy, which is lower when the gate length is shorter. Drain bias does not influence the activation energy, which is lower when using RF testing, rather than a DC approach, to perform accelerated tests.

Efforts at assessing the reliability of GaN-on-SiC through DC and RF accelerated tests and long-term operational tests will continue at the Sensors Directorate at AFRL. "The goal is to help the community build a better understanding of GaN degradation physics and increase the confidence in lifetime estimates through statistically relevant sampling of technology offerings," says Via.

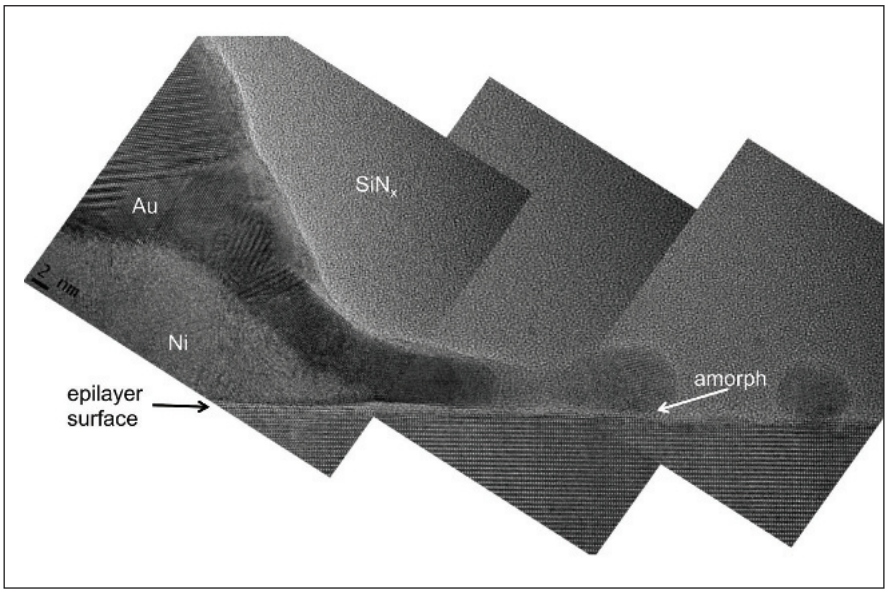


Figure 3. The ultra-high resolution, aberration-corrected transmission electron microscope at the Lawrence Berkeley National Laboratory can uncover the profile of gold near the foot of the gate of GaN HEMTs.

Electrochemical reactions

At MIT, Gao and colleagues are claiming to have a comprehensive explanation for a key structural degradation mechanism in GaN HEMTs – the creation of electrical pits near the surface of the transistor.

"It was not clear why this degradation was only seen by some research groups and not others," says team leader Tomás Palacios. "We found that the difference between the samples of different groups is probably not only in the magnitude of the electric field but, especially, in the quality of the passivation."

Engineers from MIT found that pits occur when water reaches the III-N surface. This leads to the creation of an electrochemical cell, which forms at the gate edge where gate metal, III-N surface and passivation layer meet.

Uncovering this degradation mechanism involved tests under vacuum, ambient air and a water-saturated environment, using GaN HEMTs made both at MIT and at an industrial collaborator. These transistors consisted of a 3 nm-thick GaN cap, a 14 nm-thick AlGaN barrier, a 1 nm-thick AlN interlayer and a thick GaN buffer deposited on semi-insulating SiC.

Metal evaporation added a Pt/Au gate with a length of 250 nm, and a thick SiN layer deposited by plasma-enhanced CVD passivated the surface of the device.

Testing began by taking two chips from the same wafer, each with five identical HEMTs. Both were subjected for 3000s to a high-drain off-state bias: a gate source voltage of -7 V, and a drain source voltage of 43 V (which is much lower than the breakdown voltage). One of these chips was held in ambient air, and the other in a 1 x 10^{-7} Torr vacuum.

Engineers from MIT found that pits occur when water reaches the III-N surface. This leads to the creation of an electrochemical cell, which forms at the gate edge where gate metal, III-N surface and passivation layer meet

HEMTs from both chips were scrutinised with a variety of microscopy techniques. Scanning electron microscopy and atomic force microscopy were used to study an exposed area formed from removal of the gate metal. This revealed that stressing in air, rather than vacuum, led to larger, more numerous pits (see Figure 2).

These finding were confirmed by cross-sectional transmission electron microscopy (TEM) measurements on another pair of HEMTs that had not been subjected to etching of the passivation and gate metals.

The engineers discovered, via energy-dispersive X-ray analysis, that these pits had a high concentration of oxygen and a low concentration of aluminium and gallium. The two likely sources of oxygen were oxygen gas and water. To identify the culprit from these two suspects, the team took another two chips of five identical HEMTs and applied the same stress test as before. However, this time they placed these devices in either a water-saturated argon or dry argon environment. Many more pits were found in HEMTs stressed under water-saturated argon conditions, pointing the finger at water molecules as the cause of pitting.

To rule out other causes, the team considered other gases, such as oxygen, nitrogen and carbon dioxide, comparing results for a water-saturated and a dry environment. Pit sizes were always greater when water was present, and there was very little pitting when the only source of oxygen was dry oxygen gas or dry CO_2.

The team argues that the root cause of the pitting is an electrochemical cell at the gate edge that causes anodic oxidation of the AlGaN layer. This reaction starts at the GaN surface and proceeds into the AlGaN barrier during electrical stress. The gate metal acting as the cathode provides electrons to the water at the SiN/AlGaN interface when the gate-to-drain diode is reverse biased, while trap-assisted inter-band tunnelling in the AlGaN barrier provides holes for the reaction.

MIT's findings may raise a few eyebrows, because a thick layer of SiN has been widely viewed as an excellent barrier to moisture. "However, there is nothing perfect," says Palacios, who points out that it actually takes a very small volume of water to penetrate through SiN and destroy a HEMT.

The obvious approach to reducing the formation of pits is to switch to a better water barrier. "Our group has used hydrophobic materials such as Teflon to delay these water-assisted electrochemical reactions and this largely improves the device reliability and lifetime," reveals Palacois.

He points out that this approach complements a well-trodden path for increasing device lifetimes: reducing electric field strengths via the introduction of field plates and other structures. Targets for his group are to understand how the electric field impacts the device, and how the degradation physically happens. "In collaboration with colleagues at MIT and elsewhere, we are now interested in studying if dislocations and other lattice defects play a role in accelerating device degradation."

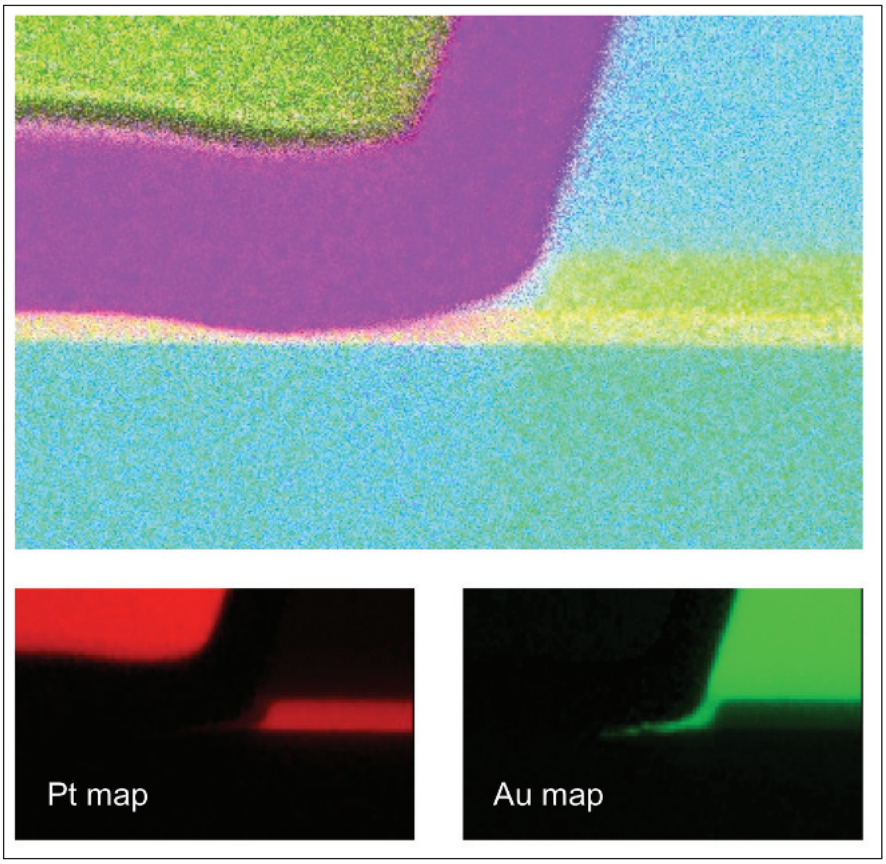


Figure 4. Electron dispersion spectroscopy can identify the location of elements such as silicon, nitrogen, oxygen, aluminium, gallium, platinum, and gold. This measurement technique revealed: the absence of a GaN cover layer; the formation of AlO_x at the surface; a decrease in the nitrogen profile, which occurs with increasing oxygen content; and the accumulation of gold at the surface of the 'dip' area.

Uncovering point defects

Another group looking at defects in GaN HEMTs is that involving Specht, plus colleagues at the Naval Research Lab and the Naval postgraduate School. Their efforts have focused on finding and identifying point defects with an ultra-high resolution, aberration-corrected TEM that can deliver local chemical analysis. Using this approach they separated effects coming from epilayer growth, device processing, transistor operation and the environment.

"The high-resolution imaging techniques we are using were developed for nano-structure and two dimensional material research, but have never been tried before on complete device structures," says Specht. "We have reason to expect

that we can go beyond the current results available on GaN-based device reliability, finding and ambiguously identifying the sources of failure mechanisms."

Sample preparation involved a novel 'all ion-mill' approach that begins with a high-energy, focused-ion beam lift-out process, followed by a low-energy argon ion milling that enables local cleaning of the sample, while maintaining its structural integrity. Cutting involved a 30 kV gallium beam, while additional thinning and cleaning of the sample employed argon beams with energies of just 900 eV and 500 eV, respectively.

"The resulting clarity in our images is rarely seen anywhere else," claims Specht, who puts this down to the use of the world's best transmission electron aberration-corrected microscope, which has a resolution of 0.5 Å and is located at Lawrence Berkeley National Laboratory.

The team looked at a variety of HEMTs, which were all formed on silicon and featured buffer layers with a thickness of 1.2 μm, followed by an 800 nm-thick layer of GaN, a 17.5 nm layer of AlGaN and a 2 nm-thick GaN cap. The portfolio of devices under study included those with gates made from PtAu and NiAu, and those that were either fresh, had degraded after operation or failed during operation.

Imaging with the ultra-high-resolution TEM revealed two typical defects close to the gate edge: a gold 'foot' area; and beside it, a crater-like 'dip', which is much deeper and wider in devices with a PtAu gate (see Figure 3). Specht and co-workers believe that the relative location of these two extended defects – the foot and the dip – indicates that they are process related.

Energy dispersive spectroscopy unveiled gold contamination in the dip, which is believed to occur due to diffusion from the gate contact (see Figure 4). This technique also revealed a thinning of the AlGaN layer, with a larger, gold-containing amorphous layer forming at the surface.

One of the most surprising findings of the study was the absence of the 2 nm-thick GaN cap in all structures apart from the epilayer.

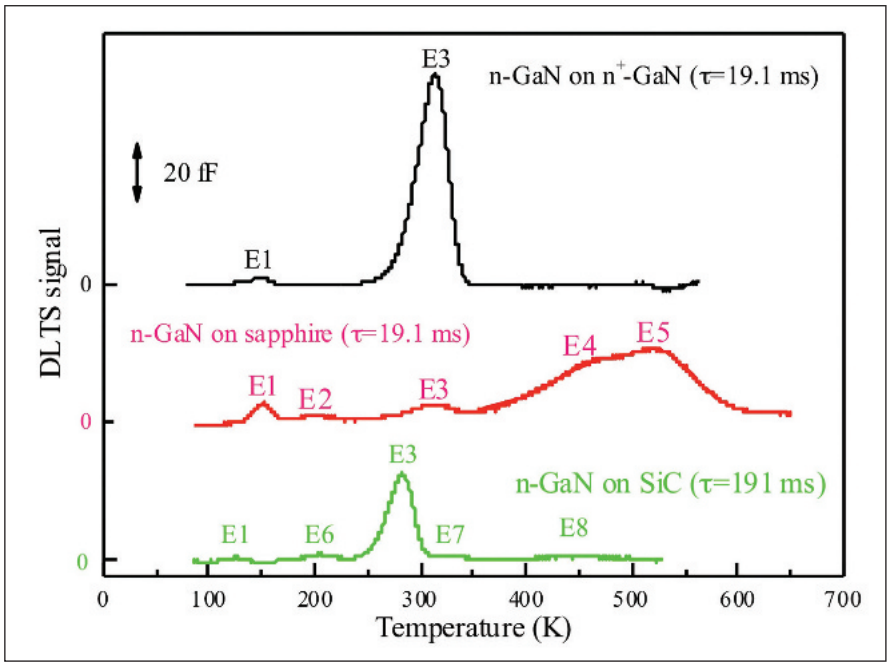


Figure 5. Deep-level transient spectroscopy can reveal electron traps in GaN layers grown on a variety of substrates.

"It is still unclear to me how uncharacteristic this is for the initial wafer," admits Specht. "The piece I got may have also come from the edge of the wafer, and may have had some inhomogeneous deposition there." It is also possible that an initial cleaning step applied to this piece, prior to device processing, could have led to the loss of the GaN cap. "We are clarifying those issues right now," says Specht.

Cataloguing traps

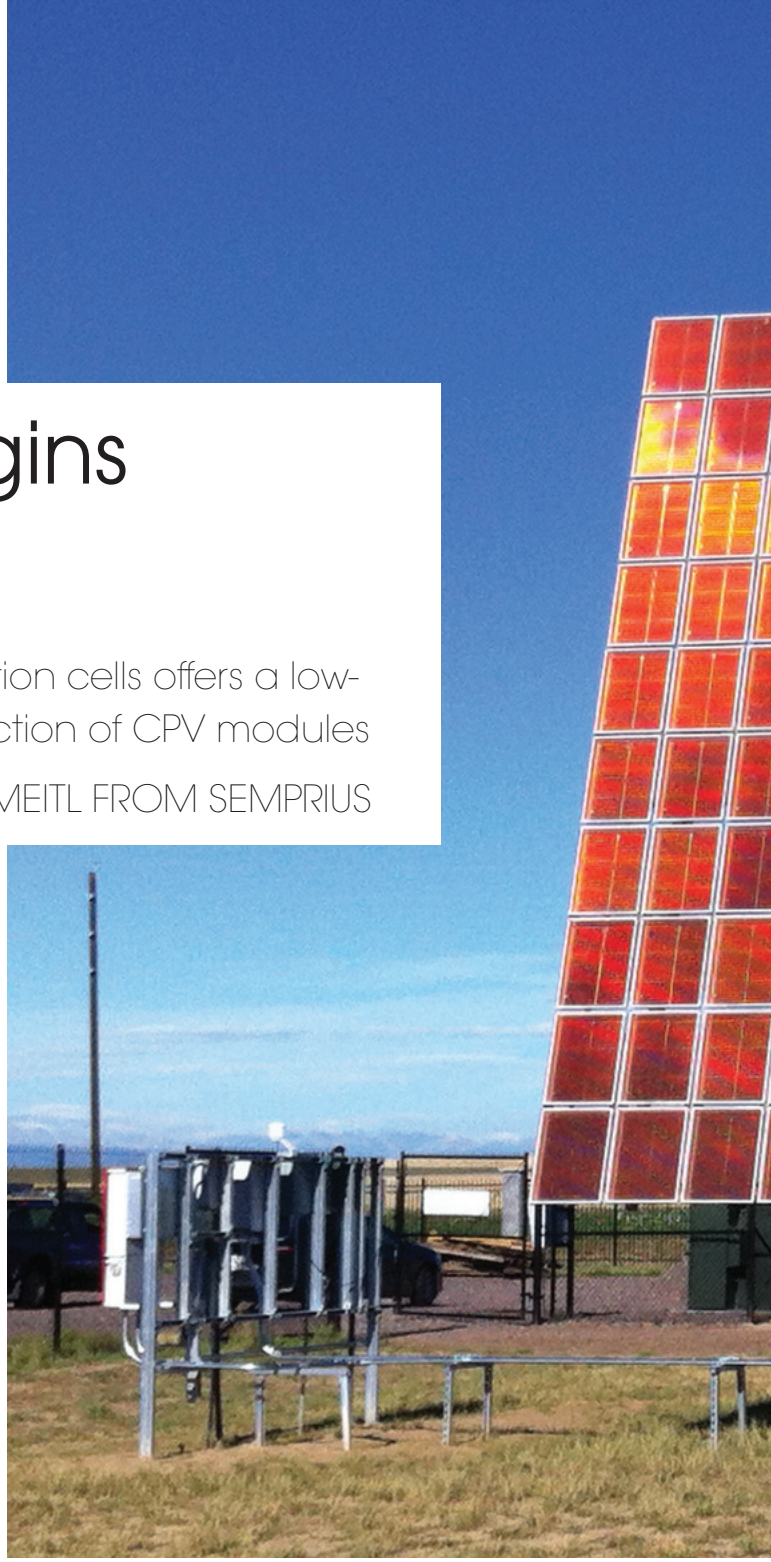
Meanwhile, Tokuda is continuing his comprehensive study of electron and hole traps in *n*-type GaN grown on sapphire, GaN and SiC. At CS Mantech he revealed that the combination of deep-level transient spectroscopy and minority carrier transient spectroscopy on Schottky diodes, p^+n diodes and MOS structures had uncovered nine electron traps with energies between 0.24 eV and 1.2 eV, and five hole traps with energies ranging from 0.25 eV to 1.8 eV (see Figure 5).

Of this total of 14 traps, three are commonly observed in MOCVD grown GaN, regardless of the substrate: electron traps at energies of 0.24-0.26 eV and 0.57-0.61 eV, and a hole trap with an energy of 0.86-0.88 eV. According to Tokuda, the lower energy electron trap may be due to dislocations; while its higher-energy cousin may depend on growth conditions, such as temperature and pressure; and the hole trap may depend on growth conditions.

"We are [now] studying the distribution of trap concentrations on each two-inch and three-inch MOCVD *n*-GaN wafer, to understand the relationship between the trap concentration and the performance of fabricated devices," says Tokuda.

This effort, plus those by other researchers that are studying the weaknesses in GaN HEMTs, will help to address the flaws of this device and ultimately drive its commercial success.

Note that the views, opinions, and/or findings associated with Glen David Via should not be interpreted as representing the official views or policies, either expressed or implied, of the Air Force Research Laboratory or the Department of Defence.



Magnifying margins with microcells

Parallel printing of miniature multi-junction cells offers a low-cost, scalable approach to the production of CPV modules

BY KANCHAN GHOSAL AND MATTHEW MEITL FROM SEMPRIUS

THE CPV INDUSTRY is in the midst of a transition. The days of building first-generation prototype systems are now behind us, and the manufacture of high-performance, reliable systems that can turn a profit are underway. Deployment is rising fast, with installations of 80 MW in 2013 following on the heels of about 40 MW in 2012, and suppliers such as Soitec have shown five-year field results with minimal degradation and an availability in excess of 99 percent.

However, despite all this success, CPV is still dwarfed by the incumbent solar technology, silicon – deployment of this totalled 40 GW in 2013. The plummeting prices of crystalline silicon over the last few years have made it challenging for advanced technologies that are not already at gigawatt levels to make a commercial impact.

One solar technology that can compete is a novel form of CPV developed by our team at Semprius, headquartered in Durham, NC. Our CPV technology is based on the parallel printing of thousands of cells, which are far smaller than those used by other CPV companies. Thanks to this move to greater miniaturization, alongside the selection of cost-effective, high-quality materials and processes, it is possible to address the challenges of scale, cost and reliability that must be overcome to have success in today's highly competitive solar market.

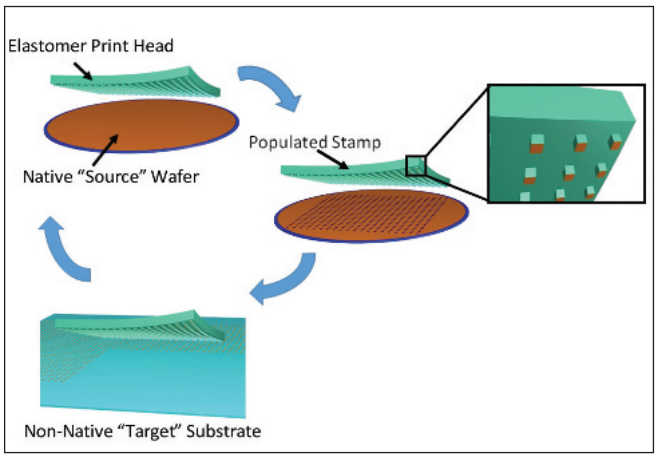
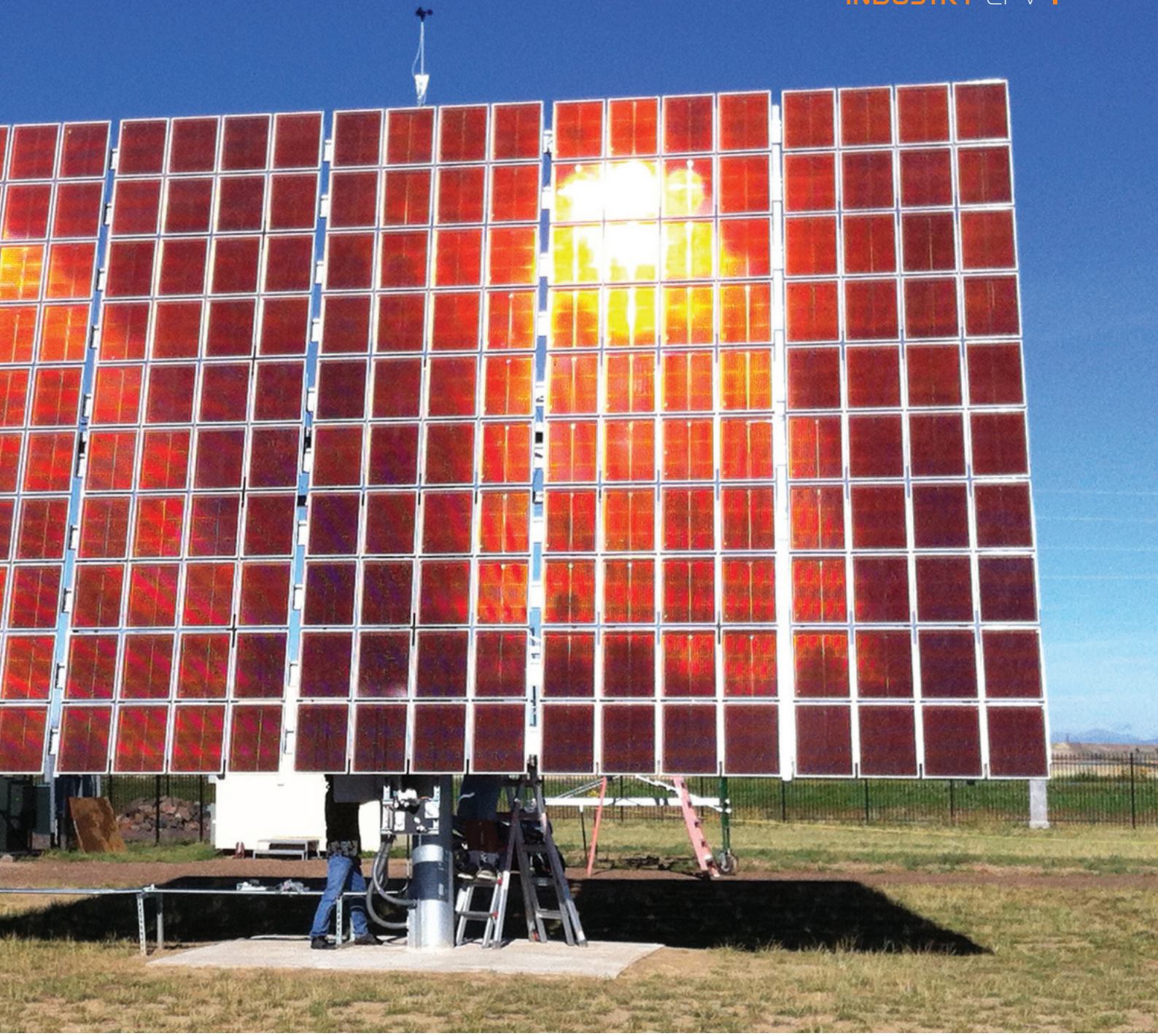


Figure 1. Micro-transfer printing using a rubber stamp enables the parallel transfer of many chips

The micro-assembly technology that we employ, which we refer to as micro-transfer printing, has its origins at the University of Illinois. Researchers working there developed a technique that enables the removal of semiconductor devices from the growth substrate and subsequent printing on another platform in a massively parallel manner (see Figure 1). Armed with this technology, it is possible to print thousands of devices simultaneously, each with a ±2 μm placement accuracy. This capability allows us to work with devices that are too small, numerous, fragile, or otherwise difficult to handle by conventional methods.



Semprius 64 m² system at Solar Technology Acceleration Center, Denver, Colorado, USA.

Using our printing technique, we transfer sub-millimetre solar cells from their native growth substrates onto low-cost interposers (see Figure 2) to form surface-mountable sub-receivers that serve as the engines of our modules. To make a module, hundreds of sub-receivers are mounted onto a backplane, each with a spherical secondary optic (see Figure 3). The backplane is then mounted inside a steel enclosure upon which a primary optic is attached.

The steel enclosure protects the receivers from the environment and maintains the focal distance between the primary optic and the cell. The primary optic consists of a silicone lens array on a tempered front glass sheet, each lenslet perfectly aligned to a cell. The primary optic concentrates sunlight by a factor of 1,111 onto the micro-cells.

This module architecture is compatible with the most advanced III-V cell materials, which operate at the highest efficiencies and increase the competitiveness of CPV technology. Traditionally, cells used at high concentrations have been based on up to three junctions, but we, like several other CPV companies, are now progressing to devices based on four or more junctions that could lead to cell conversion efficiencies in excess of 50 percent.

These include those produced mechanically by combining sub-cells from different kinds of growth substrates. Recent work by us, in collaboration with colleagues at the University of Illinois and Solar Junction, has demonstrated how micro-assembly can facilitate this kind of mechanical stacking, using a micro-scale, heterogeneous integration approach.

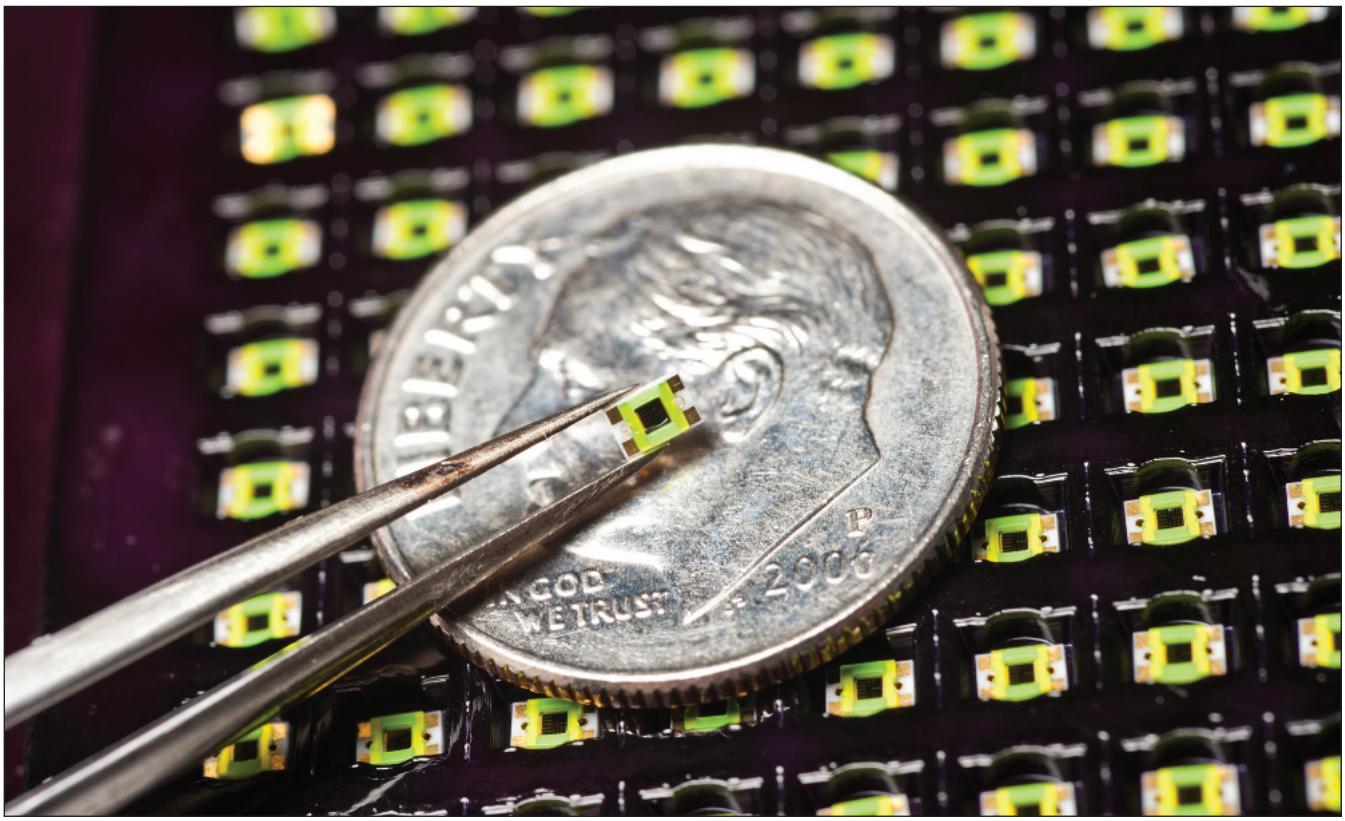


Figure 2. The 600 μm cell on interposer lies at the heart of the Semprius CPV module

Small cells

Our team at Semprius have made significant strides with our printed micro-cell technology since we started work in this area in 2008. Our initial proof of concept module consisted of printed single-junction GaAs cells, measuring 0.1 to 0.3 mm on a side, which were designed for a concentration of a few hundred suns. After significant development and optimisation, we have progressed to 0.6 mm multi-junction cells that operate optimally at more than a thousand suns and are built from state-of-the-art epitaxial materials from partners such as Solar Junction.

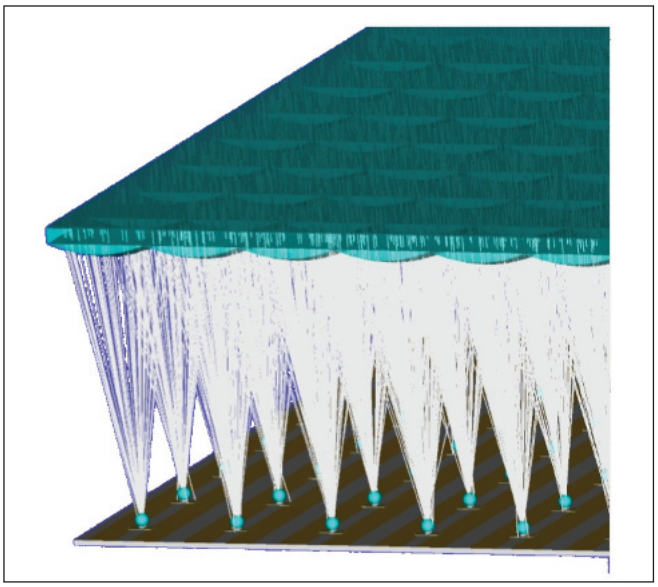


Figure 3. Semprius' optical train enables high levels of concentration on an array of triple-junction cells

Cell size optimization is a complex process that maximises the performance-to-cost ratio. Cost is influenced by the part count, yield and wafer utilization. Performance considerations include passive thermal dissipation, current density and optical efficiency. A small cell size delivers many benefits, which are discussed below, including a reduced optical path, better thermal management, superior optics, and a lower series resistance for the cells.

Reducing the optical path unlocks the door to thinner modules. A thin module design has multiple benefits, including lower weight, a reduction of the material required to construct the modules, reduced wind loading, and greater packing density. This means lower cost modules, lower cost trackers and lower cost shipping.

Thermal management is a big issue for CPV, because focusing sunlight by factors of more than a thousand can lead to significant cell heating. Our design is superior in this regard, because the thermal load is distributed over a larger area. For example, each of our cells has to dissipate about 220 mW of heat, compared to about 60 W for a more typically sized cell with an area of 1 cm^2. Thanks to the reduced requirement for heat dissipation, our modules don't require heat sinks, and this leads to significant cost savings.

Crucially, we can do this without compromising performance or reliability – even without heat sinks, our cells remain relatively cool during operation. Another strength of our design is that it allows the use of unique, high-performance secondary optics. In our case, the secondary optic is a tiny ball lens placed on top of the cell (see Figure 4). The advantages of this pupil-imaging optic are that it provides a wide acceptance angle, delivers a

uniform distribution of light on the cells and produces minimal chromatic aberration. While micro-cells are compatible with this type of optic, it is impractical for larger cells because larger ball lenses require too much glass and are therefore too costly.

In order for the electrons generated in a solar cell to provide useable electricity, they have to traverse the lateral extent of the device. With smaller cells, electrons travel a shorter distance, leading to a lower series resistance and an increase in the power produced by the module. On top of all these benefits, our approach to module production has several other virtues, including substrate re-use, whereby the relatively expensive substrate can be cleaned after the micro-transfer printing process and re-used many times. This significantly reduces the cost of the solar cell.

Another benefit of our approach to module production is that it is similar to a standard microelectronics process. After we use micro-transfer printing to transfer thousands of cells from the source wafer to a ceramic substrate in a massively parallel manner, receivers are then attached to a backplane using standard surface mount technology. By adopting this approach, the only 'assembly' part of the process is the attachment of the lens and the backplane to the enclosure. Alignment, though critical, is easily performed with adequate precision using existing technologies. As a result, the capital expenditure for setting up a manufacturing plant is among the lowest for PV module technologies and the process is highly scalable.

One major benefit of this manufacturing process is that it allows for a distributed manufacturing strategy. The receivers can be fabricated at a wafer fab, shipped as tiny die in tape and reel, while the modules can be assembled closer to the end markets, reducing transport costs related to materials such as steel and glass and addressing 'local content' requirements, as necessary.

Module evolution

In 2008, we prototyped a module that operated at 1000 suns and was based on 4 single-junction microcells. This design evolved into an engineering prototype module with nominal dimensions of 14 inches by 14 inches, using 384 transfer-printed two-junction cells. Evaluation of this module's performance on-sun for more than 18 months confirmed the feasibility of this design and provided valuable insight for our production module. A small number of engineering prototype modules were integrated into a 1.3 kW research, development and demonstration (RD&D) system in Tucson, Arizona.

Thanks in part to a SunShot Incubator Award for $ 3 million from the US Department of Energy, we have refined our module design, making it better-suited to high-volume manufacturing and improving its performance-to-cost ratio. The latest version, which has now been in the field for more than two years, operates at 1111 suns and has a nominal surface area of 18 inches by 24 inches with a thickness of 2.7 inches. This module, manufactured at a pilot plant in Henderson, NC, features 660 transfer-printed triple-junction cells.

One of our overriding aims from a very early stage has been to develop cost-optimized modules that can be manufactured in high volumes and perform reliably in the field for more than 25 years. To accomplish this goal, we have taken great care to select materials that are already available and cost-effective

Figure 4. The fabrication of the module backplane with receivers employs processes based on surface mount technology

in high volume, and have been characterized outdoors and in reliability chambers. We have used processes and equipment that are standard in the semiconductor, optoelectronic and automotive industries; the only unique process is the micro-transfer printer.

Reliability is paramount, and to address this in an appropriate manner, we have been running a rigorous outdoor and chamber testing programme for several years. The benefits of this programme includes being able to accurately characterize the impact of our development progress and to gain feedback on the suitability of the design to field conditions. Maturation of the CPV industry has also led to the development of IEC and UL standards that have been agreed to by the industry, vendors and national and commercial test labs. Additional characterization of our modules – both the early engineering prototype and the current design – has been performed at various independent labs, including NREL, Sandia National Labs and the Fraunhofer Institute for Solar Energy, providing valuable feedback to our design and characterization process.

Efficiency gains

Today's modules, which are produced in our pilot plant, have an efficiency of 34 percent to 36 percent at concentrator standard test conditions (CSTC): 1000 W m^{-2} direct normal irradiance, 25˚C cell temperature and spectrum defined by the standard AM 1.5. Independent testing of one of our higher performing modules by scientists at Fraunhofer ISE revealed an efficiency of 35.5 percent (see Figure 5).

Encouragingly, after more than two years in the field, our latest generation of modules are showing no measurable deterioration in performance, or any other unwanted effects. Testing in this operating environment continues, with our modules currently under scrutiny in 15 pilot systems in eight countries. These systems are providing data from locations on three different continents, and are enabling us to understand the performance of our modules under different geographical and climatic conditions. The seven systems installed since late 2012 range from 14 kW to 24 kW and are suitable for future commercial deployments. They feature optimized trackers from mature vendors and industry standard inverters. This effort has involved working with tracker partners, who have partnered with us to design a system that optimises the performance-to-cost

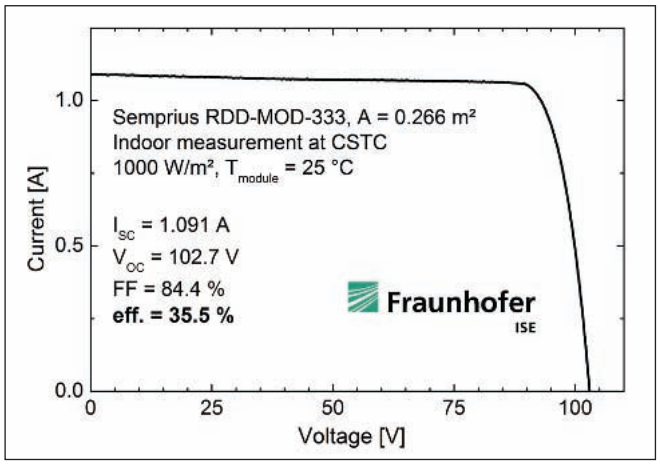


Figure 5. Independent test results from the Fraunhofer Institute for Solar Energy confirming a module efficiency of 35.5 percent

ratio. To alleviate any concerns relating to tracker reliability, we have only selected tracker partners with field experience spanning years and hundreds of megawatts of deployment. These systems have now been operating for more than a year, and they have a peak AC efficiency exceeding 30 percent.

High efficiency, low equipment cost and reliability are clearly important, but they are not the only issues relating to CPV deployment – there are also more underappreciated aspects, such as equipment transport, field installation, operation and maintenance. For example, it is critical that both the tracker and the modules are optimised for transport in standard ocean containers; otherwise transportation to the project site can add significantly to the costs. Thanks to the low profile of our module and the configuration of the module arrays, it is possible for us to realise a high packing density that is competitive with flat plate silicon modules and better than CPV modules made by our peers. It is also critical to devise installation methods that are standard in the construction industry, can be executed by construction labour, are safe and can be performed with high velocity and at a low cost.

We have also developed installation, operation and maintenance methodology and documented best practices that have drawn on our and our partners' experiences in civil construction, field assembly and commissioning. The experience gained from these activities will aid our next deployments, and lead to further refinements in the ways we approach fulfilling our customer's orders, as we deploy systems in larger projects.

Goals for the future

We have just completed the design and initial tests relating to our third generation module, and we unveiled the results at the 40th IEEE PVSC, which was held this June in Denver, CO. The overarching goal for this latest design was to cut costs further, while maintaining much of the existing design elements and making no impact on the pilot plant process and toolset. These considerations have led to a design that maintains the dimensions of the existing design, while increasing concentration to 1600 suns. Indoor and outdoor testing of the new module, which has 30 percent fewer receivers than the existing design and provides a significant reduction in module cost, shows it delivers a similar performance to its predecessor.

Another recent breakthrough that we have made is to demonstrate stacked cells that are fabricated by printing two micro-cells, grown on different substrates, on top of each other. In this project a top InGaP/GaAs/InGaAsNSb cell is grown on a GaAs substrate, released from it by etching a sacrificial AlInP layer and printed on a germanium bottom cell. A spin-cast, 300 nm-thick film of As_2Se_3 binds together these two cells together while providing a low-loss optical interface that is thermally conductive and electrically insulating. The triple-junction and germanium cells operate independently with separate sets of terminals, thereby avoiding current matching issues. Operating at 1000 suns, these multi-junction and single junction cells have efficiencies of 42.1 percent and 1.8 percent, respectively, and thus combine to deliver an efficiency of 43.9 percent.

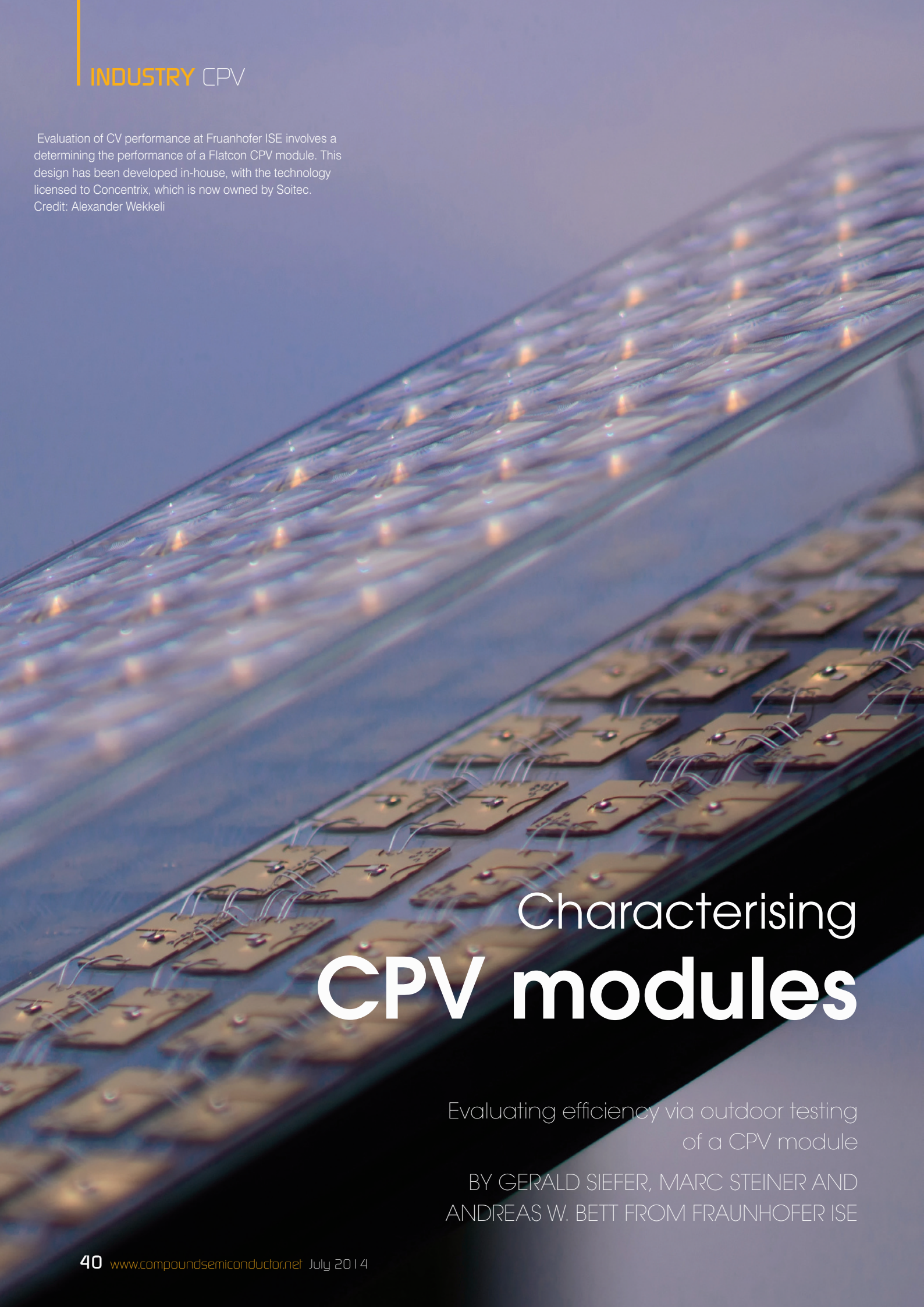
This work represents the first demonstration of a four-junction, four terminal cell, and it lowers the barriers towards developing a cell operating at an efficiency greater than 50 percent, and a module operating at an efficiency in excess of 40 percent. Such cells can be fabricated on existing equipment and quickly integrated into our current module design, which will help to accelerate the adoption of CPV systems that are more competitive in sunny climates than those based on silicon.

Semprius has increased the concentration factor of its modules. This version operates at 1100 suns

Other opportunities for micro-transfer printing

MICRO-TRANSFER-PRINTING is a powerful device assembly technology that can serve various compound semiconductor applications. For non-photovoltaic applications, it is being commercialized by X-Celeprint Limited of Cork, Ireland.

This micro-assembly technology offers a practical way to combine arrays of micron-scale, diverse, high-performance materials and devices with substrates that have vastly different properties and cost structures compared with traditional packages. It is a technology that opens new levels of component miniaturization, facilitates heterogeneous integration, and readily interfaces with epitaxial lift-off techniques for substrate re-use.



Evaluation of CV performance at Fruanhofer ISE involves a determining the performance of a Flatcon CPV module. This design has been developed in-house, with the technology licensed to Concentrix, which is now owned by Soitec. Credit: Alexander Wekkeli

Characterising CPV modules

Evaluating efficiency via outdoor testing of a CPV module

BY GERALD SIEFER, MARC STEINER AND ANDREAS W. BETT FROM FRAUNHOFER ISE

ELECTRICAL GENERATION COSTS are the key metric for comparing the competiveness of different solar technologies. But in order to make this comparison, one needs to know the cost of assembling each type of solar system, and the peak power that it can generate. So it is essential to put a procedure in place for accurately determining the power produce by all forms of solar system.

That's not easy to do, because the multi-junction solar cells produced by this community are deployed in terrestrial systems operating in a very different manner from those based on silicon cells. While the latter are often fixed in position, multi-junction solar cells are carefully positioned in systems that track the position of the sun in the sky to ensure its radiation is focused onto the chips from dawn to dusk. Sunlight is typically concentrated by a factor of several hundred, leading to an acceptance angle for the incident radiation of at most a few degrees, and sometimes as little as half a degree.

One attractive option for assessing the performance of this technology is to turn to indoor sun simulators designed for CPV modules. With this approach, testing can take place even when the sun isn't shining, and matching of the prevailing spectral conditions to the reference conditions is not required. However, these indoor simulators have only just become available and are still under development.

So, at the moment, most assessments of CPV modules are still performed outdoors. That's the approach we still take at the Fraunhofer Institute for Solar Energy in Freiburg, Germany, using a system that features additional single-junction cells that offer insights into the performance of the triple-junction.

Modules that are attached to our tracker system include a Flatcon CPV module that we built in-house (our Flatcon technology has been licensed to Concentrix, now Soitec, but we still build small-size CPV modules). This module features lattice-matched $Ga_{0.50}In_{0.50}P/Ga_{0.99}In_{0.01}As$/Ge triple-junction cells, contains 52 silicone-on-glass Fresnel lens-cell pairs, and has an aperture area of 832 cm^2.

Our characterisation of modules mounted on the tracker includes measurements of current-to-voltage (IV) curves every few minutes. In addition, prevailing meteorological conditions are monitored, including the ambient temperature, wind speed, air pressure and humidity, plus the global normal (GNI) and direct normal irradiance (DNI) – these are measured with a pyranometer and a pyrheliometer mounted on the tracker.

It is possible to determine the module efficiency by measuring the DNI, because this corresponds to the level of irradiance that a CPV module can use for power generation. If the GNI is also known, an indication of the clearness of the sky can be obtained by calculating the DNI-to-GNI ratio.

We also consider the clearness of the sky, using a camera mounted on the tracker to take photos and provide very valuable information concerning cloud coverage. When clouds are in the proximity of the sun they can influence system performance by, for example, disturbing the sensors used to track the sun.

With a multi-junction cell architecture, the individual subcells are connected in series. The downside of this configuration is that the electric current generated by the whole cell stack is limited to that of the subcell with the lowest current. Since each of the subcells absorbs a different spectral region, the sensitivity to spectrum is higher compared to single junction cells. However, the seasonal variation in power output over the year is similar to flat-plate PV.

The spectral distribution of the sunlight can be determined with direct measurements, using spectroradiometers, or by using models based on measured atmospheric parameters, such as the aerosol optical depth. However, if one wishes to directly assess the impact of the spectrum on the current output of multi-junction cells, it is possible to employ an elegant method based on so-called component cells (also referred to as isotype cells) – they have structures that are similar to multi-junction solar cells, but only have one active *p-n* junction.

One of the great merits of using component cells is that they allow the current in a particular cell to be measured without affecting the current generation in the other subcells, which are electrically inactive. We have fixed this type of measurement tool to our tracker system, using a commercially available Black Photon sensor set containing three component cells corresponding to the subcells of a lattice matched triple-junction cell.

Real data

We have now been recording data from our Flatcon CPV module for more than a year, and over that time we have acquired

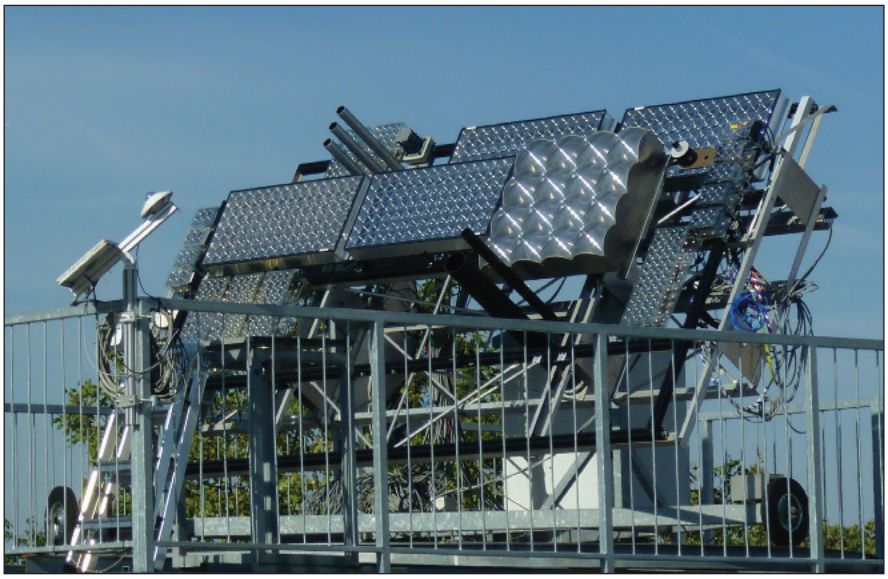


Figure 1. Sun tracking unit on the roof of Fraunhofer ISE. Several CPV modules, as well as different meteorological sensors, are continuously tracked to the sun with an accuracy of ±0.1°.

more than 10,000 I-V curves. This has given us an insight into variations in module efficiency, which are similar to those for flat plate PV (see Figure 2). Note that the plotted efficiency is based on the measured power output of the module and the impinging direct normal irradiance – there is no data filtering related to either the DNI, temperature, wind speed or spectral conditions.

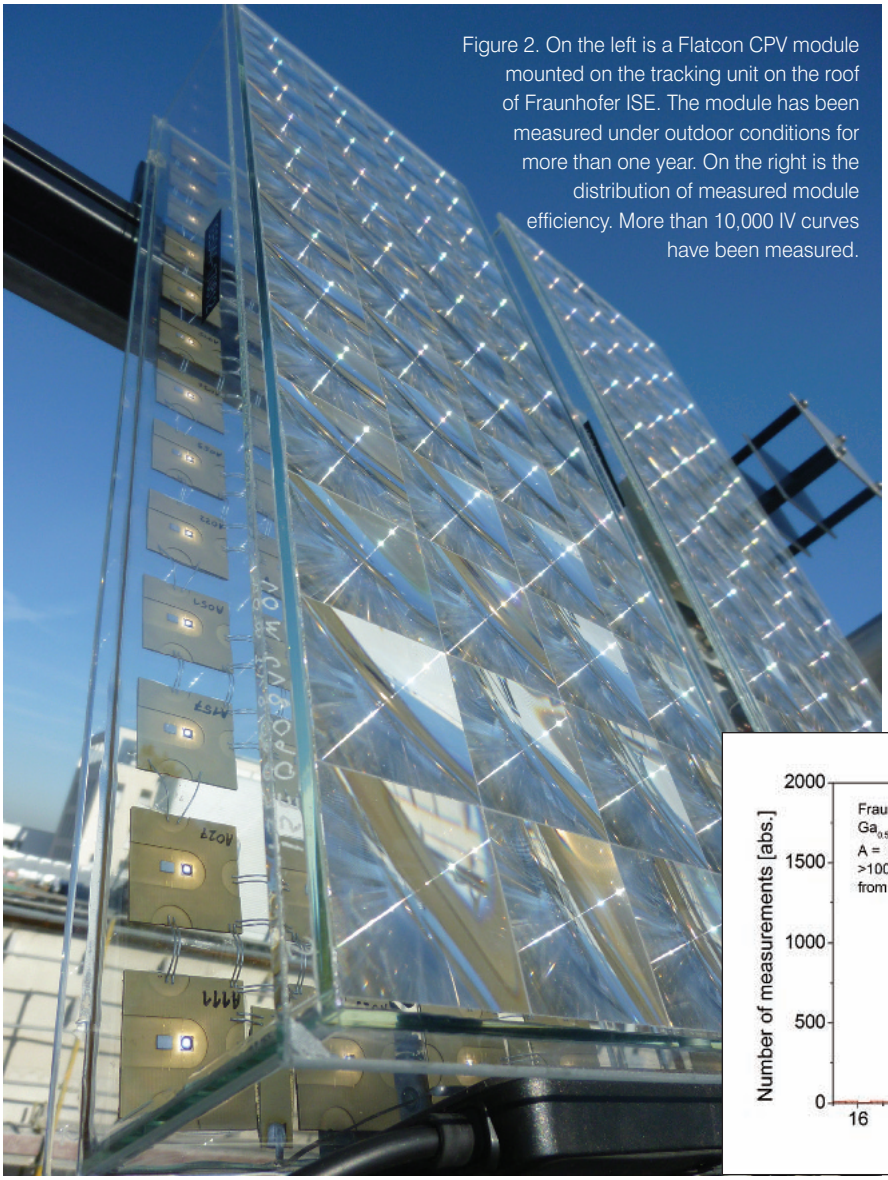
Ratings of PV modules have to conform to international standards. For CPV, the standard conditions for devices are defined in IEC 62670-1, which was published in 2013. Within this document there are two kinds of standard conditions: Concentrator Standard Operating Conditions (CSOC) and Concentrator Standard Testing Conditions (CSTC). The requirements related to direct normal irradiance (DNI), temperature, wind speed and spectral distribution are summarized in table 1. The CSTC conditions are related to indoor measurements of modules (and CPV cells) under controlled laboratory conditions, while CSOC relates to outdoor measurements of CPV modules. So for CSTC, a definition of wind speed is pointless, as wind will mainly influence the cell temperature that is fixed to 25 °C.

Although the rating conditions for CPV devices are defined, thanks to IEC 62670-1 documentation, there is still substantial work going on in this area. Efforts are related to the definition of procedures for performing the actual rating under these conditions. These discussions are taking place within the working group 7 of the technical committee 82 of the International Electrotechnical Commission (IEC TC82 WG7) where we work together with colleagues from the CPV industry and other research institutes in order to develop international standards for CPV. IEC TC82 WG7 is currently working on the draft standard IEC 62670-3 that will update CPV rating procedures.

We have determined a module efficiency under CSOC conditions by filtering our measured module data. It is relatively easy to filter for ambient temperature, wind speed and DNI, because they all correspond to directly measured quantities. It is more complicated to account for the variations in the spectral distribution of the sunlight impinging on the modules. However, using measurements on the component cells in our Black Photon system helps: each of the three cells generates current by absorbing light in a different wavelength range, so the magnitude of the current reveals the relative intensity at different spectral ranges.

Calculations of effective irradiance in the three spectral bands corresponding to the three sub-cells can then be made by dividing the generated current with the current of the component cells measured under standard test conditions. This allows the prevailing spectral conditions to be parameterized, based on the measurements of the component cell sensor.

Applying all of these criteria has enabled us to determine an average rated module efficiency of 31.6 percent, and an associated standard deviation of 0.4 percent. This involved filtering data for DNI, ambient temperature, wind speed and spectral conditions. We found that especially tight filtering on spectral conditions is necessary to achieve a low uncertainty in rated efficiency. Meanwhile, the dependence of the module efficiency on other ambient parameters is much weaker at least for this module.



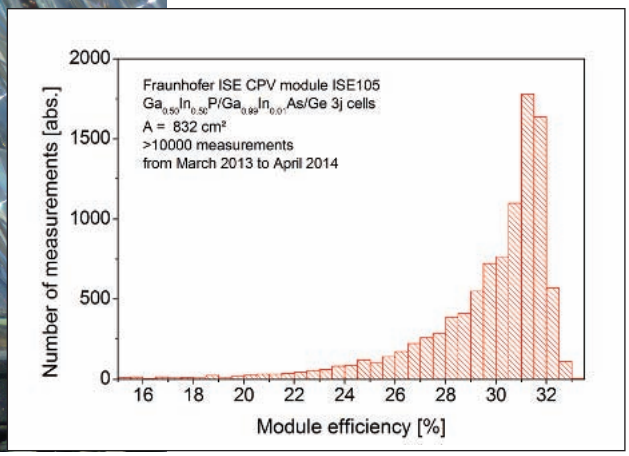


Figure 2. On the left is a Flatcon CPV module mounted on the tracking unit on the roof of Fraunhofer ISE. The module has been measured under outdoor conditions for more than one year. On the right is the distribution of measured module efficiency. More than 10,000 IV curves have been measured.

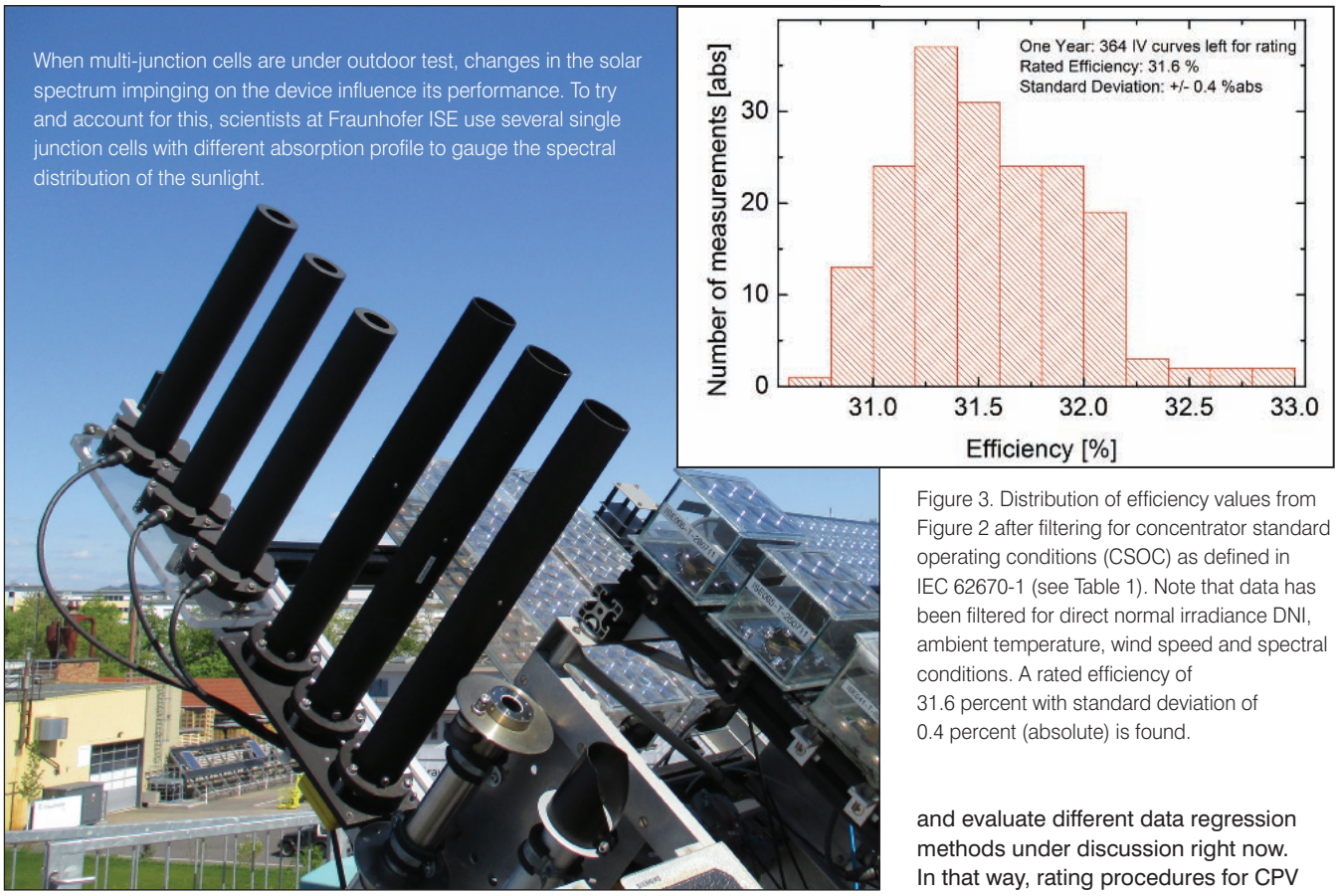


Figure 3. Distribution of efficiency values from Figure 2 after filtering for concentrator standard operating conditions (CSOC) as defined in IEC 62670-1 (see Table 1). Note that data has been filtered for direct normal irradiance DNI, ambient temperature, wind speed and spectral conditions. A rated efficiency of 31.6 percent with standard deviation of 0.4 percent (absolute) is found.

It is worth noting that just 364 of the 10,000 measurements are left after filtering. That's because at most times on most days, the weather does not correspond to standard conditions, and the measurements have to be discarded.

While it may be acceptable to take a year to carry out the occasional in-depth study on a particular module, the CPV industry clearly needs a far quicker way to determine the rated module power output. This is under consideration by the IEC TC82 WG7, which are looking at requirements for measuring data, considering the filtering bands to be applied to measured data, and evaluating data treatment. Discussions by this working group also include whether it is better to derive a rated efficiency at CSOC from the translation of IV curves, or from averaging via multi-linear regressions. To help to answer this, we have initiated an international CPV module round robin where several Soitec CPV modules are being measured at different locations using different kinds of equipment. Data gathered in this round robin activity will be used within IEC TC82 WG7 to test and evaluate different data regression methods under discussion right now. In that way, rating procedures for CPV modules that lead to reliable rated measurements will be available in the near future, which will hopefully help to verify that when it comes to generation costs, CPV systems are increasingly competitive with the incumbent technology.

	CSOC	CSTC
DNI [W/m²]	900 W/m²	1000 W/m²
Temperature [°C]	20 °C (ambient)	25 °C (cell)
Wind speed [m/s]	2 m/s	n.a.
Spectrum	Direct normal AM1.5 spectral irradiance distribution consistent with conditions described in IEC 60904-3	

Table 1: Standard conditions for CPV as defined in IEC 62670-1.

Further reading

G. Peharz *et. al.* "Indoor Characterization of CPV modules at Fraunhofer ISE", Proceedings of the 5th International Conference on Solar Concentrators, Palm Dessert, CA, 2008.
C. Domínguez *et. al.* Optics Express **16** 14894 (2008)
A. W. Bett *et. al.* "FLATCON-Modules: Technology and Characterisation", Proceedings of the 3rd World Conference on Photovoltaic Energy Conversion, Osaka, Japan, 2003, pp. 634-637
G. Peharz *et. al.* Solar Energy **83** 1588 (2009)
G. Siefer *et. al.*"SOPHIA CPV Module Round Robin: Power Rating at CSOC", to be published, presented at the 10th International Conference on Concentrator Photovoltaics, Albuquerque, New Mexico, April, 2014

LED droop:

A critical review and novel solution

The debate over the cause of efficiency droop in nitride LEDs is heating up as recent publications 'unambiguously' assign this malady to Auger recombination. Here we take a critical look at the proposed efficiency sapping mechanisms, discuss several missing pieces in the droop puzzle and offer an intriguing new LED architecture for efficiency enhancement

BY JOACHIM PIPREK FROM NUSOD INSTITUTE

THE ERA OF SOLID-STATE LIGHTING is now upon us, with affordable LED bulbs lining the shelves of many hardware stores. Compared to the compact fluorescent, the LED bulb lasts much longer and turns on far faster, but it is yet to deliver high efficiencies due to a simple but widely disputed phenomenon: efficiency droop. Due to this mysterious malady, a doubling of the current delivers less than a doubling of the light power, causing the battalion of LEDs within the bulb to operate well below their peak efficiency, which occurs at a very low current (see Figure 1).

A fall in quantum efficiency is behind this sub-linear power increase. In an ideal world LEDs would operate at a quantum efficiency of 100 percent, with every injected electron generating a photon that is emitted from the chip. However, during the transfer of electrical to optical energy, there are always losses of electrons and photons.

To keep track of these losses, the total (external) quantum efficiency (EQE) is split up into the internal quantum efficiency (IQE) and the photon extraction efficiency (EXE). Electron (and hole) losses are widely believed to be the primary reason for efficiency droop, causing a strong reduction in IQE as the current through the LED is cranked up.

If electrons and holes don't generate photons inside the active layers (quantum wells – QWs), then what do they do? Well, there are a few other options for these carriers. In addition to the radiative recombination inside the QWs that leads to the generation of light, the electrons and holes can: undergo crystal-defect-related recombination inside the QWs; Auger recombination inside the QWs; and recombination outside the QWs, caused by electron leakage from the QWs (see Figure 2).

Adding up these contributions produces a simple, popular model, where the total recombination rate is given by $R = An + Bn^2 + Cn^3 + Dn^4$. In this model, n is the carrier density, while the linear, quadratic, cubic and quartic terms of n are related to crystal defect related recombination, radiative recombination, Auger recombination, and recombination caused by electron leakage, respectively. Note, however, that the leakage contribution term is often ignored.

If you remember your algebra classes, you may realize that by simply manipulating the A, B, C and D coefficients, it is possible to fit many different characteristics with such a formula – and it has been shown that different $ABC(D)$ parameter sets can lead to almost identical results.

More detailed models further undermine the merit of this approach, by showing that for each of the four recombination mechanisms these coefficients are not constant, but change with carrier density. Thus, it is quite risky to draw final conclusions on the leading non-radiative mechanisms from such a simple *ABC(D)* model – especially since the quantum well carrier density is usually unknown.

It is only direct measurements that can provide the final proof for the dominating droop mechanism. Electron leakage was first observed in ultraviolet LEDs [Zhang 2008] by measuring

the light emission from *p*-doped layers, which can only produce radiative recombination when electrons travel beyond the QWs (see Figure 2). A few similar reports followed, but none could demonstrate that the magnitude of leakage fully explains the magnitude of the efficiency droop.

In fact, I am puzzled as to why there have been fewer than ten direct measurements of electron leakage published – far less than the hundreds of papers claiming that leakage is the main reason for the efficiency droop in a particular device. It is my view that authors, reviewers, and editors should pay more attention to the experimental validation of such claims. If leakage is indeed the only culprit, it is hard to fathom why none of the many experimental LED device designs have been able to eliminate droop.

Direct evidence for Auger recombination

The first direct evidence for QW Auger recombination only appeared in 2013, with two different groups employing somewhat contradicting methods. The first reported work came from a partnership between scientists at UCSB and CNRS, France, and involved measurements of high-energy (hot) electrons emitted from the surface layer of an LED [Iveland 2013]. The authors attribute these hot electrons to the QW Auger process. They argue that electron-hole recombination is facilitated by transferring the excess energy to a second electron, which becomes 'hot' and can travel to the LED surface.

However, Monte-Carlo simulations of this electron transport by other researchers from Boston University and Politecnico de Torino, Italy, indicate that the Auger-electron cannot maintain its high energy over the distance between the quantum wells and the LED surface [Bertazzi 2013].

In contrast, a very short travel distance for hot Auger electrons is assumed in the second piece of direct evidence for Auger recombination published in 2013 [Binder 2013]. In that work by researchers at Osram Opto Semiconductors, hot Auger electrons are assumed to lose their energy quickly, so that some are captured by a neighbouring quantum well. However, numerical simulations of this experiment show similar results without Auger recombination [Hader 2014].

Even if one accepts that both experiments provide proof of relevant QW Auger recombination, despite conflicting assumptions, none of them presents direct evidence that the Auger process is strong enough to single-handedly cause the measured efficiency droop.

By assigning droop solely to Auger recombination, another question crops up, which I keep puzzling over: If Auger recombination really is the only reason for the efficiency droop, why do we need an AlGaN electron blocker layer (EBL)? After all, the EBL energy barrier is not high enough to stop hot electrons generated by the Auger process.

Defects may also play a role in droop. No one disputes the influence of defect-related recombination on the LED efficiency,

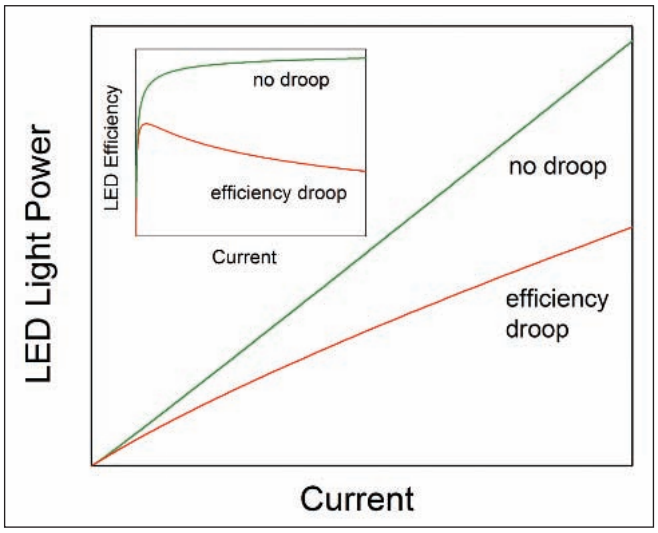


Fig. 1: Sub-linear LED light power characteristic related to efficiency droop, as shown in the inset (red curves). For comparison, the ideal of linear power without droop is plotted in green.

but this only dominates at low current or in non-commercial LEDs that are riddled with defects. Some researchers [Lin 2012] measured the efficiency droop of brighter and darker regions of a single LED separately, identifying less droop in the darker regions, accompanied by lower absolute efficiency. Such droop reduction is not desirable as the main quest is for high efficiency.

Gold Rush

The continuing ambiguity concerning the origin of LED droop has triggered a 'gold rush' in worldwide research in this topic, culminating in an ever-growing number of papers that often contradict each other. A confusing range of efficiency droop observations and explanations are resulting from varying LED fabrication and measurement conditions, and from the application of diverse models and parameters.

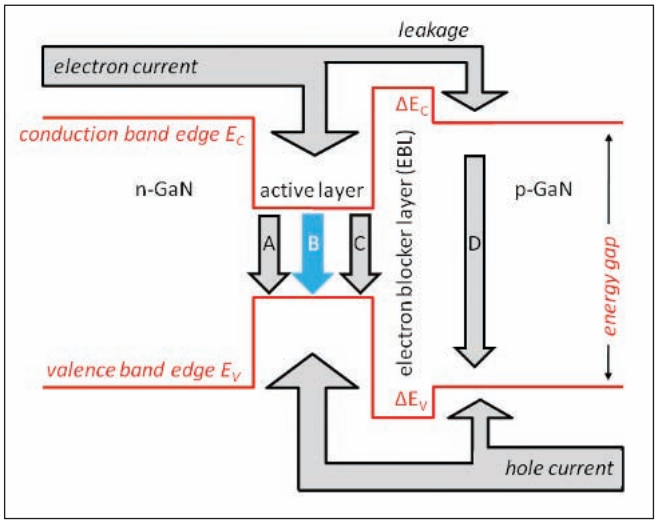


Fig. 2: Schematic illustration of the LED energy band diagram (red) with electron and hole current components. Light is generated inside the active layer which typically comprises multiple quantum wells (QWs). The four possible options for electron-hole recombination are labelled *A-D* (*A* - defect-related recombination, *B* – radiative recombination, *C* – Auger recombination, *D* – recombination outside the active layers).

Note that the employed mathematical models are based on different physical concepts – yet several of them reproduce the same type of measured efficiency characteristics. That should set some alarm bells ringing, because if dissimilar models can quantitatively explain the same experiment, then most of these models must be wrong. This dilemma represents a great challenge – but also a great opportunity to come together and work it out (see "How can we end the debate on droop?"). Let's now look at some of these advanced droop models in more detail.

Defect-related recombination is unable to cause efficiency droop if one applies the simple *ABCD* formula, because the linear term (An) does not increase faster with the carrier density than the light emission (Bn^2). To account for droop, the A coefficient itself must instead rise with the density in a super-linear way, which means that the defect-related carrier lifetime needs to decrease rapidly with higher carrier density.

How is that possible? Well, in 2007 Andreas Hangleiter from the Technical University of Braunschweig and collaborators proposed the idea that some QW recombination centres are located on an energy 'mountain', and they can only be reached after the QW 'flatland' is filled up with carriers.

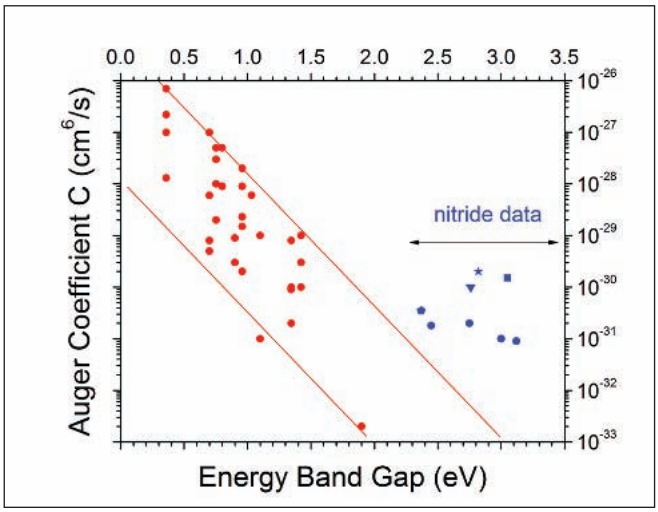


Fig. 3: Reported Auger coefficients for various semiconductors with different energy band gap scatter widely for the same material. The nitride data (blue) contradict the expected steep decline with larger band gap (red lines).

Later on, Hader and co-workers put this idea into a numerical model, described as 'density activated defect recombination' or DADR. One strength of the DADR model is that it shows good agreement with IQE measurements at low currents, all the way down to very low temperatures. However, it fails to reproduce the efficiency droop measured at higher currents. The same is true for a band tail localization model developed by Sergey Karpov from St. Petersburg and a droop model based on the influence of QW barrier states, which was proposed by Weng Chow from Sandia National Laboratories. In other words, all these models need to include Auger recombination or electron leakage to fully reproduce droop measurements.

What about Auger models?

Auger recombination is typically identified as the droop mechanism using a simple *ABC* fit. However, this approach is

flawed, since the Cn^3 term in the *ABC* formula is the only term rising faster with carrier density than the light emission (Bn^2), so any *ABC* fit of the measured efficiency droop will result in a large *C*-parameter, no matter what the real cause of the droop is. For instance, if leakage is to blame for droop, Auger recombination would be wrongly identified with this approach. Moving to an *ABCD* model does not fix this issue, because this would assign part of the leakage to the *C*-parameter.

Such indirect measurements of the Auger coefficient have always been controversial. Plotting the *C*-parameter as a function of the energy band gap of various semiconductor materials shows both the steep decline in Auger coefficient with increasing band gap, and the uncertainty in values of several orders of magnitude (see Figure 3). What's more, data for nitride materials are clearly outside the broad band predicted, and this has caused great scepticism towards the Auger model for the efficiency droop.

To try and get to the bottom of whether Auger recombination is able to cause droop, several groups have been working on quite sophisticated calculations for the *C* coefficient. The direct Auger process – involving only three carriers – was initially determined to be very weak. Indirect Auger recombination was then proposed as a possible explanation, with calculations considering electron-phonon coupling and alloy scattering. However, even then the calculated indirect Auger coefficients are still below the values required to fully explain the efficiency droop, and they are only obtained for bulk layers.

This is by no means the end of the story for Auger-related droop models, though. When Marcus Deppner and colleagues from the University of Kassel included Auger electron leakage in the LED model, this appeared to enable relevant levels of droop to occur with lower Auger parameters. And somewhat surprisingly, some recent studies suggest that direct QW Auger recombination may still be to blame: The team from Boston University and Politecnico de Torino, Italy, calculates that Auger recombination strongly depends on QW width and composition; while Roman Vaxenburg from Technion, Israel, and co-workers are arguing that the electric field in the QW can exert a large influence on the Auger recombination. I believe that we should wait for some consolidation of all these different models before fundamental physics is claimed to validate Auger recombination as possibly dominating the efficiency droop mechanism.

Leaky wells?

Another popular model for LED droop, electron leakage into *p*-doped layers, tends to attribute the decline in efficiency at higher drive currents to thermionic emission from the QWs. However, it has also been argued that leakage results from hot electrons or tunnelling from the QWs.

Simulations of electron leakage are commonly based on a numerical drift-diffusion model. The leaking electrons recombine with holes in the *p*-doped layers before those holes reach the active layers (see Figure 2). Obviously, electron leakage and reduced hole injection are two sides of the same process – and not two different mechanisms. What's more, it appears that the low hole conductivity in *p*-doped GaN is actually the main reason for the electron leakage.

I have looked into this with Simon Li from Crosslight Software [Piprek 2013]. We have found that the magnitude of the electron leakage is extremely sensitive to properties of the electron blocker layer (EBL), such as the built-in polarization and the EBL band offset ratio (see Figure 4). Unfortunately, both material parameters are not exactly known. On top of this, the magnesium doping creates even more uncertainty in leakage simulations, since only a small and unknown fraction of magnesium atoms form AlGaN acceptors. For these reasons, almost all of the many published simulation studies on EBL design and optimization are quite speculative, as long as the leakage current is not validated experimentally.

How can we end the debate on droop?

THE DEBATE on the cause of droop has now been going on for the best part of ten years and various camps still seem entrenched in their contradicting positions. One obstacle to a consensus is that none of the droop models covers all possible mechanisms in sufficient detail. Complicating matters even more, the analysis of different LED designs and fabrication technologies may lead to different results. It would therefore be desirable to apply each model to exactly the same LED structure, reproduce the same LED measurements, and compare in detail all model assumptions, parameters, and results. But for understandable reasons, the LED industry is very secretive about the specifics of their device structures, while public research projects at universities often fall short of producing high-quality devices. So, dear reader, would you be able to contribute the needed details on an industry-quality LED ? If so, please send an e-mail to piprek(at)nusod.org. I will gladly forward such information to the different modelling groups to foster a consensus on the cause of the LED efficiency droop. The annual conference on "Numerical Simulation of Optoelectronic Devices" could provide a forum to discuss the results of such joint modelling effort (www.nusod.org)

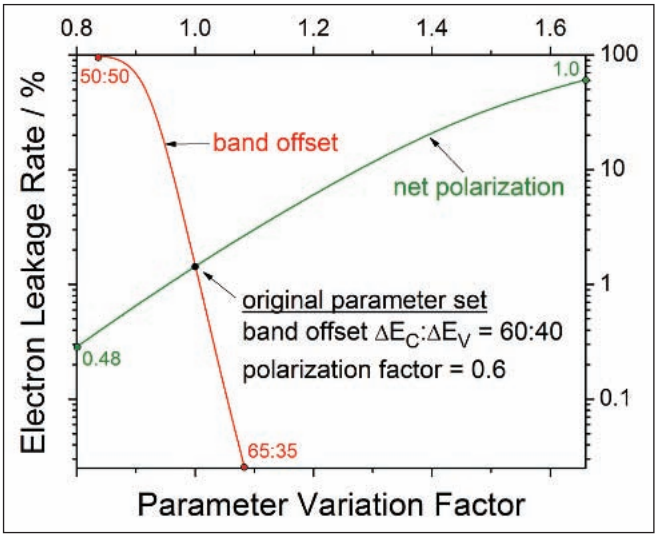


Fig. 4: The calculated electron leakage is extremely sensitive to variations of band offset (red) and net polarization (green) of the electron blocker layer (see Figure 2).

Although those debating droop can't agree on its cause, most believe that the efficiency reduction is triggered by the rise in QW carrier density. Now, is it possible to lower the carrier density without losing light power?

A Novel Solution

Although those debating droop can't agree on its cause, most believe that the efficiency reduction is triggered by the rise in QW carrier density. Now, is it possible to lower the carrier density without losing light power? One seemingly obvious answer is to increase the number of QWs, but this approach is handicapped by the strong carrier accumulation on the *p*-side of the active region.

Another approach is to insert tunnel junctions into the multi-quantum well active region [Piprek 2014]. Thanks to carrier recycling by the tunnel junction, repeated use of electrons and holes for photon generation inside the QWs is then possible.

Using advanced device simulation, the performance of a design with three tunnel junctions that separate four pairs of QWs has been calculated (see Figure 5). In this case, each electron has four chances to generate a photon. If there were no losses, the quantum efficiency could be as high as 400 percent. But there is a price to pay for such an astronomical EQE: A four-fold hike in the bias required to operate the LED.

To assess the performance of this novel LED architecture, plots of the light output power as a function of the electrical input power have been simulated for three different designs with the same total active layer thickness (see Figure 6).

These calculations show that the tunnel junction design delivers twice the output power of a conventional LED – and therefore double the wall-plug efficiency – and it also outperforms the alternative approach of merging all QWs into one thick active layer (a double-heterostructure LED). However, even with the tunnel junctions, a large efficiency droop still remains – and the debate over what causes it is unlikely to go away anytime soon.

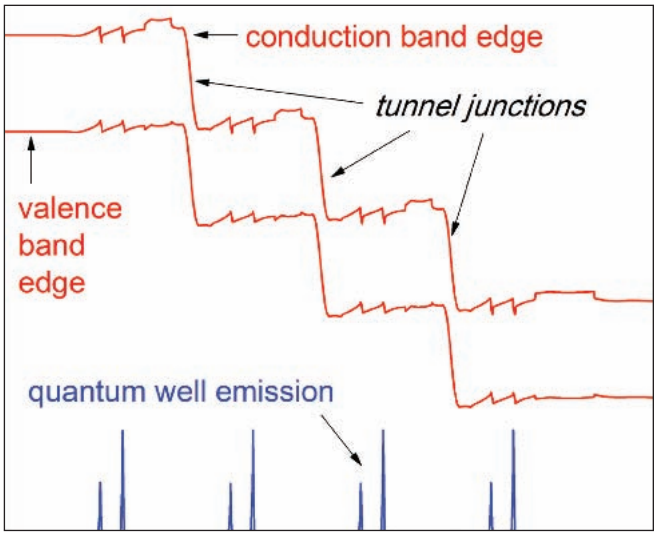


Fig. 5: Energy band diagram (red) and photon emission profile (blue) of the proposed tunnel-junction LED.

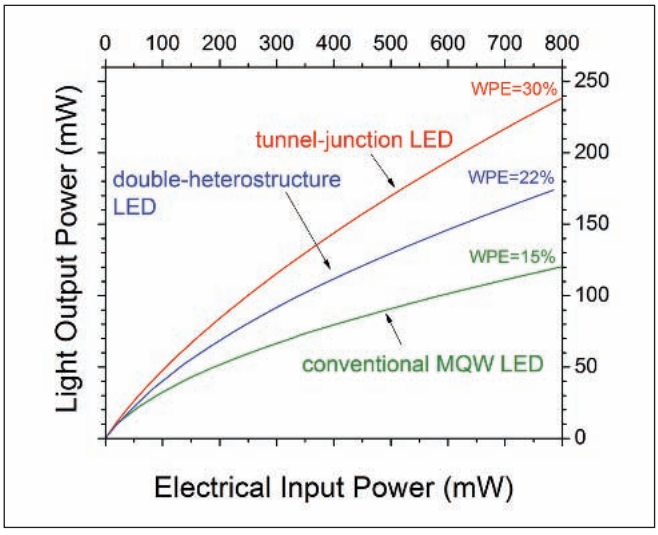


Fig. 6: Performance comparison between different LED design concepts (WPE – wall plug efficiency, numbers given for an 800 mW input power).

References
F. Bertazzi *et al.* arXiv:1305.2512 (2013)
M. Binder *et al.* Applied Physics Letters **103** 071108 (2013)
J. Hader *et al.* SPIE Proceedings **9003** 900311 (2014)
J. Iveland *et al.* Physical Review Letters **110** 177406 (2013)
Y. Lin *et al.* Applied Physics Letters **101** 252103 (2012)
J. Piprek *et al.* Applied Physics Letters **102** 131103 (2013)
J. Piprek Physica Status Solidi Rapid Research Letters **8** 424 (2014)
J. C. Zhang *et al.* Applied Physics Letters **93** 131117 (2008)

Investigating the LED's dark side

Novel LED model offers new insights into droop

BY WENG CHOW FROM SANDIA NATIONAL LABORATORIES

A REVOLUTION IN LIGHTING is well on its way. Rewind the clock a year or so and the prices of LED bulbs made many shoppers wince. But now it is possible to get a high-quality 60 W equivalent for well under $10, and that's allowing sales of LED bulbs incorporating chips from the likes of Cree and Philips Lumileds to take off.

Although these solid-state bulbs are much more pricey than incandescents, which have largely disappeared from shelves due to legislation, they more than make up for that additional up-front cost with a substantial trimming of the electricity bill. It is a more tricky decision, however, whether it makes more sense to buy an LED bulb or a cheaper compact fluorescent (CFL). In terms of durability, adaptability and environmental impact, the solid-state bulb is the clear winner. But both types of light are similar in the efficiency stakes, and thus the running costs.

The performance of the LED bulb is partly compromised by a power loss associated with the electrical conversion of the AC 110 V or 220 V source from a wall socket to the handful of volts of DC needed to drive the semiconductor chip. But this loss is overshadowed by a saturation of light output – or equivalently, a degradation of efficiency – that kicks in at a current density well below the desired operating range (Figures 1a and 1b). Identifying this mysterious power-sapping mechanism, known as LED efficiency droop, will aid attempts to combat it. This could lead to a single LED, operating a very high current density, replacing the battalion of chips currently crammed together in the bulb. Such a move would slash production costs and boost efficacy, giving the manufacturer a bigger profit and the consumer a bulb that retails for less and is cheaper to run.

The contenders

Attempts to uncover the origin of droop are well underway by researchers in industry, academia and in national

laboratories. Efforts throughout the world have already led to the proposal of several competing explanations for the cause of this efficiency sapping mechanism.

One explanation that appears to be surviving the test of time, and perhaps even gaining ground, is carrier loss via Auger scattering. When a semiconductor emits light, electrons and holes have to come together and recombine. So, if there are more electron-hole pairs, more light is emitted. However, electrons and holes don't always recombine to emit light – instead, Auger scattering can take place, with an electron recombining with a hole to give the resulting energy to a second electron or a hole (this is depicted in Figure 1c). At low current densities, the Auger recombination process is far less likely than the radiative, light-emission process. However, as the current is cranked up, carrier density increases and Auger recombination takes off, with droop kicking in.

A great deal of controversy surrounds the question of whether Auger carrier loss is the primary culprit of LED droop. The disagreement is not really concerned with whether Auger scattering will eventually lead to efficiency loss – at some point it will make a contribution – but whether it can come into effect at current densities as low as tens of mill-Amps per square centimetre, where experiments show that droop is present. The two primary criticisms of an Auger explanation are that curve fitting of efficiency-verses-current density curves has to invoke Auger coefficients that are much larger than any calculated values, and have temperature dependence strongly contradicting first-principles physics.

Working at Sandia National Laboratories, I have been looking into these issues and have developed a new LED model that replicates the features seen in experimental current-efficiency curves. With this approach, the efficiency droop is predicted using Auger coefficients within the range calculated for phonon-assisted Auger scattering. Replicating the experimental temperature dependences is then possible, thanks to a model that features an Auger coefficient that increases with temperature.

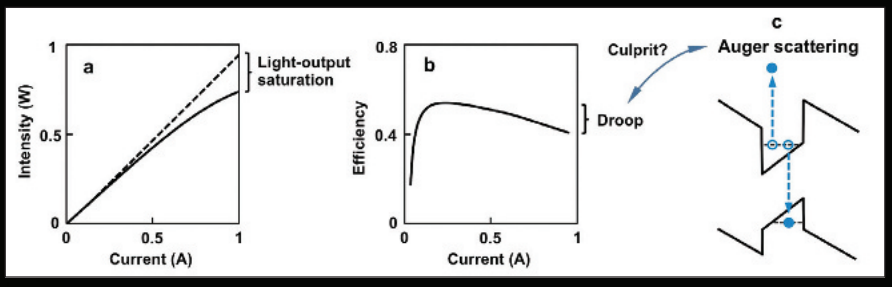


Figure 1: One serious, puzzling weakness associated with LEDs manifests itself as (a) intensity saturation or (b) efficiency droop. Auger scattering (c) is a strong candidate for the cause of this problem, which is known as LED droop. Each Auger scattering event involves non-radiative recombination of an electron-hole pair and promotion of a carrier (shown here as an electron) to conserve energy.

Although the above quantitative agreement between experiment and microscopic theory helps strengthen the Auger argument, that was never the intent for pursuing this new modelling approach. Rather, my motivation came from noticing that efficiency droop occurs in many forms of LED – including those emitting at different wavelengths, those built on polar and non-polar substrates, those that do and don't have an electron blocking layer, and those with quantum wells and quantum dots.

As droop is observed in all these LEDs, it may be that instead of one cause dominating in all device architectures, there are several competing mechanisms. And it may be possible that their relative importance, or order of appearance with increasing excitation, changes under different experimental conditions.

To see if this is the case will require a modelling approach that systematically and consistently gathers all possible droop contributions – including Auger scattering, carrier leakage, plasma heating or defect losses – and incorporates them into a microscopic description of radiative and band-structure effects. Armed with such a model, researchers will be able to investigate and compare devices at the heterostructure-design level.

Conventional approaches

The approach that I have taken differs from the most common one for computing LED efficiency. This popular alternative will be referred to from now on as 'Approach A', and is sketched in Figure 2. Its starting point is to choose the populations in the electron and hole states (carrier distributions), often by specifying a total carrier density and assuming thermal equilibrium at room temperature. Rates for various carrier loss processes, such as those associated with light-emission and defects, are then determined for that carrier population.

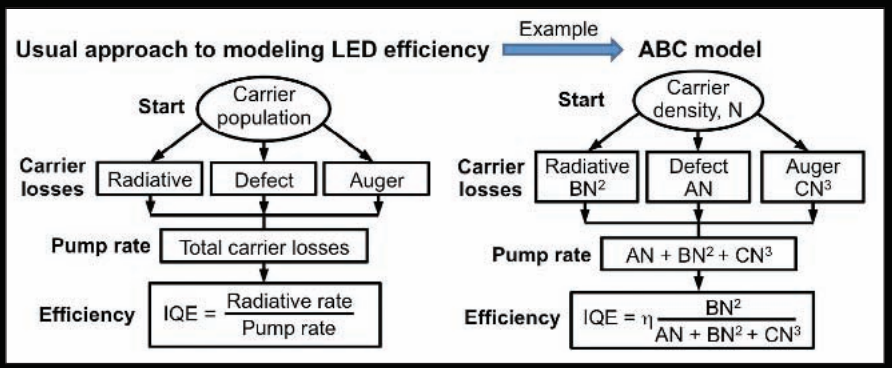


Figure 2: (Left) An outline of the widely adopted Approach A for determining LED efficiency versus pump rate. It is used to evaluate possible efficiency droop mechanisms, and to extract Shockley-Read-Hall, radiative and Auger coefficients from experimental data. (Right) Sketch of the *ABC* model, which is a simple implementation of Approach A.

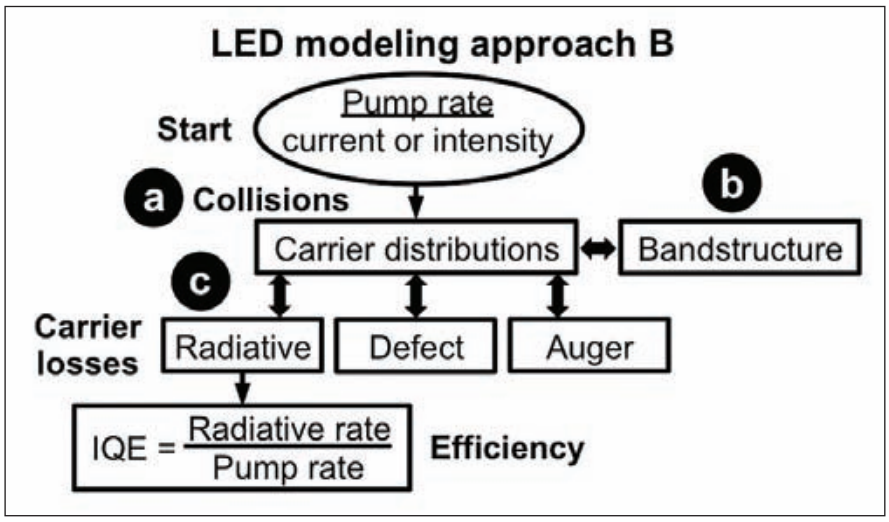


Figure 3: Approach B, which is introduced by Weng Chow from Sandia National Laboratories, follows more closely the sequence of events leading to light emission in an experiment. Starting with the pump, carrier distributions are created, which in turn produce light and losses.

Summing this, and then dividing the radiative rate by it, gives a value for the internal quantum efficiency (IQE). This can also be thought of as the rate of photon production, divided by the rate of carrier injection.

One example of implementation of Approach A is the widely used *ABC* model, (see right side, Figure 2). Here, phenomenological constants *A*, *B* and *C* are introduced to account for defect (Shockley-Read-Hall), radiative-recombination, and Auger-scattering carrier losses, respectively. With this approach, the input parameter is total carrier density, and the defect, radiative and Auger rates are assumed to depend on this in a linear, quadratic and cubic manner, respectively.

Note that these relationships are consistent with the simplest functional dependences known for these processes. With this *ABC* model, the IQE, as indicated in the figure, declines at higher current densities. This approach can also include a term to account for carrier injection efficiency, which is the fraction of injected carriers ending up in the emitting region.

When *A*, *B* and *C* are treated as fitting parameters, the *ABC* model is very successful at reproducing practically all experimental curves involving a plot of IQE versus pump rate. However, concerns arise when *A*, *B* and *C* are associated with the physical processes of defect, radiative and Auger losses. Taking this approach oversimplifies carrier-density dependences and leads to disagreement with coefficient values from microscopic calculations that are far more rigorous – they directly account for the quantum mechanics of electrons and holes, the effects of band structure, and so on. This departure from the results of microscopic calculations is particularly alarming in the Auger case: Here, the values for the *C* coefficient for fitting experimental data can be several orders of magnitude higher than those provided by microscopic calculations.

It is also possible to implement approach A using less phenomenology than the *ABC* model. Greater rigour results from using rates for carrier losses that are determined from microscopic theory. This is possible with the radiative contribution, thanks to semiconductor quantum luminescence equations that provide a truly predictive treatment, and include many-body Coulomb effects. And for the defect contribution, it is possible to turn to microscopic models that predict deviations from the linear carrier-density dependence of the widely used Shockley-Read-Hall expression.

A similar capability exists for computing the Auger rate. However, here the challenge is not simply computing the actual rate: It is also employing accurate band-structure information, one band-gap energy removed from the conduction or valence band edges, for this is where the second electron or hole will end up.

One of the weaknesses of the microscopically based approaches is that they fail to replicate experimental results. Instead they predict that the efficiency droop is not as severe or as prevalent as that encountered in experiments. This discrepancy boils

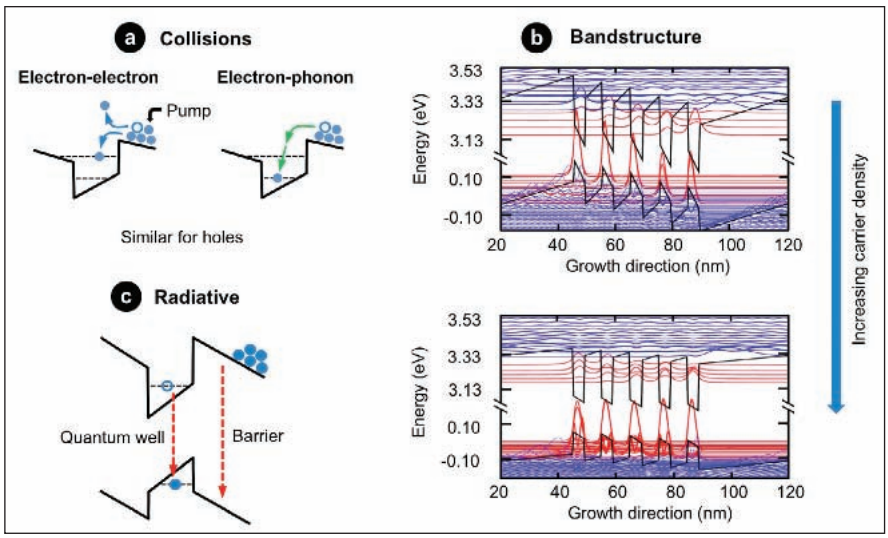


Figure 4: a) Carrier transport mechanisms are carrier-carrier and carrier-phonon collisions. b) Change in carrier density leads to changes in band structure, such as envelope wavefunctions for electrons and holes (red and blue curves for quantum wells and barriers, respectively), energy levels (vertical placements of envelope functions) and quantum-confinement potentials (black lines). c) Radiative transitions from quantum well and barrier.

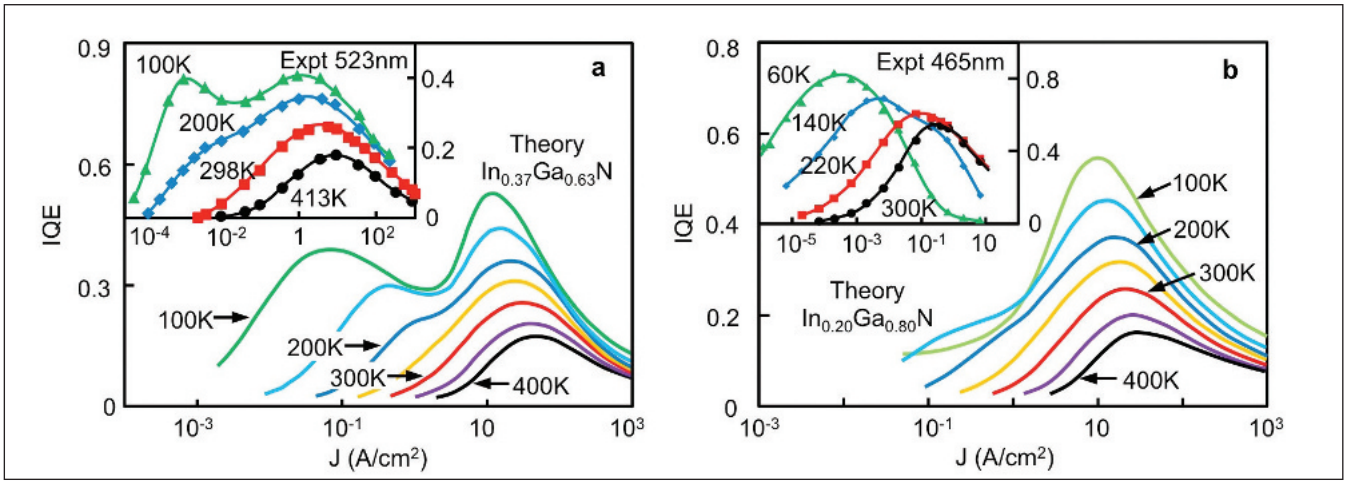


Figure 5: IQE versus current density for LED with (a) 2nm $In_{0.37}Ga_{0.63}N$ and (b) 3nm $In_{0.20}Ga_{0.80}N$ quantum-well active media. Approach B is used to obtain the computed curves. The insets show the experimental results.

down to the microscopically calculated Auger contribution being too small to comfortably reproduce experimental droop observations.

An alternative approach

The alternative approach that I have pursued, which is referred to here as Approach B, is procedurely different (see Figure 3). This time, the starting point is the pump rate, which is the current for electrical injection. At the heart of these calculations is the determination of carrier distributions resulting from the pump, according to the band structure and loss mechanisms. Note, however, that when modelling optically pumped experiments – such as that conducted by a team at Philips Lumileds that led to the first suggestion that Auger scattering is a concern – the pump rate is equal to the pump-laser intensity.

In an LED, carriers are injected into the barrier and cladding layers via carrier-carrier and carrier-phonon collisions. These interactions cause carrier capture and escape into and out of the quantum wells. What's more, they can cause heating of carrier distributions above the lattice temperature (see the illustration of carrier-carrier scattering in Figure 4a).

Note that there is a complex interplay between the band structure and the carrier distributions (depicted by the two-way arrows in Figure 3). The band structure plays an important role in determining the carrier distributions – but in turn, the carrier distributions can alter the band structure, due to a screening of the internal electric fields (see Figure 4b).

These fields are strong in *c*-plane grown, wurtzite InGaN quantum wells, which are found in the light-generating region in the vast majority of LEDs. Note that in some other material systems, such as those used to produce telecom lasers, the carrier population exerts a far weaker influence on the band structure.

The strong internal electric fields produce a large distortion to the quantum-confinement potentials, and this can blur the distinction between quantum-well and barrier states (see hole energies and envelope functions in the left plot in Figure 4b). When this happens, the well and barrier can be equally occupied, with both contributing to optical emission (see Figure 4c). Emission from the quantum-well is then determined by the quantum-confined Stark effect, while barrier emission can occur due to the quantum-mechanical possibility of finding electrons and holes inside the band gap – this is known as the Franz-Keldysh effect.

When an Auger event occurs in a wide band-gap material, such as InGaN, transfer of a significant amount of energy to a second electron or hole can occur, leading to highly energetic carrier distributions. Due to rapid carrier-carrier scattering, any changes in the carrier distribution can then be described by changes in plasma temperature. With the *ABC* model, carrier losses are assumed to be fully accounted for by the Cn^3 term

The strong internal electric fields produce a large distortion to the quantum-confinement potentials, and this can blur the distinction between quantum-well and barrier states. When this happens, the well and barrier can be equally occupied, with both contributing to optical emission.

(where *n* is the carrier density), and are based on a combination of the Auger process sketched in Figure 1c and carrier-phonon collisions depicted in Figure 4a. The latter is assumed to be infinitely fast, so that plasma temperature remains at the lattice temperature.

Modelling real devices

To see if the approach that I have developed provides a more accurate description of LED behaviour than other models, I have used it to calculate the behaviour of two LEDs. They were chosen to provide a very stringent test of my model, because the experiments conducted on these devices involved measurements of the IQE as a function of current density at a range of temperatures.

The devices that I have modelled emit at 523 nm and 465 nm, and have single-quantum-well active regions with a GaN barrier and either a 2 nm $In_{0.37}Ga_{0.63}N$ quantum well or a 3 nm $In_{0.20}Ga_{0.80}N$ quantum well, respectively. Results of the modelling show interesting similarities with the experimental data (see Figure 5). Changes in the shape of the IQE-versus-current-density curves due to differences in temperature are also seen in the model. At high lattice temperatures, both types of LED exhibit the familiar IQE-versus-current-density behaviour that can be described by the *ABC* model. However, at low temperatures, the device with the $In_{0.37}Ga_{0.63}N$ quantum well has a second bump in its IQE profile that becomes more pronounced with decreasing temperature. An *ABC* model cannot describe the appearance of this feature, but it exists in the model that I have developed – and it might also be present in microscopic models based on Approach A that account for emission from barrier regions (this is shortly discussed).

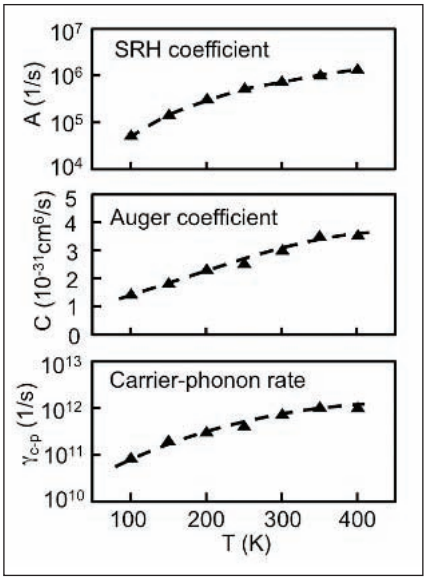


Figure 6: (From top to bottom) The Shockley-Read-Hall coefficient, Auger coefficient and carrier-phonon scattering rate used in producing the curves in Figure 5. An important result is Auger coefficient magnitude range and increasing value with increasing temperature, consistent with first-principles physics.

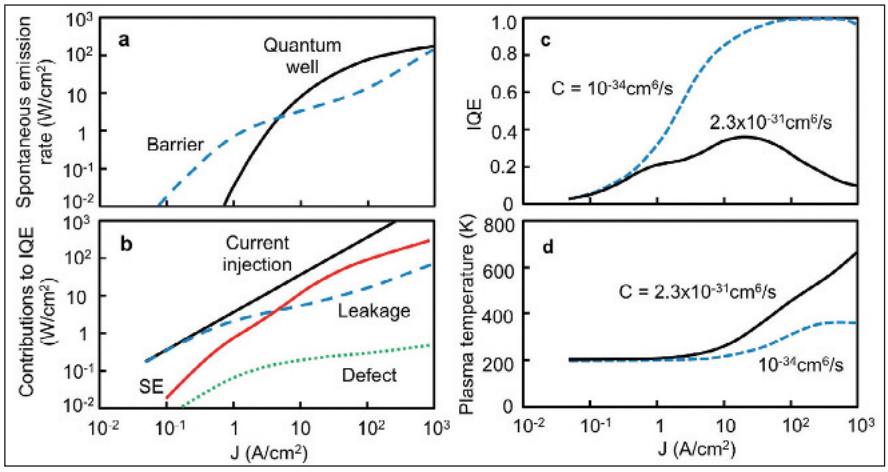


Figure 7: a) Spontaneous emission contributions from quantum wells and barriers (solid and dashed curves, respectively) versus current density. b) Contributions to IQE from recombination and scattering processes. The solid red curve is the sum of quantum-well and barrier emission, the dotted curve shows the defect loss, and the dashed curve shows the leakage contribution. c) IQE and d) plasma temperature versus current density. Differences between solid and dashed curves indicate the Auger contributions. All results are for an $In_{0.37}Ga_{0.63}N$ device at 200K lattice temperature.

With my model, there is no double bump transition in the LED with the $In_{0.20}Ga_{0.80}N$ quantum well, replicating the experimental result. The difference between the devices with $In_{0.37}Ga_{0.63}N$ and $In_{0.20}Ga_{0.80}N$ wells is fundamental to the quantum-well structures, and depends entirely on the band-structure differences that result from a smaller piezoelectric field in the active region with a lower indium concentration.

Attempts to model LED behaviour should involve plausible physical assumptions. That is the case in the model that I have proposed: magnitudes and temperature dependence features in the Shockley-Read-Hall and Auger coefficients, and the carrier-phonon scattering rate (in figure 6, these coefficients are plotted as a function of temperature).

The decrease in the Shockley-Read-Hall coefficient with decreasing temperature is expected for defect-related loss, and the increases in Auger coefficient and carrier-phonon scattering rate with increasing temperature are consistent with microscopic calculations. Meanwhile, the values for the Auger coefficient are within the range predicted for phonon-assisted Auger scattering, and are below values obtained from experimental curve fitting with the *ABC* model, which are thought to be unrealistically high.

A great strength of my model is that it provides physical insight into the double bump behaviour. In Figure 7a, there are plots for the quantum-well and barrier contributions to spontaneous emission at various current densities for the $In_{0.37}Ga_{0.63}N$ device at a lattice temperature of 200K. The curves show that the first bump is primarily due to barrier emission, while the dominant cause of the higher excitation bump is quantum-well emission. An interplay of the quantum-confined Stark and Franz-Keldysh effects governs these relative contributions, and explains the blue shift of the emission peak with increasing excitation.

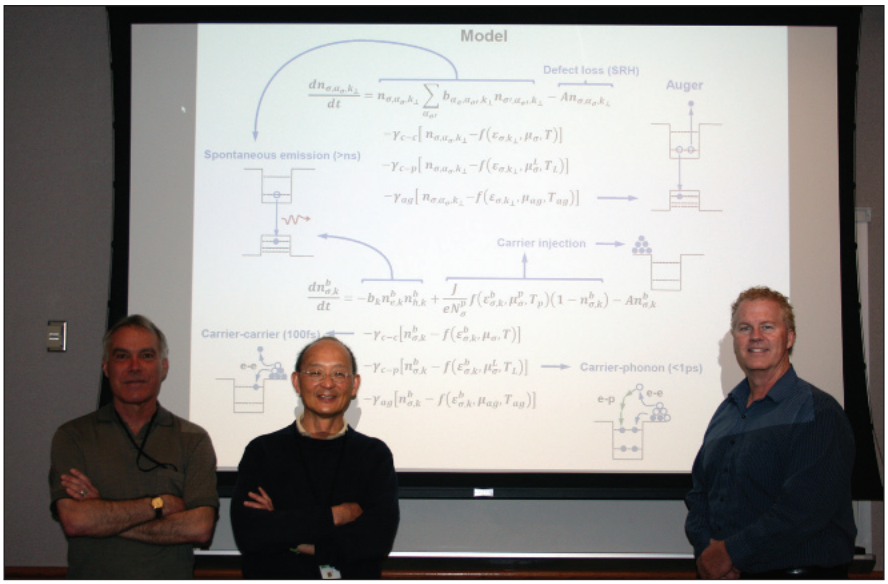
Also included in Figure 7 are the

physical mechanisms integrated into Approach B. As excitation increases, their relative contribution changes. Figure 7b suggests that the required Auger coefficients are smaller, because the onset of Auger carrier loss is delayed to higher carrier densities with the help of carrier leakage. Loss due to leakage includes failure to capture, and loss of barrier carrier population through non-radiative recombination, as well as drift and diffusion out of the active region. Its domination at low carrier densities is due to the distortion of the confinement potential by strong internal electric fields. The solid red curve in Figure 7b is the sum of quantum-well and barrier emission: This has a slope change at low current density resulting from a switch between predominately barrier and predominately quantum-well emission. At higher excitation, a second slope change appears, due to the onset of Auger carrier loss. This appears as the difference between the solid black curve and the sum of all the other curves.

A more complete description of Auger effects is possible with the model based on Approach B, thanks to the tracking of carrier occupations over time in individual momentum-resolved states. By taking this approach, it is possible to model side effects from Auger scattering, such as increases in plasma temperature or carrier leakage.

The influence of the Auger coefficient on plots of IQE as a function of current density is illustrated in Figure 7c. Two values are employed: a *C* coefficient of 2.3×10^{-31} cm^6 s^{-1}, which was used to produce the 200K lattice temperature curve in Figure 5a; and a value of 10^{-34} cm^6 s^{-1}, which is what one would expect by extending an Auger coefficient calculation for near-infrared semiconductors to one with roughly a 2.7 eV band-gap energy.

In these plots in Figure 7c, there is no efficiency droop when a value of *C* equal to 10^{-34} cm^6 s^{-1} is used for the current densities considered. These plots also indicate the efficiency loss from Auger scattering when the value for *C* is 2.3×10^{-31} cm^6 s^{-1} – this is the difference between the solid and dashed curves. Plots of the plasma temperature versus current density are shown in Figure 7d. Here, the dashed curve shows the rise in temperature that primarily results from the capture of carriers from barrier to quantum-well states. Indicated by the solid curve is a significant additional rise in plasma temperature because of Auger scattering.



A projected slide shows the equations of motion for a LED model following Approach B. Similar equations have been used to explore dynamical response and instabilities in quantum-dot and quantum-well lasers, under conditions such as the presence of optical feedback or injected signal. Also in the picture are (left to right) Alan Wright, Weng Chow and Jeff Nelson, who contributed to the early GaN research at Sandia National Laboratories. During the early 1990s, they welcomed the emergence of wide-band-gap lasers and solid-state-lighting as providing opportunities to continue exploring many-body physics, and how to handle defects and the d-shell electrons in density-functional-theory calculations.

These results are encouraging, given that my work is still in its infancy. So far, it is a very rudimentary implementation of a new modelling approach that can successfully replicate experimental results with microscopic theory. There is much room for improvement, including more careful treatment of band-structure and carrier-dynamics coupling, the inclusion of many-body effects and a more detailed description of defect loss.

If these refinements are made, hopefully this will deliver an even closer agreement between theory and experiment, and ultimately offer new insights into the origins of LED droop.

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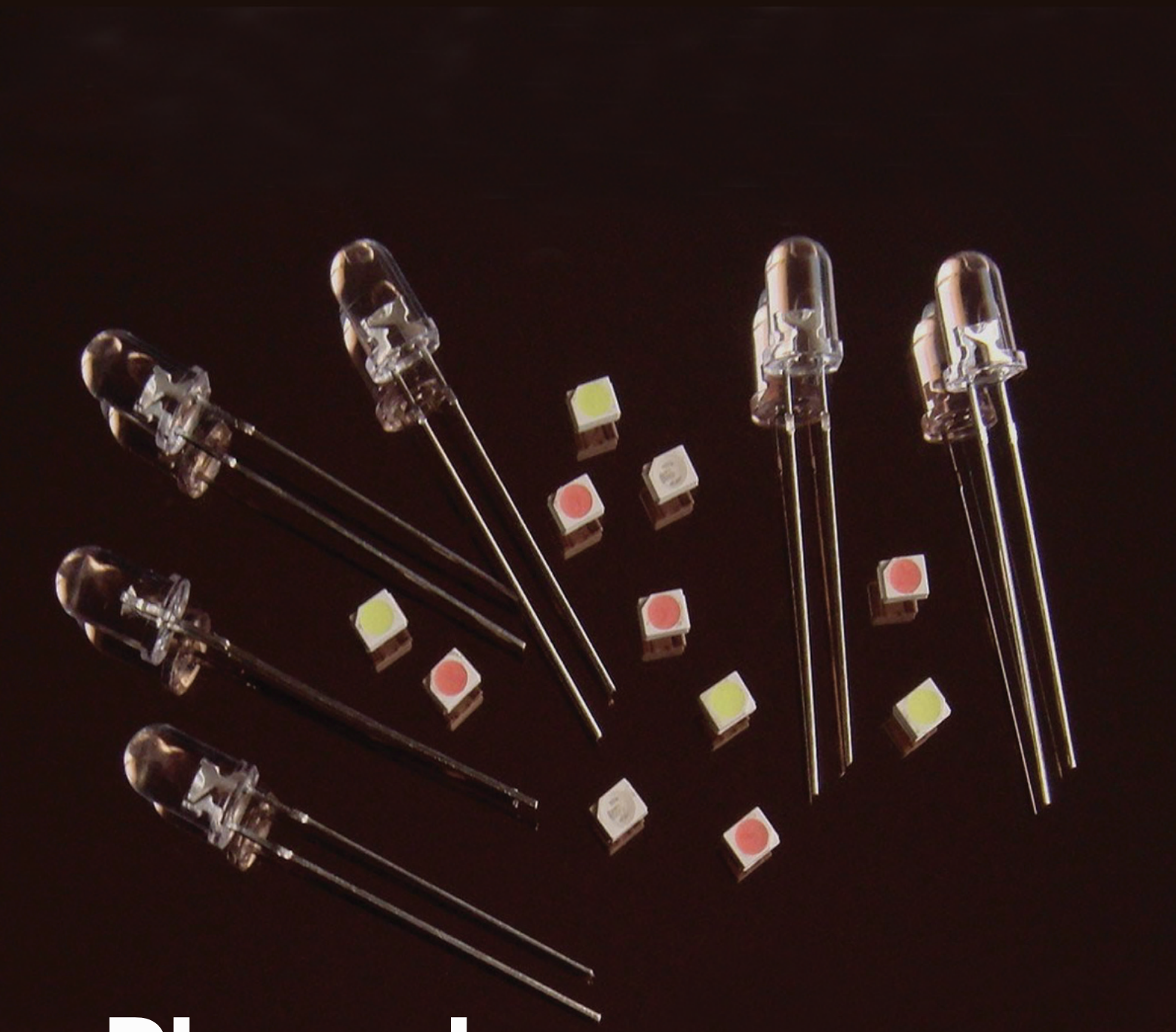
Further reading

Further information on Modeling Approach B:
W. W. Chow Optics Express **19** 21818 (2011)
W. W. Chow Optics Express **22** 1413 (2014)

Information on experiments used to illustrate Approach B:
J. Hader *et. al.* Appl. Phys. Lett. **99** 181127 (2011)
A. Laubsch *et. al.* Phys. Status Solidi C **6** S913 (2009)
K. Fujiwara *et. al.* Phys. Status Solidi C **6** S814 (2009)



Phosphors:

The driving force behind white LEDs

Faiz Rahman and Wojciech Jadwisienczak from Ohio University review the progress of phosphors, the key ingredient in the white LED

THANKS TO THE INCREASING USE of the LED in car headlights and light bulbs, sale of this white-emitting source continue to rocket.

To produce its broad emission profile, this device features a blue-emitting LED chip with a yellow phosphor coated on top. Some of the blue emission pumps the yellow phosphor, and white light results from the mixing of these two colours (see Figure 1).

The quality of white light produced by this class of LED is almost exclusively dependent on the properties of the phosphor. So to make better illumination-quality LEDs, which hold the key to the penetration of this light source into new markets, it is essential to develop better phosphors.

Although it is possible to make phosphors with organic light converting materials, all commercial white LEDs use inorganic phosphors that are much more robust. They typically consist of a host crystal doped with a small amount of one or more 'activator' ions, which are usually rare-earth atoms. Colour conversion results from electronic transitions within the rare-earth ions.

The rare-earth series of elements, which are also known as the lanthanides, are ideal for making phosphors, because they absorb light at shorter wavelengths (typically, blue and ultra-violet), before efficiently emitting at longer wavelengths. The inherent downside of this process is an energy loss, called the Stokes loss, which stems from the lower energy of longer wavelength photons compared to shorter wavelength ones. In a phosphor-driven light emitter, this down-conversion process accounts for most of the energy loss in the LED.

Most phosphors are two-component systems, consisting of a host crystal matrix containing luminescent ionic centres. An example of such a system is one of the first phosphors used for making white LEDs: cerium-doped yttrium aluminium garnet (Ce:YAG). Here, cerium ions that enable the production of cool-white LEDs are doped into a host crystal formed from a mixed oxide of aluminium and yttrium.

Note that in a two-component system such as this, the host matrix plays a crucial role, affecting the energy levels of the dopant atoms and thus determining the absorption and emission wavelengths of the phosphor.

The spectral characteristics of this phosphor govern the quality of white light emitted by the LED. It requires several parameters to quantify the quality of this emission, including the colour or chromaticity point (x,y) on a chart of saturated and unsaturated colours, called a chromaticity diagram (see figure 2). Another parameter is the colour-rendering index (CRI), which describes how closely the light from a white LED matches that of natural daylight. If the match is perfect, the CRI is 100 – the lower the value, the poorer the approximation to natural white light.

Making phosphors

Phosphors are made by high temperature solid-state reactions. Usually, finely ground inorganic salts of various elements are thoroughly mixed in stoichiometric proportions, before this concoction is heated to temperatures that may exceed 1000 ˚C.

Heating occurs in phosphor firing furnaces, which can hold anywhere from 100 grams to several kilograms of material. Once the phosphors have been heated under an atmosphere of nitrogen or similar inert gases and the reaction is complete, the material is removed, reground and may be washed in either water or organic solvents to remove any unreacted compounds. Following mandatory testing, the phosphor is ready to be deployed in blue-pump LEDs.

To make a white LED, most device manufacturers prepare a slurry of phosphors mixed with a thermoplastic resin. Polycarbonate and silicones are widely used, with the polymer acting as a binder to keep the phosphor in place. The high-viscosity liquid slurry is dispensed on to pump LED chips resting in their packages, using precision dispensing machines (see figure 2). Heat or ultraviolet radiation cures the coating, while the assembly is placed in vacuum to remove any air bubbles that might form. In some instances, a dome lens is added on top of the phosphor-coated LED chip using a polymer-moulding step.

Today, much of the effort associated with the development of phosphors for high CRI, high-efficacy light sources is directed towards the use of phosphors with one or more rare-earth ions. Their electronic excitation and subsequent de-excitation can produce narrow spectral emission, such as that resulting from 4*f*-4*f* transitions in triply-charged +3 rare-earth ions; and it can also deliver a broad emission, such as that coming from 5*d* transitions in doubly-charged +2 rare-earth ions. Thanks to the

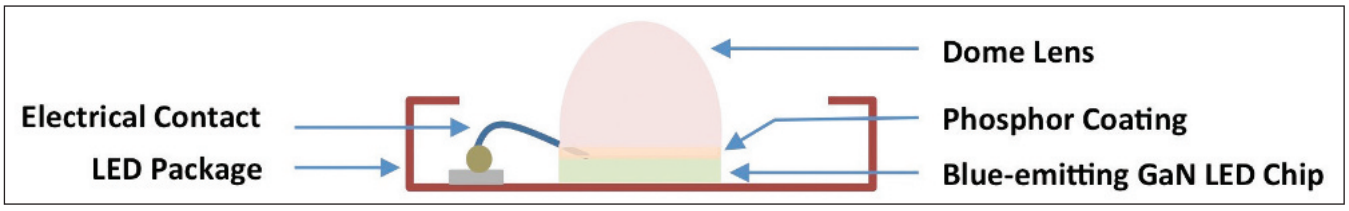


Figure 1. A white LED is formed from a blue-emitting chip pumping a yellow-emitting phosphor.

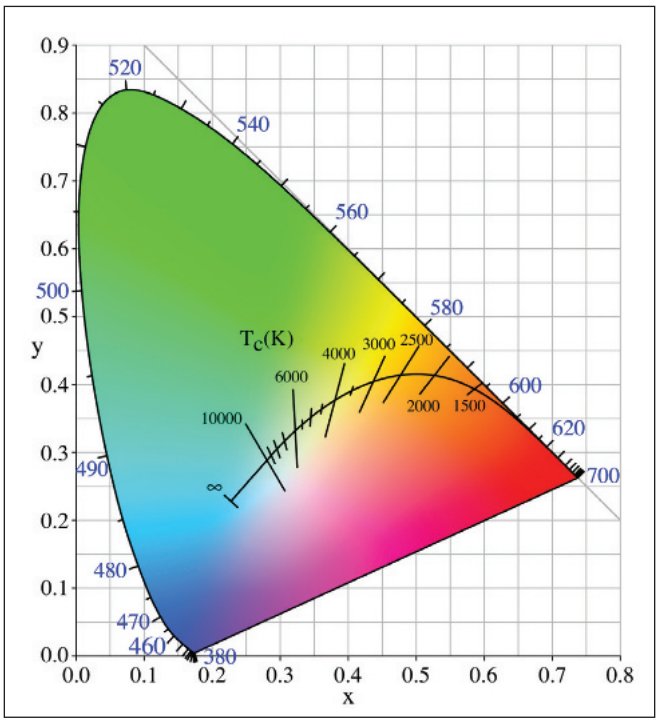


Figure 2. A CIE 1931 chromaticity diagram bounded by monochromatic wavelengths. The curved black line inside the diagram is the blackbody locus, which passes through the colours that would be emitted by a heated black object at different temperatures. The short black lines intersecting the locus show the various correlated colour temperatures (CCTs) – temperatures of non-blackbody emitters emitting light similar to a blackbody.

relatively slow luminescence kinetics of these rare-earth ions – they are in the range 10^{-6}-10^{-3} s – effective energy transfer can take place between optically-active rare-earth ions and the host matrix. This relaxes pumping requirements, while increasing device efficacy.

Selection of the matrix material plays a large role in determining the emission properties of the phosphor, because it has a profound effect on the active ion coordination chemistry. This allows phosphor makers to engineer the crystal field surrounding the doping sites of the ions. This crystal field determines the covalency of the lattice, and has different effects on the energy levels of 5*d* and 4*f* electrons.

One example of this kind of phosphor engineering is the creation of a new, warm LED phosphor based on a magnesium aluminium silicate, $Mg_2Al_4Si_5O_{18}$ (MASO), crystal matrix doped with Eu^{2+}, Ce^{3+}, Tb^{3+} and Mn^{2+}. Wei Lü and colleagues from the Chinese Academy of Sciences showed that the CRI and CCT of the light source could be successfully controlled by altering the crystal structure and doping ions. The phosphor's luminescence profile was fine-tuned by stimulating different energy migration pathways among active metal ions. However, the quantum efficiency of this phosphor requires further improvement, so work is underway to gain a better understanding of energy exchange in multi-rare-earth phosphors.

The cost of rare-earths has encouraged researchers to investigate other types of phosphors. Some of these resemble the traditional combination of host and luminescent ion, but are based on non-rare-earth elements such as manganese.

Others, meanwhile, are just very small particles of crystalline materials such as cadmium sulphide or cadmium selenide. These so-called quantum dots have sharp, atom-like transitions that give rise to sharp spectral lines with an emission wavelength governed by the size of the dot – the larger it is, the longer the emission wavelength. By combining six or more different sizes of quantum dot together, it is possible to generate customised broadband white light that is tailored to special needs.

Replacing traditional tungsten filament bulbs requires the production of LEDs with yellowish light. In contrast, illumination in museums and art galleries demands a fuller spectrum of white lighting, while medical and rehabilitation applications have their own, often very stringent, specifications.

These differing requirements can also be met by mixing phosphors together to obtain compounded or blended phosphors with desired spectral characteristics. Red-emitting, europium-based phosphors are often combined with yellow-emitting phosphors to reduce the colour temperature of emitted light. This is a cheaper, easier route to producing warm-white-light LEDs than using more expensive, colour-tuned phosphors. But to make a full-spectrum white LED requires phosphor mixtures containing three and even four components.

Blending of phosphors can be performed by a phosphor manufacturer – but most often an LED manufacturer, seeking to meet a specific spectral profile requirement, does it. One example of a blended phosphor LED is a tungsten-halogen lamp simulation LED, which mimics the spectrum of the filament source with a sloping spectral profile (see figure 4). Note that it would not be possible to reproduce this characteristic with a single phosphor.

It is the compounding of the phosphors that is behind much of the recent improvement in the quality of LED-based white lighting. With the continuing development of solid-state lighting, blended phosphor compositions will no doubt lead to speciality LEDs that have no counterpart in conventional incandescent lighting.

Long lifetimes

One of the great strengths of LED-based luminaires over those based on a tungsten filament, and even a fluorescent tube, is their longevity. Even though LED bulbs cost far more than incandescents, their long lifetimes easily compensate for their significantly higher price tags. Of the various components and materials inside a typical LED bulb, phosphors exhibit the longest lifetime. Rather than any malfunctioning of the LED itself, most bulbs fail prematurely because of the failure of one or more electronic components, such as electrolytic capacitors, in their power supply.

The GaN pump chip and the phosphor are extremely reliable, so if a switch-mode power supply itself holds up, the bulb can last for tens of thousands of hours. Unlike filament lamps, which experience catastrophic failure when their filament breaks, phosphor-coated LEDs have no sudden destruction mode. Instead, light output gradually declines over a long period of use.

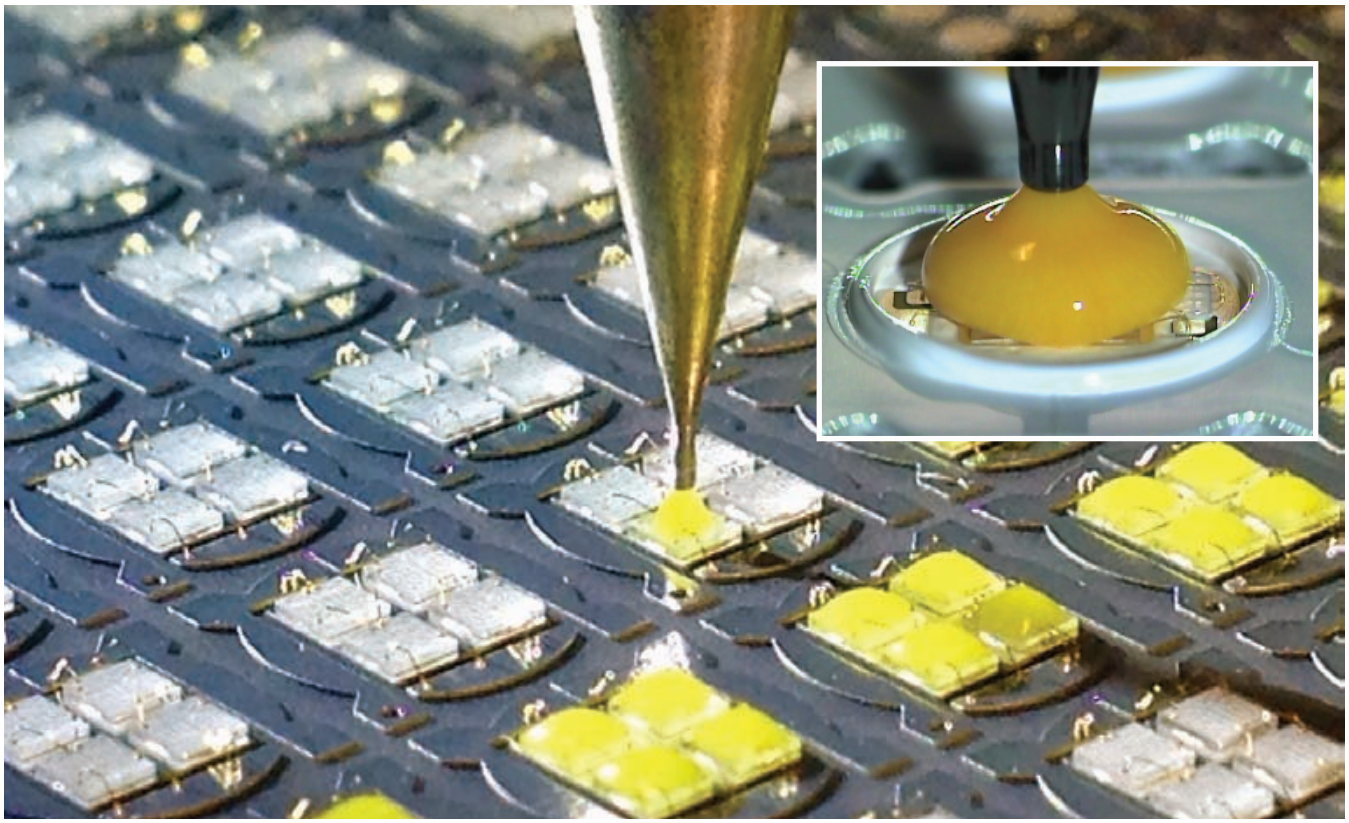


Figure 3. The phosphor that provides wavelength conversion in the LED is embedded in a polymer slurry. Courtesy: GPD-Global Corporation

Due to this behaviour, it makes sense to define the lifetime of the LED as the number of hours before the intensity of emission falls to a certain level. It is common to consider the time taken for intensity to half, and this leads to quoted lifetimes for modern LEDs of 10,000 hours to 50,000 hours.

A steady fall in light output comes from the degradation of the LED's phosphor. Although this class of materials may be considered to be hardy inorganic, thermodynamic processes inside the crystals cause defect formation. Deterioration is accelerated at a higher temperature, due to an increase in the density of defect centres, which seep energy away from the light-generating, wavelength-down-conversion process. Making matters worse, these crystal defects convert pump light from the LED chip to heat, magnifying defect formation and diminishing light output.

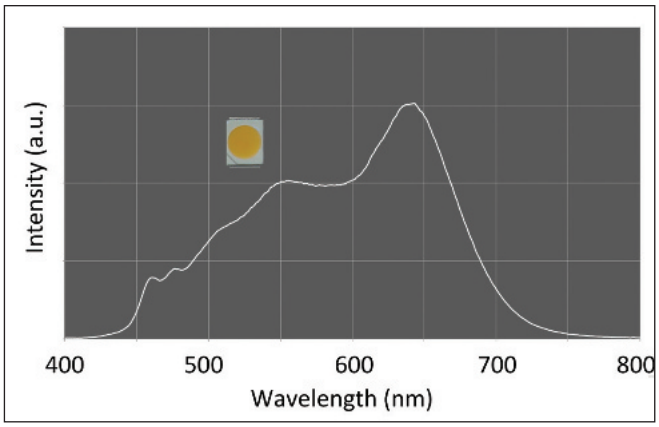


Figure 4. Through careful selection of several phosphors, it is possible to build an LED that can mimic the spectral output of a tungsten-halogen bulb (inset shows a tungsten LED device). Courtesy: Electrospell Corporation

Another problem associated with a high phosphor temperature is that it drives subtle changes in the chemistry of the active ionic species, such as changing the oxidation state. This is bad news, because it leads to changes in colour temperature and colour coordinates. The often talked-about changes in the chromaticity of LEDs are a result of solid-state reactions going on inside the phosphor matrix.

To reduce colour shifts with age and prolong LED life, some manufacturers of solid-state bulbs separate the phosphor from the main source of heat – the pump LED – so it is held at a lower temperature. Thanks to this modification to the design, useful lifetimes are as high as 50,000 hours.

In addition to the inorganic phosphors discussed here, which are deployed in contemporary luminance conversion, some researchers have been investigating luminescent organic compounds that can function as LED phosphors. Their main drawback is their lack of heat and oxidation resistance, which leads to a short operational lifetime. But these phosphors have very promising conversion efficiencies. That makes them an interesting addition to the worldwide effort to improve phosphors and develop new ones, and ultimately aid the growth and diversification of the market for white LEDs.

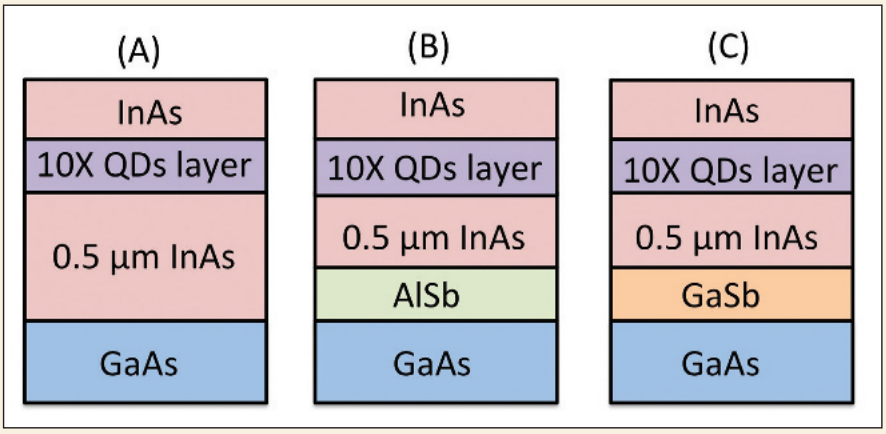
Dots offer promise for mid-infrared sources

InSb quantum dots deliver mid-infrared electroluminescence

A TEAM FROM THE UK has made significant strides in the development of low-cost, mid-infrared optical sources based on InSb quantum dots.

By producing these structures on GaAs substrates, these emitters could provide a competitively priced, low-cost optical source for sensing gases such as carbon monoxide, methane, and hydrogen sulphide.

The team's devices promise relatively high yields, because they are easier to fabricate than many other mid-infrared III-V sources, such as those based on inter-subband quantum cascade and type-II interband cascade structures.



Transmission electron microscopy, X-ray diffraction and photoluminescence were used to investigate the three different quantum dot samples.

"Quantum cascade lasers typically contain hundreds of alternating layers, which require precise control of their thickness and composition over a long growth time," says team member Qi Lu from Lancaster University.

He explains that the InAs structures that he and his co-workers envisage typically have no more than ten quantum dot layers within the active region, so growth procedures are relatively simple for a mid-infrared source.

The UK team, which involves researchers from Lancaster University and the University of Warwick, initially worked with InSb dots on InAs substrates, reporting room-temperature electroluminescence from an LED in 2008. Now they are trying to replicate this success on GaAs substrates, which are larger, cheaper, easier to handle, and will enable more affordable devices that can serve more applications.

InSb quantum dots must be grown within an InAs matrix, so to form these dots on a GaAs substrate, the team has had to overcome material quality issues stemming from the 7.2 percent lattice mismatch between InAs and GaAs.

They believed that the solution would be to insert an interlayer between the substrate and InAs. "We hoped that the interlayers that we were developing could largely reduce the thickness of the InAs metamorphic buffer while maintaining its top surface quality for subsequent quantum dot growth," reveals Lu. To test this theory, the team used a VG-V80H reactor to produce three samples by MBE. In all cases, deposition began with the growth of a 15 nm-thick layer of GaAs to smooth the substrate surface. All InAs layers were grown at 550 °C, and the AlSb and GaSb interlayers were deposited at 620 °C and 600 °C, respectively. After reducing the substrate to 490 °C, quantum dot layers and InAs spacers were grown on all samples (see Figure).

Surprisingly, interlayers failed to improve the material quality of the structure. Transmission electron microscopy revealed that the lowest threading dislocation density occurred in the sample with a 3 μm-thick InAs layer, with material quality increasing with distance from the GaAs-InAs interface.

X-ray diffraction measurements confirmed the superior material quality of the sample without an interlayer: This produced a peak associated with the InAs layer that had a full-width-at-half-maximum of 235 arcsec, compared with 483 arcsec and 416 arcsec for the other two samples.

Superior material quality led to the most intense photoluminescence, and confirmed that an interlayer-free structure should be used to form light emitting devices. The team fabricated 1 mm-long ridge-shaped *p-i-n* LEDs with a 75 μm wide light-emitting edge.

Driven with 1A current-pulsed excitation with a duty cycle of 1 percent and a repetition frequency of 20 kHz, these LEDs produced a peak at 3.1 μm that results from radiative recombination in the InAs layer and dominates emission from this device.

However, there is also emission associated with the dots that occurs at around 3.6 μm. Electroluminescence from the dots persists up to temperatures of 180 K.

According to the team, the results from this device are in good agreement with those from InSb quantum dot LEDs grown on InAs substrates, which exhibit electroluminescence at room temperature with the addition of an electron-blocking layer.

"Room temperature operation is highly desirable, especially for portable applications," says Lu. "Additional cooling for the device is not practical in many cases, and would increase the cost of future products – although thermoelectric cooling is often used for temperature stabilisation."

The team is now trying to improve the metamorphic buffer layer in its structure, and increase hole confinement in its long-wavelength InSb quantum dots.

Q. Lu *et. al.* Semicond. Sci. Technol. **29** 075011 (2014)

Improving AlN with an insulator

Silicon-on-insulator substrates provide the foundation for high-quality AlN films

ENGINEERS from Tsinghua University, China, have shown that switching from a silicon substrate to a silicon-on-insulator variant improves the quality of AlN film.

These efforts will aid the development of low-cost, high-quality AlN templates that can form the foundation for ultraviolet optoelectronic devices and high-power electronics.

There is already much interest in using a silicon substrate as a platform for the growth of nitride epilayers, because of its low cost, large size, and the promise for device processing in under-utilized, fully depreciated CMOS fabs. However, growth of high-quality AlN-on-silicon is particularly challenging, due to the significant thermal and lattice mismatch between the two materials.

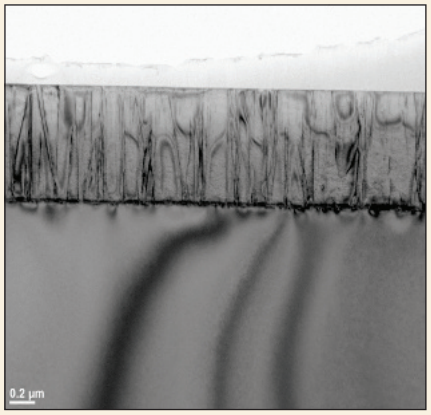
To overcome these challenges, many groups employ buffer layers and complex structures, such as superlattices. However, improvements in material quality then come at the expense of increased growth times and material costs.

An alternative to this, which researchers from Tsinghua reported in 2013, is to form high-quality AlN films on silicon (111) by coincidence domain matching with a ratio of 5:4.

"Based upon this technique, we [now] prove the stress caused by the lattice and thermal mismatches can be further released by utilising the 'stretchable' property of SOI substrates," says team member Zhibiao Hao. This 'stretchability' holds the key to forming high quality AlN thin films on silicon that are free from thick, complicated buffers.

To demonstrate the superiority of the novel substrate, the team grew AlN films by plasma-enhanced MBE on silicon, and also on SOI substrates produced by IceMOS Technology, UK.

Both substrates underwent an RCA cleaning process to create SiO_2 terminated surfaces, before being loaded in a preparation chamber and heated to 280 °C. This led to outgasing, which continued when the substrates were transferred to the MBE chamber and heated to 940 °C for 15 minutes.



Cross-sectional transmission electron microscopy reveals the stress in the top silicon layer of a SOI substrate capped with AlN

With the SiO_2 layer removed, the engineers performed a nitridation step at 600 °C for 60 s to create a Si_3N_4 layer, before depositing AlN films with thicknesses of 240 nm, 1 μm and 3 μm. To do this, they used a substrate temperature of 900 C, an aluminium source held at 1320 °C, and a nitrogen flux delivering a flow of 1.4 sccm under 375 W of RF power.

In both types of sample with a 240 nm-thick AlN layer, there is a similar density of screw threading dislocations, according to transmission electron microscopy. However, when the AlN thickness increases to 1 μm, the binary film grown on SOI has superior material quality.

The behaviour of these threading dislocations is also quite different in both samples. AlN grown on silicon (111) has a screw threading dislocation density of 1.1 x 10^{11} cm^{-2}, with most of the dislocations generated at the interface penetrating through to the top of the epilyer, and many new dislocations forming during the growth.

In contrast, when AlN is deposited on SOI, many threading dislocations merge in the epilayer, and none appear to form during the growth.

These observations are reflected in the screw threading dislocation density, which has an average value of 5.1 x 10^{10} cm^{-2} in the film, and just 7.4 x 10^{9} cm^{-2} near the surface.

Transmission electron microscopy reveals that in the 1 μm-thick AlN-on-SOI film – but not in the AlN-on-silicon equivalent – there are remarkable lattice distortions in the SOI layer that run through the entire top silicon layer and stop at the silicon-SOI interface.

According to the team, this distortion of the top silicon layer provides a mechanism for partially releasing the accumulated stress in the AlN epilayer.

Success with this approach hinges on the thickness of the AlN layer being comparable to that of the top layer of silicon. If the AlN layer is significantly thinner, its accumulated stress is insufficient to drive a lattice distortion in the upper layer of silicon.

Cracking occurs in epiwafers with 3 μm of AlN growth on either silicon or SOI. For the former structure, cracking occurs in just the AlN film, while in the latter heterostructure, lattice distortion leads to the crack penetrating into the silicon layer. This can drive apart the AlN and top silicon layer from the SOI.

Hao believes that it will be possible to replicate the team's results with the more common growth technique for nitride deposition, MOCVD. "Key processes such as nitridation and aluminization can be adapted, and the stress-release mechanism works in a large temperature range."

The researchers will now work to optimise the AlN-on-SOI templates. "Based on those achievements, we will try to develop thin-film based devices, such as sensors and nanostructure devices," adds Hao.

L. Niu *et. al.* Appl. Phys. Express **7** 06505 (2014)

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News Digest Contents

LEDs

Voids boost LED light emission

Higher light extraction efficiency results from a novel architecture formed by laser drilling and photochemical etching

A partnership between researchers in the US and China has increased LED output power by more than one-fifth via the creation of air gaps within the device.To deliver the increase in extraction efficiency, the researchers from National Chung Hsing University and Yale University drilled holes with a laser, before etching a heavily doped GaN layer beneath the LED structure.

Fabrication of these novel LEDs began with growth of an epistructure on sapphire that had a low-temperature buffer, an 1.2μm-thick undoped GaN layer, a heavily doped 0.2μm -thick GaN layer and a 0.2μm-thick undoped GaN layer. On top of this they deposited a relatively conventional device structure, which was capped with a 250 nm-thick layer of the transparent conductive material indium tin oxide.

Engineers employed a 355 nm laser to drill 10μm -diameter holes down to the heavily doped n-type layer, and used an electrochemical wet-etching process to create disk-shaped voids with a diameter of 40μm.

Driven at 20 mA, the etched LED delivered a light output power that was 22 percent higher than that of the control. However, this gain in the output came at the expense of a small increase in operating voltage from 3.12 V to 3.19 V, due to the slightly reduced emission area and the increased resistance of the treated LED structure.

Philips to merge lighting businesses

Stand-alone company will combine Lumileds and automotive lighting

Philips has announced plans to combine its Lumileds (LED components) and automotive lighting businesses into a stand-alone company within the Philips Group. The process is expected to be completed in the first half of 2015.

“Philips’ strategy in Lighting is to intensify its focus on connected LED lighting systems and services, LED luminaires, and LED lamps for the professional and consumer markets,” said Frans van Houten, CEO of Philips.

“By combining Philips Automotive lighting and Lumileds, the Automotive lighting customers will continue to benefit from a fully integrated end-to-end R&D and supply chain, enabling the adoption of LED technology in automotive applications,” said Philips Lighting CEO Eric Rondolat.

Sales of the combined businesses were approximately EUR 1.4 billion in 2013. The chief executive officer of the new company will be Pierre-Yves Lesaicherre, the current chief executive officer of Lumileds.

Costs associated with setting up the combined business are expected to amount to EUR 30 million in the second half of 2014.

Nanowin upgrades its GaN substrate production

High volume 2in GaN substrates with reduced dislocation densities

Benefiting from an upgraded HVPE system and improved growth technology, Suzhou Nanowin is announcing mass production of 2 inch GaN substrates with improved dislocation densities. Its production capacity has been increased by around five times this year. Dislocation density will be reduced from around 5x106cm-2 to less than 5x105cm-2.

Suzhou Nanowin has been providing 2 inch freestanding GaN substrates since 2010, mainly for manufacturing UHB-LED and blue laser diodes. Since 2012, Nanowin has been able to grow undoped GaN substrates with carrier concentration of the order of 3x1015cm-3 to to 5 x1016cm-3, and dislocation density as low as in 104cm-2, which is

suitable for fabricating switch devices.

Now, Nanowin can provide most customer-defined GaN substrates, including polar (Ga-face or N-face) and non-polar (a-plane and m-plane) substrate, GaN and AlN templates on sapphire or SiC substrates.

Epistar to reach 15 percent total global GaN wafer capacity following FOREPI merger

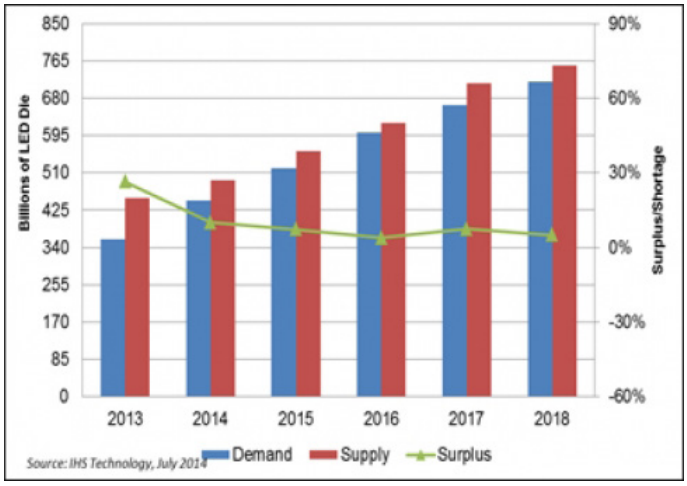
With 400 MOCVD reactors, this is more than double its nearest competitor

Following the announcement on June 30 that Epistar is acquiring Formosa Epitaxy (FOREPI), Epistar will have over 400 MOCVD reactors including those from FOREPI's China subsidiaries- more than double the GaN MOCVD of its nearest competitor, according to the latest research note from Alice Tao, senior analyst for IHS Technology, on Q2'14 GaN LED supply and demand.

Epistar will now take an even clearer lead as the number GaN LED die and wafer supplier. Epistar's projected wafer capacity share of 11 percent in the fourth quarter of 2014, added to FOREPI's 4 percent, will mean that the newly united group will account for 15 percent of total global capacity, according to IHS Technology.

Meanwhile at the packaged LED level, Nichia is the market leader with 12.5 percent as of the first quarter this year. Sanan, a shareholder of FOREPI, was previously projected by IHS to challenge Epistar for wafer capacity by the end of 2014. But Sanan will now have less than half of Epistar and FOREPI's combined share given the new development. Samsung, ranked third, is another top player for total which also leads for yielded die and binned die in addition to GaN wafer capacity.

LED companies have long since recovered from the 2011 to 2012 time period when capacity utilisations were very low, and Epistar and others have had stable, high-capacity utilisations for some time now. At the same time, the oversupply seen from 2011 to 2013 is projected to greatly reduce from 2014 to 2018 because of increased demand in lighting, says IHS.



According to the latest issue of the IHS Technology Quarterly GaN LED Supply and Demand Market Tracker, wafer surplus is projected to reduce from 27 percent in 2013 to 10 percent in 2014, and will be below 10 percent from 2015 to 2018, mostly due to the expansion of the lighting market as LED lamps and luminaires gain share, at the expense of traditional technologies.

Revenue from GaN packaged LEDs in lighting applications is projected to grow from $5.2 billion in 2013 to $6.0 billion in 2014, and then rising to $6.8 billion in 2015. Shipment growth is even stronger with 2015 shipments forecast to be almost double those of 2013.

Overall, GaN MOCVD installation is forecast to reach 257 reactors in 2014, with 830 reactors to be needed for the four combined years from 2015 to 2018 inclusive.

The top purchasers of MOCVD in 2014 are projected to be leading Chinese companies like Sanan and HC Semitek. Both announced plans for 200 MOCVD reactors recently.

Sanan stated it will invest 10 billion RMB (approximately US$1.6 million) to purchase 200 MOCVD reactors in Xiamen, while HC Semitek anticipates to reach 200 MOCVD by 2016. It should be noted, however, that not all LED companies historically have ordered as many MOCVD as they initially estimated. The top 10 purchasers are expected to have 89 percent market share in 2014

as leading suppliers continue to grow strongly; in comparison, smaller companies and new entrants that joined the market in recent years have often failed to see growth in this competitive market.

Epistar to own Formosa Epitaxy

Taiwan's largest LED maker is set to grow a little bigger

Yesterday, shareholders of Formosa Epitaxy, a Taiwanese firm maker of InGaN LED wafers and chips, approved a merger with Epistar Corporation, Taiwan's largest LED manufacturer. Epistar will acquire a 100 percent stake in Formosa Epitaxy through a share swap, which will complete by December 30, 2014.

Epistar, which makes AlGaInP, InGaN, and AlGaAs EPI wafers and chips, and GaAsP chips, has been looking to increase its production capacity. Epistar's has 385 MOCVD sets. The acquisition of Formosa Epitaxy, will add a further 103 MOCVD sets with an additional monthly production capacity of more than 200,000 LED epitaxial wafers.

Avantor to showcase new cleaning chemistries at SEMICON West

NMP-free organic film stripper for LEDs

Avantor Performance Materials will be showing a number of new products for photoresist and post-etch residue removal during SEMICON West 2014 in San Francisco next week. These include the new J.T.Baker ALEG-368 NMP-free organic film stripper and residue remover for LED applications

For lines, via, and bond pad cleaning, ALEG-368 is developed for technologies containing aluminum interconnects. The ALEG-368 formulation removes ash residue, sidewall polymers, and bulk photoresist, and is NMP-free in response to environmental and regulatory concerns.

The ALEG-368 material supports the integration of Environmental, Health, and Safety (EH&S) roadmaps, and allows for process optimisation and cost reduction programs.

Researchers make full-colour InGaN LEDs using LCD-type process

Low cost pulsed sputtering technique shows promise for large area InGaN LED displays

InGaN-based LEDs are now widely accepted as highly efficient light sources that can replace incandescent bulbs. But so far they been limited to small devices. Now a team from the University of Tokyo has shown that InGaN LEDs could form large area displays on amorphous substrates using a manufacturing technique frequently used for making liquid-crystal displays (LCD).

To date, most InGaN-based LEDs have been fabricated using expensive MOCVD processes on single-crystal substrates such as sapphire and SiC. In contrast, the Tokyo team used a pulsed sputtering deposition process to grow GaN and InGaN films on amorphous SiO2. They made working red, green, and blue InGaN LEDs.

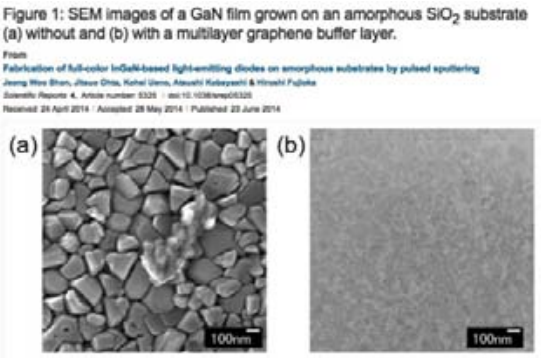


Figure 1: SEM images of a GaN film grown on an amorphous SiO_2 substrate (a) without and (b) with a multilayer graphene buffer layer.

From
Fabrication of full-color InGaN-based light-emitting diodes on amorphous substrates by pulsed sputtering
Jeong Woo Bhan, Jitsuo Ohta, Kohei Ueno, Atsushi Kobayashi & Hiroshi Fujioka
Scientific Reports 4, Article number: 6326 | doi:10.1038/srep06326
Received: 24 April 2014 | Accepted: 28 May 2014 | Published: 23 June 2014

Many attempts have been made to replace single-crystal substrates for the growth of group-III nitrides with low-cost, large-area materials such as glass and metal. Glass is the ideal substrate for large-area, low-cost LEDs because of its transparency and compatibility with existing LCD fabrication processes. But GaN films grown on glass have been impractical due to a low softening temperature (500-700degC) for glass substrates, and the amorphous nature of glass, which leads to poor crystalline quality of the overlaid nitride

semiconductor layer.

By introducing multilayer graphene as a highly oriented crystalline buffer layer between the substrate and nitride film, the team overcame the first problem (large-area graphene films like these can be easily deposited by conventional chemical vapour deposition). As for the low softening temperature, recent progress in the epitaxial growth techniques based on pulsed sputtering deposition enables the growth of high-quality group III nitride crystals even at room temperature. The successful reduction in the growth temperature was achieved because of the high kinetic energy and pulsed supply of group III atoms, which assist the surface migration of film precursors at substrate surfaces, Recently, successful fabrication of 640 nm InGaN LEDs by PSD at a maximum process temperature of 480degC has been reported (Nakamura et al Appl. Phys. Lett. 104, 051121 (2014)).

By demonstrating that full-color LEDs can be fabricated on amorphous substrates, the researchers think that since sputtering is frequently used in the LCD industry, it could be adapted to fabricate large-area inorganic LED displays on glass substrates including flexible glass foils.

This work is detailed in the paper *Fabrication of full-colour InGaN-based Light-emitting diodes on amorphous substrates by pulsed sputtering* by *Jeong woo Shon et al in Nature Scientific Reports 4, Article number 5325*

Cree delivers LED lighting and energy savings to Walgreens

The Cree lighting drives plans for a widespread LED rollout

Retailer Walgreens selected energy-efficient LED lighting by Cree for its Goodyear, Arizona location.

The firm's lighting is claimed to lower the total cost of ownership compared to fluorescent lighting alternatives.
The 14,820 square-foot store now features Cree LED troffers, linear luminaires and downlights, saving the retailer thousands in annual energy and maintenance costs.

"Cree's products deliver among the best light levels in the industry matched with superior efficacy, which helps lower our total cost of ownership since less power is needed to illuminate all levels of our shelves over alternative light fixtures," says Jamie Meyers, manager of sustainability for Walgreens.

"We had been looking to add LED technology to our corporate sustainability program for a while, and with the successful Cree lighting implementation at the Goodyear store, it's clear that it's time to roll this out on a larger level. We are planning to incorporate LED lighting into all of our new stores moving forward."

Supporting Walgreens' commitment to PURE (People Using Resources Efficiently), which focuses on environmental sustainability by managing energy consumption, the Cree LED lighting system allows Walgreens to reduce its energy usage and operating costs without compromising light quality.

Cree CS18 and CS14 LED linear luminaires deliver strong vertical light levels throughout the sales floor, while Cree CR24 troffers, designed to last 100,000 hours, help Walgreens reduce energy consumption and maintenance needs in the pharmacy. More importantly, the Cree luminaires are backed by Cree's ten-year limited warranty, providing investment protection.

"Our innovative LED lighting delivers real value by supporting the bottom line. Retailers no longer need to look to outdated technologies for a comprehensive lighting solution," says Steve Barlow, senior vice president of lighting sales, Cree. "LED technology is the perfect complement to corporate social responsibility programs for leading retailers like Walgreens that are exemplifying the benefits of high-quality illumination with significant energy savings."

"Lighting has been an integral part of Walgreens since its first store opened in 1901, which featured "new, bright lights to create a cheerful, warm ambiance," a marked departure from the dimly-lit stores of competitors.

Powered by Cree TrueWhite Technology, Cree

CS18 and CR24 architectural troffers deliver over 90 CRI, providing exceptional color rendering to showcase merchandise in their truest colours.

"With Cree, the colours of our merchandise pop to such an extent that customers can easily see items on the bottom shelves," adds Meyers. "There is a distinctively different feel when you walk into this store. Cree LED lighting has a better quality to it. It's crisper and cleaner. That's valuable to us, particularly as a retailer trying to make our product look as appealing as possible."

Phoseon to exhibit UV LED curing systems at Shanghai

These solutions are claimed to optimise UV LED curing technology for the curing of inks in digital inkjet, screen, flexographic and other printing processes

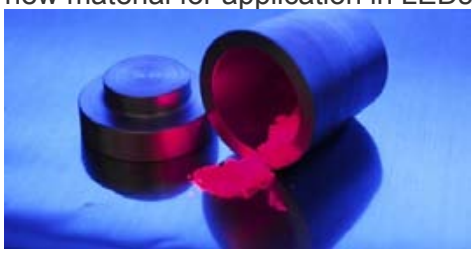
Phoseon's UV LED solutions will be exhibited at the upcoming Shanghai International Ad & Sign Expo (booth number W1-594).

UV LED curing technology is ideal for the UV curing of inks in digital inkjet, screen, flexographic and other printing processes.

Red phosphor brightens white LEDs

Based on Sr[LiAl3N4], when doped with an appropriate amount of europium, the compound displays intensive luminescence over a very narrow range of frequencies in the red band

Working with Peter Schmidt of Philips Technologie GmbH in Aachen, a team of researchers led by Wolfgang Schnick at LMU Munich, has developed a new material for application in LEDs.



The newly developed phosphor enhances the quality of colour rendition by white-emitting LEDs. (Source: Wolfgang Schnick, LMU Munich)

"With its highly unusual properties, the new material has the potential to revolutionise the LED market," says Schnick. The two teams report their results in the latest edition of *Nature Materials*.

Conventional incandescent light bulbs have a very low energy conversion efficiency, which has led the EU to order their withdrawal from the market. As a result, LEDs have become the light source of choice for the foreseeable future.

The light emitted by LEDs is generated by electronic transitions in solid-state semiconductors. In contrast to so-called energy-saving lamps, which contain toxic mercury, LEDs are environmentally friendly. What's more, they are highly efficient and promise significant reductions in energy consumption.

A single LED can produce light of only one colour tone. However, Schnick and his team had previously achieved a breakthrough by synthesising innovative phosphor materials that allowed the blue light produced by conventional LEDs to be converted into all the colours of the visible spectrum -in particular, those at the red end.

Mixing of the different colours results in high-quality white light and this invention earned Schnick and his colleagues a nomination for the German Future Prize 2013.

A new material with great potential?

LEDs that generate blue light can be converted into white-light emitters by coating them with various luminescent ceramics. These materials absorb some of the blue light and re-emit the energy at wavelengths corresponding to all the other colours of the visible spectrum from cyan to red.

The combination of these colour components with the unabsorbed blue light results in pure white light. The process sounds simple, but its practical realisation is very challenging. It requires phosphors which display extremely high thermal stability and operate with very high efficiencies.

"The problem with commercially available white-light LEDs is that there is always a trade-off

between optimal energy efficiency and acceptable colour rendition," says Schnick. The red-emitting phosphor materials so far used are the principal factor responsible for this, because they have a particularly significant influence on the so-called colour rendering index.

There is also a growing demand in the industrial sector for new phosphors capable of emitting in the deep-red region because this would enable the conflicting demands of optimal efficiency and most natural colour rendition to be reconciled.

The new material developed by Schnick, Schmidt and their colleagues is based on the nitride Sr[LiAl3N4]. When doped with an appropriate amount of europium, a rare-earth metal, the compound displays intensive luminescence over a very narrow range of frequencies in the red band.

Peak emission occurs at wavelengths of around 650 nm and peak width (full width at half-maximum) is only 50nm. The first prototype LEDs incorporating the new material generate 14 percent more light than conventional white-light LEDs and have an excellent colour rendering index.

"With its unique luminescence properties the new material surpasses all red-emitting phosphors yet employed in LEDs and has great potential for industrial applications" Schnick concludes.

Peter Schmidt and his associates at the Lumileds Development Centre Aachen (Philips Technologie GmbH) are currently modifying the synthesis of the new red phosphor to optimise it for large-scale manufacture. Their goal is to open the way to the next generation of brighter and more efficient white-emitting LEDs with the best possible colour rendition characteristics.

TrendForce: Chinese LED lighting package manufacturers booming

Lighting-use LED component market share last year surpassed 40 percent making it the sector with the largest market demand in the Chinese LED package industry

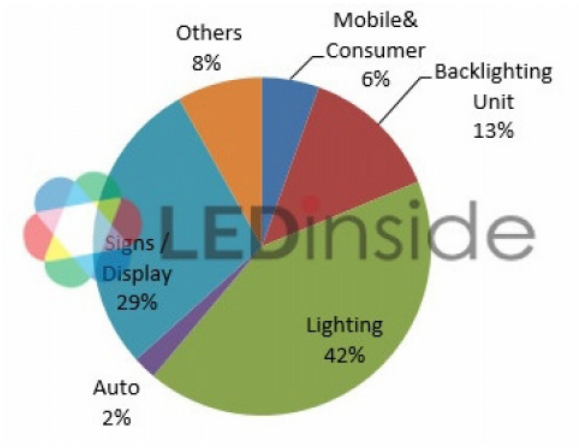
Chinese LED package manufacturers sales performance in 2013 was mediocre, the LED package market value was up slightly by 16 percent due to plunging prices, according to the latest "2014 Chinese Package Industry Market Report," by LEDinside, a research division of TrendForce.

As can be seen from each application market, display-use LED component market demands clearly declined as a result of easing market growth and falling prices.

In addition, backlight-use LED components, which currently have a saturated market demand, will have limited growth as technology improvements bring down usage volume. Chinese package manufacturers growth was mainly driven by lighting-use LED components.

In 2013, lighting-use LED component market share surpassed 40 percent making it the sector with the largest market demand in the Chinese LED package industry.

Distribution of Chinese LED package component application in 2013



Source: LEDinside

Manufacturers with their main business in lighting-use LED components such as Honglitronic, ChangFang Light, MLS Lighting and others, showed a clear growth in their lighting-use LED component business in 2013.

Last year, Honglitronic and ChangFang Light's revenue increased 39 percent and 41 percent respectively. Refond Optoelectronics, who focuses on mid to large sized backlight LED market, saw

an increase of 84 percent in lighting-use LED sales performance. Small size backlight manufacturer Jufei Optoelectronics' lighting-use LED component revenue also grew 84 percent.

Rapid upstream chip industry development has been the propeller behind the fast emerging Chinese package manufacturers, due to low-priced LED chips and geographical advantages where local LED package manufacturers have the advantage of being close to local resources.

Ample manufacturing resources and factory distribution gives Chinese downstream lighting industry an advantage in cost and manufacturing. During the first half of 2014, San'an Optoelectronics (San'an Opto), HC SemiTek, and Tongfang utilisation rates reached full capacity of 100 percent.

ElecTech also saw an increase and estimates remaining MOCVD will be put into production during the second half of 2014. Over the next few years, San'an Opto, HC SemiTek and other large Chinese chip manufacturers will continue to expand production capacity. Among them, San'an Opto plans to introduce another 200 MOCVD sets by 2018, expanding production capacity mainly for lighting applications.

First Chinese supplier makes top 10 LED rankings

Most new LED production capacity that has been added in last three years has occurred in China

China's massive investments in light-emitting diode (LED) manufacturing capacity are paying off, with a Chinese company entering the top ranks of the global market for the first time ever, according to IHS Technology.

China's MLS Electronics Co. Ltd. in 2013 rose to the No. 10 rank in the worldwide market for packaged LEDs, up from 14th place in 2012. With the other top 10 players based in South Korea, Japan, the United States, Germany and Taiwan, this represents a first for China's burgeoning LED industry.

"Since 2011, most of the new LED production capacity that has been added worldwide has occurred in China," said Jamie Fox, principal LED analyst for IHS. "Because of this, it was inevitable that Chinese companies would eventually penetrate the ranks of the top 10 LED suppliers. MLS was first, having established itself by capitalizing on strong domestic demand. For the major suppliers, MLS's ascent into the market's upper ranks represents a clear signal that Chinese firms soon will become major competitors in the global LED business.

MLS is one of many Chinese LED suppliers that have sprung up amid the surge in production. However, the other firms do not even rank among the top 20 global suppliers. China's LED supply base is massive and highly fragmented, with thousands of small manufacturers located across the country.

"Despite leading the domestic market, MLS accounted for less than 10 percent of Chinese LED revenue in 2013," said Alice Tao, China LED analyst at IHS. "The next five largest LED suppliers in China represented only about 20 percent of the market."

With the rise of LED manufacturing capacity in China, concerns have risen relating to overcapacity. Some of the equipment purchased for metal-organic chemical vapor deposition (MOCVD) manufacturing—the most important process step in LED production—is now sitting idle in China. Observers have fretted that the overcapacity could result in the shutdown of some Chinese suppliers.

So far only a few of the smaller Chinese vendors have closed their LED operations. Most of the top companies remain active in the market, with some posting strong profit margins.

MLS and the smaller Chinese suppliers mostly compete among themselves for a share of the large domestic LED market.

The international portion of sales for these companies is very small and the extremely low prices in the Chinese market make the country inaccessible to overseas suppliers. Because of this, foreign LED makers don't encounter Chinese competitors very often.

But that situation will change rapidly. IHS expects the LED revenues of Chinese vendors to grow

steadily over time, as the country's economy continues to grow strongly. Because of this, Chinese LED suppliers will begin to sell more internationally and come into competition with foreign rivals.

Both intellectual property and quality are concerns for international customers that are considering Chinese suppliers. However, several factors suggest these concerns could be alleviated over time. These factors include patent expirations, China's established history in other industries, the sheer volume of manufacturing capacity in the country and the fact that many LED lamps are assembled in the nation.

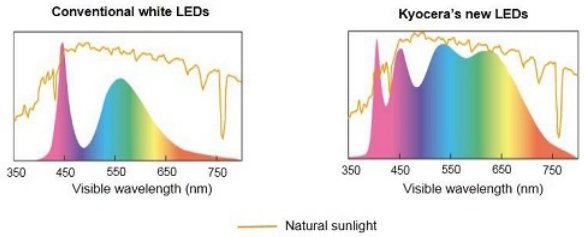
Kyocera says its compact LEDs mimic the sun

The new LEDs are said to produce spectrum close to sunlight and the ceramic technologies deliver low power consumption and extremely long life

Kyocera believes it has developed a new type of LED that produces a colour spectrum very close to natural sunlight making it ideal for colour inspection applications.

The new products are said to offer low power consumption and extremely long life in an array of lighting options. These include fluorescent tubes, standing lights and compact handheld lamps - making them a good alternative to large, heat-producing xenon lamps in areas such as automotive paint inspection.

Kyocera's new LEDs come in an array of lighting options: desktop type (top left), straight tube (top right), and handheld (bottom; front and side views) (Product images are not shown to scale)



Kyocera's new LEDs render a wider and more intense spectrum of light, approximating natural sunlight, than conventional LEDs

MicroSense ships LED measurement tool

The systems will be used for sapphire wafer process control

MicroSense, LLC has announced multiple shipments of its new, next-generation automated sapphire wafer metrology tool, the MicroSense UltraMap C200 (pictured below).

Designed specifically for high throughput dimensional measurement of sapphire wafers for LED manufacturing, the UltraMap C200 provides throughput of ninety 6" diameter sapphire wafers per hour with lowest cost of ownership (CoO).

The UltraMap C200 utilises MicroSense's novel two sided capacitive sensing technology to measure sapphire wafer geometry including thickness, TTV (total thickness variation), bow, warp, and LTV (local

site thickness variation).

"LED manufacturers typically don't make their own sapphire wafers, so incoming quality control has become a requirement for LED chip makers as the industry continues to migrate from primarily 2" wafers to 4", 6" and 8" wafers," according to David Kallus, Director of Dimensional Wafer Metrology at MicroSense. "LED manufacturers have found high sapphire wafer bow strongly correlates to LED yield loss. The UltraMap C200 utilizes our proprietary capacitive sensing technology and advanced high density wafer mapping algorithms to provide world leading measurement repeatability and throughput."

"Sapphire has become a break out substrate material, and sapphire factories are scaling to capacities unheard of before, driven by the LED and smartphone component markets," continues Kallus. "In order to improve sapphire wafer yields and drive down wafer cost, wafer manufacturers need to measure at more steps in the wafering process. Unlike metrology tools based on optical methods, the MicroSense UltraMap C200 measures sapphire wafers and substrates with any surface finish - as cut, lapped, ground, polished, textured and patterned sapphire substrates (PSS) - without sacrificing wafer throughput or measurement repeatability. Wafer surface condition has no effect on measurement performance."

The UltraMap C200 is available in three versions including tools with robotic loading, robotic loading with cassette sorting and a bench top tool. The UltraMap C200 handles wafers ranging from 2" to 8" in diameter.

Crystal IS launches AIN based UVC LED technology

The substrates grown on aluminium nitride substrates aim to improve productivity and increase accuracy

Crystal IS, a developer of ultraviolet (UVC) LEDs, has announced the availability of Optan.

The firm says this is the first commercial semiconductor based on native AIN substrates, Optan provides a technology platform for increased detection sensitivity, essential for analytical and life sciences instrumentation - from monitoring of chemicals in pharma manufacturing to drinking water analysis.

The Optan product enables design engineers looking to overcome limitations associated with traditional UV lamps, including deuterium and xenon flash lamps. As an enabling technology, Optan claims to allow developers to fully exploit the power of UV-based technology to improve productivity, increase accuracy and create greater flexibility in product designs.

"This is an exciting time for Crystal IS and an achievement for the semiconductor industry as a whole," said Larry Felton, CEO of Crystal IS. "Optan will help instrument manufacturers build smaller, more powerful tools and products with a lower overall system cost. We look forward to the scientific and environmental contributions their new products will provide."

Crystal IS says the light output and spectral quality of the Optan UVC LED technology, made possible by the low defect AIN substrate delivers good reliability. The firm also says the UVLEDS have a longer lifetime and are a game changer for life sciences and analytical instrumentation, including environmental monitoring.

There are several uses for these devices. They include:

HPLC (high-performance liquid chromatography), a powerful tool in analysis for detecting chemicals and compounds in life sciences.

Spectrometers, used in multiple applications in testing and analysis across biotech, life sciences and environmental monitoring.

Water quality monitoring sensors, becoming increasingly important for detecting chemicals in water from fracking, water security and the use of treated wastewater.

The Optan LEDs suited to spectroscopic applications.are currently available in peak wavelengths from 250nm to 280nm and power bins from 0.5 mW to 2 mW,

Full availability for all bins under 3 mW is anticipated for next quarter with higher power bins

with 3 - 4 mW available in Autumn 2014.

Plessey orders Ferrotec metallisation tool

The UEFC-4900 will bring the Auratus deposition process enhancement methodology benefits to Plessey's MaGIC LED production line

Ferrotec Corporation has confirmed that the first Temescal UEFC-4900 will be delivered to Plessey Semiconductors.

Plessey's proprietary MaGIC process produces a unique, thin layer of GaN-on-Silicon and the UEFC-4900 offers the benefits of the Auratus deposition process to attain near-perfect uniformity and reduction in material consumption.

UEFC-4900 system

"At only 2.5 µm for both buffer and epitaxial layer, our MaGIC process uses a much thinner GaN layer compared to the 8 µm thickness typical on most other LED processes," says Mike Snaith, operations director at Plessey. "When you're working with this level of precision, the uniformity and efficiency that you can achieve with a Temescal system is essential. The UEFC-4900 will be an excellent upgrade from our FC-2800 platform with its Auratus enhancements such as increased capacity, faster throughput and reduced cost of operations."

"Plessey is making tremendous inroads into reducing the cost of high brightness LEDs with its unique GaN-on-Silicon process. By producing high performance GaN LED structures on standard silicon substrates, Plessey is able to deliver industry-standard performance at a dramatically reduced cost of manufacture," Gregg Wallace, managing director of Ferrotec's Temescal division, comments.

"With the UEFC-4900, our most advanced Auratus process enhancements and our excellent local support, this tool will help Plessey achieve larger batch sizes and improved efficiencies, all while maintaining the critically precise process parameters," Wallace adds.

Everlight introduces new fog light LED

The III-nitride based LEDs enable energy savings and environmental protection

Everlight Electronics has put its three decades of experience in optoelectronics in developing LED components into the new Argus series fog light source.

Everlight's single-chip Argus LED packages for fog light are based on Everlight's Shwo D high-power LED

This product is capable of providing a clear forward visibility when driving in dense fog or heavy downpour. Combined with the colour temperature of sunlight (5600K), the LED front fog light increases

the driver's ability to perceive contrasts.

The Argus series combined fog light and daytime running light module will be showcased in the 2014 Guangzhou International Lighting Exhibition.

Similar to general lighting, car lighting has a long history from the earliest kerosene lamps to halogen light to the most popular HIDs of today. Alongside with the popular applications in lighting, LED is making its way into car products.

As the "eye" of a car, car lights are the most important contributors to driving safety and evolved from satisfying night time lighting needs to taking care of driving safety 24/7.

The LED head lamps and adaptive front lighting system, such as those installed on Audi A7, A8 and BMW M3, M4, as well as commonly seen LED brake lights and indicator lights not only show the unequalled ability of LEDs in energy saving and environmental protection, but also suggest that the use of LEDs improves the selling point and value of products themselves.

This year, Everlight is rolling out new high-power Argus single-chip LED fog light sources. In addition to the traditional 3.5 x 3.5mm package, the Argus comes with 2.5 x 2.5 and even 1.5 x 1.5 single-chip packages to make the LED fog light modules more compact.

Therefore, the light energy using the diffusion area in a reflective design is not lowered, and thus, the light efficiency and in turn the flexibility of space design are greatly improved. In the Argus single-chip series, the lens and chipset are put through rigorous optical reflection tests to improve colour temperature and uniform halo effect.

Regarding brightness performance, the single-chip module running on 1W produces a lighting effect as high as 150lm. Everlight will target rigorous requirements of zero defects like in car manufacturing as well as a global team of professionals to build a milestone for car lighting market.

The quality of Everlight's car LED components is certified to TS16949, and the LEDs themselves are AEC_Q101 certified. They are at the top of rank in stability, efficiency and cost/performance ratio, which makes Everlight an indispensible link in the supply chain of major international car manufacturers. The practical experience in the OE market has been highly recognised among major international firms.

Argus is said to meet the demands and technical criteria of the highest quality in the market particularly for the high temperature and harsh environment in the headlight assemblies.

Everlight Argus headlamp LED

Low thermal resistance and high heat dissipation rate with outstanding cost/performance ratio Everlight's high-power Argus series of LED headlight modules feature low thermal resistance and a high heat dissipation rate.

The overall package size is reduced to allow flexible space for the component manufacturers to design their headlight products. During the car LED design stage, Everlight works with several car lighting manufacturers for the demands and concepts of car LED products in the product design.

From heat dissipation to optical design, Everlight has developed double-chip, 4-chip, 5-chip and 6-chip designs based on top-notch cooperation of optical and heat dissipating technologies.

The latest Argus products are a line of high-performance headlight LED modules based on ceramic substrates featuring high heat dissipation rate up to 170W/mK, far better than those provided by conventional ceramic substrates. A single chip running at 1A provides up to 1200lm.

With a properly designed heat dissipating mechanism, a single chip provides highly stable performance even at 1.2A. The single-chip Tj design that has passed the 150°C high-temperature test is perfect for the harsh, extremely hot environment in a headlight assembly. For the optical element technology,

Everlight was able to control the multi-chip intervals within 0.08mm thanks to meticulous manufacturing process and innovated technology, allowing much simpler optical design and highly refined cut-off lines.

All of these improve clients' flexibility in style and

space design and added values, bring out the strength of Everlight's products in lighting efficiency and flexible applications of products, and meet clients' demands for high standard and complete service.

The quality of Everlight's car LED components is certified for TS16949, and the LEDs themselves are AEC_Q101 certified. They are claimed to be top in stability,efficiency and cost/performance ratio.

LatticePower to showcase GaN-on-silicon LED developments

The pioneer of blue/white gallium nitride-based LEDs on silicon substrates will be describing its latest developments at LIGHTFAIR International

LatticePower, which has commercialised GaN-on-silicon LEDs, will display at LIGHTFAIR International 2014, its next generation of light fixtures demonstrating the true convergence of performance, design and affordability.

The company's new proprietary GaN-on-silicon LED track, highbay and flood fixtures are claimed to deliver outstanding efficacy, superior brightness and excellent colour rendering.

Lightfair international, is one of the world's largest annual architectural and commercial lighting trade events and is celebrating twenty-five years of innovation. LFI blends continuing education courses with innovative products ranging from high-end design to cutting-edge technology.

This year in Las Vegas, the conference is expected to attract more than 25,000 lighting professionals, designers and architectures, as well as manufacturers and lighting fixture suppliers, from over eighty countries.

LatticePower will demonstrate its latest high performance lighting fixtures based on its proprietary GaN-On-silicon technology platform.

Digi-Key to distribute SunLED illumination products

Digi-Key's reach in the global electronic marketplace suits SunLEDs broad line of LED products and packages

Global electronic components distributor Digi-Key Corporation has signed a global distribution agreement with SunLED, an specialist in optoelectronic technology.

SunLED manufactures SMD LEDs, LED lamps, LED displays and other optoelectronic products.

The firm says its flexibility and breadth of LED product offerings provides design engineers the freedom to become more creative with their designs during the product development stage.

SunLED acknowledges the requirements of design engineers in the major core technology industries and provides them with optimum performance LEDs to meet or exceed their expectations.

"LED adoption is accelerating in numerous applications, regardless of industry," notes Mark Zack, Vice President, Global Semiconductor Product at Digi-Key. "Versatile, reliable LED solutions such as those offered by SunLED are ideally placed to address this growing need and we are pleased to add these products to our industry-leading in-stock selection."

SunLED focuses on niche markets and upcoming trends to ensure that new breakthroughs in LEDs are shared with the engineering community. Providing quality, innovative and high performance LED products to various engineers enhances designs, allowing groundbreaking, aesthetically eye-catching products to be introduced to the marketplace.

"We are excited to have Digi-Key as a global distribution partner. Their broad reach in the global electronic marketplace fits hand in hand with our extensive line of LED products and packages," says Grace Chang, Manager, SunLED Company, LLC. "This agreement enhances the scope of support for design engineers worldwide, both at well-

established manufacturers and new start-ups, to turn mechanical and electrical designs into the next generation of electronic products. We look forward to the bright future offered by this partnership."

These LED solutions from SunLED are available for immediate shipment on the Digi-Key website.

SunLED offers an extensive line of LED Lamps, Surface Mount LEDs, and LED Displays that are RoHS and REACH compliant. The firm supports customers with production capabilities exceeding 350 million LEDs per month.

Plessey branches out into Italy

The UK headquartered firm will use Comprel Srl to distributeits GaN-on-silicon LED products

Plessey has entered into a distribution agreement with Comprel Srl to expand its European network with coverage in the Italian market.

Comprel Srl is an Italian electronics distributor and provider of advanced complete solutions headquartered in Nova Milanese.

Michele Busnelli, Commercial Managing Director of Comprel, says, "Comprel is very happy to be a partner of Plessey Semiconductors. We entered the SSL (Solid State Lighting) market three years ago with the aim to introduce new technology in a booming sector. The GaN-on-silicon technology is going to be a revolution in the SSL market. I am sure that with the innovative products of Plessey and our deep knowledge of the market we are going to be very successful."

Michele Busnelli, Commercial Managing Director of Comprel

David Owen, Plessey's Regional Sales Director adds, "We are very pleased to work with a distributor that entered the lighting market some years ago and therefore has considerable knowledge of the local customer base and what is required to be successful. Comprel has a dedicated team working in the Italian lighting market place which will accelerate the time to market for Plessey GaN-on-silicon LEDs in this high growth region."

David Owen, Regional Sales Director, Plessey

Plessey's MaGIC (Manufactured on GaN-on-silicon I/C) High Brightness LED (HBLED) technology has won awards for its innovation and ability to cut the cost of LED lighting by using standard silicon manufacturing techniques.

Dot Metrics UV LEDs are cool

The compound semiconductor LEDs offer a portable system that provides a uniform, instant on and a 30 mW/cm2 field of narrow band UVA irradiation of 365nm

Dot Metrics Technologies has released the newest version of its UV Tetra - the Black Series.

It features a 30 percent increase in optical power density, dimming capabilities for optical power outputs, and PLC ON/OFF capability.

This device can be used for a variety of applications such as biological testing, counterfeit detection, sanitation, forensics, security inspection, fluorescence and perhaps most significant UV curing.

The UV Tetra Black Series is configurable for a wide range of UV curing applications. This family falls between large high powered arrays for line curing, and smaller devices for single point curing.

It utilises the technique of flood curing, giving it the ability to easily integrate into existing jigs for part curing, simultaneously bond multiple epoxy joints and cure both 3-D parts and materials containing intensity sensitive compounds.

In its standard configuration the new and improved UV Tetra Black Series is a turnkey, portable system that provides a uniform, instant on and a 30 mW/cm2 field of narrow band UVA irradiation (365 nm) of over an area of 1 inch2 at a distance of 1 inch with dimming capabilities.

Thanks to its mercury-free UV LED technology, UV Tetra Black Series provides “cool” UV without heating the target. This powerful device has a 2 inch2 footprint, weighs only 110 grams, and features a 4-point hot swappable connection for instant-on arrays with both a straight or angle positioning. Both 2D and 3D arrays can be snap assembled and used without special wiring.

The UV Tetra Black Series also features PLC ON/OFF Capability. It can be arranged in a variety of configurations, and is easily integrated into existing production lines and other systems.

Seoul Semi updates LED lighting controls

The manufacturer of III-nitride LEDs new product can improve energy savings, performance and aesthetics of LED lighting systems

Seoul Semiconductor has released the Acrich3, its next generation of smart lighting LED technology.

Acrich3 not only provides lighting designers with an easy to use solution but, coupled with smart lighting control technologies, it can further enhance energy savings, performance and aesthetics of LED lighting systems.

With Acrich3, Seoul Semiconductor believes it is positioned to penetrate the smart lighting market which is expected to reach €7.2 billion by 2020.

One of the barriers in replacing conventional lighting technologies with solid-state lighting products is the compatibility of existing TRIAC or phase-cut dimmers with LED retrofit lamps.

The Acrich3 solution is designed to work with most existing TRIAC dimmers without sacrificing on power quality or efficiency ensuring consumers can take advantage of both energy savings and ambiance lighting controls.

What’s more, the Acrich3 enables users to make the transition from wall-dimmer-controlled LED lights to smart lighting control systems. The Acrich3 technology can interface through a wide variety of wireless networks such as Zigbee, WiFi, Bluetooth to control dimming, CCT, zoning and scheduling, all from the convenience of a tablet or a smartphone to optimize both energy savings and the aesthetic benefits of LED lighting.

While existing Smart Lighting LED Systems require complex AC / DC converters, the Acrich3 IC can be operated directly off AC reducing component count and improving on reliability. It also has an in-built auxiliary power source to power sensors to interface with smart lighting controls.

Seoul Semiconductor Executive Vice President of Lighting sales division, Jay Kim has states that, “LED lighting optimised in combination with

advanced intelligent lighting control systems is becoming more important in both residential and commercial lighting applications. Seoul Semiconductor has invested over 4 years to make the perfect smart lighting system".

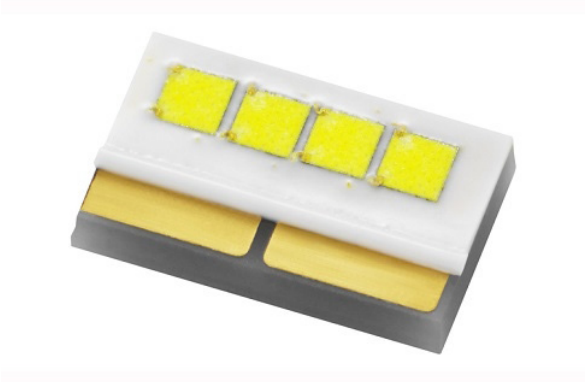
He adds, "Seoul Semiconductor plans to launch several new solutions with Acrich3 technology for the use in residential, commercial, and industrial lighting systems."

Everlight develops LEDs for automotive headlights

The III-nitride based LEDs will be showcased at the 2014 Guangzhou International Lighting Exhibition

Everlight Electronics has launched the Argus Series for automotive headlight applications.

The Argus LEDs are said to meet the demands and technical criteria of the highest quality in the market particularly for the high temperature and harsh environment in the headlight assemblies.



Everlight Argus headlamp LEDs

Low thermal resistance and high heat dissipation rate with outstanding cost/performance ratio Everlight's high-power Argus series of LED headlight modules feature low thermal resistance and a high heat dissipation rate.

The overall package size is reduced to allow flexible space for the component manufacturers to design their headlight products. During the car LED design stage, Everlight works with several car lighting manufacturers for the demands and concepts of car LED products in the product design.

From heat dissipation to optical design, Everlight has developed double-chip, 4-chip, 5-chip and 6-chip designs based on top-notch cooperation of optical and heat dissipating technologies.

The latest Argus products are a line of high-performance headlight LED modules based on ceramic substrates featuring high heat dissipation rate up to 170W/mK, far better than those provided by conventional ceramic substrates. A single chip running at 1A provides up to 1200lm.

With a properly designed heat dissipating mechanism, a single chip provides highly stable performance even at 1.2A. The single-chip Tj design that has passed the 150°C high-temperature test is perfect for the harsh, extremely hot environment in a headlight assembly. For the optical element technology,

Everlight was able to control the multi-chip intervals within 0.08mm thanks to meticulous manufacturing process and innovated technology, allowing much simpler optical design and highly refined cut-off lines.

All of these improve clients' flexibility in style and space design and added values, bring out the strength of Everlight's products in lighting efficiency and flexible applications of products, and meet clients' demands for high standard and complete service.

The quality of Everlight's car LED components is certified for TS16949, and the LEDs themselves are AEC_Q101 certified. They are claimed to be top in stability, efficiency and cost/performance ratio.

Samsung advances LED component colour rendering

With more than 90 CRI, the enhanced colour reproducibility will make the new products more attractive to lighting designers

Samsung Electronics has improved the light quality of its LED packages and modules based on a 90

CRI (Colour Rendering Index) for use in advanced lighting applications.

“With our improved colour rendering, Samsung’s LED packages and modules now provide LED lighting makers with light quality that far surpasses that of conventional lighting applications, while adding to the energy efficiency of our LED lighting line-up,” says Bangwon Oh, senior vice president of strategic marketing team, LED Business, Samsung Electronics. “With more than 90 CRI, the enhanced colour reproducibility of our best product platforms will make them even more attractive to lighting designers worldwide.”

Samsung’s LED product platforms include mid-power, high-power and chip-on-board (COB) packages as well as LED modules. With the improved CRI, Samsung LM561B and other mid-power LED packages can be used in a wider range of retrofit LED bulbs and downlights by reproducing colours comparable to those seen under natural sunlight. In addition, the improved high power LED LH351 series is suitable for MR, PAR and other spotlights that require high colour rendering, along with high light output.

Samsung’s LED modules enhanced with 90 CRI include the LT-A302 module comprised of mid-power LED packages, and the SLE series, which uses COB-type packages. The LT-A302 is a linear, lens-attached module (LAM) with a thin, 21 millimetre-wide form factor. The SLE series modules are suitable for spotlights and track lighting that prioritize high light output.

Samsung’s LED packages and modules with over 90 CRI will be commercially available in June.

Lumileds; CoB arrays hit 10,000 lm at 100 lm/W

The III-nitride based LEDs for downlights and outdoor/industrial fixtures target a CDM of 70 - 100W luminaire equivalent

Philips Lumileds says it is now delivering the highest flux and most efficient LED arrays in higher lumen packages.

The new LUXEON CoB 1211 is suited to industrial and outdoor applications and is an ideal replacement for 70W and 100W equivalent ceramic discharge metal halide (CDM) lamps.

As the latest addition to Philips Lumileds LUXEON CoB arrays portfolio, the LUXEON CoB 1211 delivers efficacy of 100 -130 lm/W, depending on colour temperature and CRI of the luminaire. The LUXEON CoB 1211 achieves cool white output exceeding 10,000 lm and 100 lm/W at 70CRI, while achieving a light emitting surface (LES) of 19 mm.

“The LUXEON CoB 1211 has the best combination of a small Light Emitting Surface and high efficacy at its specific lumen package,” says Eric Senders, Product Line Director at Philips Lumileds.

MKS branches out into vacuum with Granville-Phillips buyout

The acquisition strengthens MKS’ position in the vacuum gauge market. The firm’s primary served markets are manufacturers of capital equipment for semiconductor devices, and for other thin film applications including LEDs and solar cells

MKS Instruments has completed its acquisition of the assets of Granville-Phillips, formerly a division of Brooks Automation, Inc. for $87 million in cash

Granville-Phillips is a provider of vacuum measurement and control instruments to the semiconductor, thin film and general industrial

markets, with sales of approximately $30 million.in 2013.

This acquisition further strengthens MKS' position in the vacuum gauge market. MKS is the market leader in direct pressure measurement and Granville-Phillips is a well-regarded leader in indirect vacuum gauges, with a premium brand and an excellent reputation for quality, reliability and performance.

The Granville-Phillips business will be operated as the Granville-Phillips division of MKS and will be integrated into MKS' Pressure Measurement business. The acquisition is not expected to have a material impact on second quarter revenue or non-GAAP earnings.

Management expects the acquisition to be accretive to non-GAAP earnings in fiscal 2014, and also expects future cash flow benefits due to the availability of tax amortisation on most of the purchase price.

Jerry Colella, CEO and President, says, "We are pleased to be able to offer our customers and existing Granville-Phillips customers an extended portfolio of quality products supported by our global sales and service infrastructure. We are also excited to welcome Granville-Phillips employees to MKS and look forward to their contribution to business synergies as we integrate Granville-Phillips into MKS."

Telecoms

Advanced Photonix›s line of credit extended

SVB has agreed to extend the maturity date of the company's $5 million line of credit to June 20th, 2016

Advanced Photonix, Inc. has announced that the company has amended its lending agreements with Silicon Valley Bank (SVB) and Partners for Growth (PFG) given the successful firm underwriting by B. Riley of 6.2 million shares of its Class A Common Stock for net proceeds of approximately $2.9 million.

Under the terms of the amendment, SVB agreed to extend the maturity date of the company's $5 million line of credit to June 20th, 2016.

SVB also restored an interest rate matrix based on covenant performance that results in an interest rate on the line of credit ranging from prime rate plus 50 basis points on up to prime rate plus 400 basis points and an interest rate on the term loan ranging from prime plus 75 basis points on up to prime plus 450 basis points.

Both SVB and PFG agreed to convert the three month trailing adjusted EBITDA covenant into a six month trailing adjusted EBITDA covenant, measured at each fiscal month end, of negative $850,000 through June 2014, negative $300,000 for July through September 2014, and positive $1 for October through December 2014 and $100,000 each month thereafter subject to reset upon the submission of the fiscal 2016 budget, but in no case lower than $100,000 on a rolling six month basis. SVB and PFG also agreed to reset the existing liquidity ratio covenant to 1.30 to 1.00 through May 31st, 2014 and 2.0 to 1.0 for all months on or after June 2014 as measured at each month end.

Richard Kurtz, Chief Executive Officer, comments, "We are pleased that our lending partners have returned to similar terms that we enjoyed in the past given the proceeds from our recently completed shelf offering. This $2.9 million cash infusion has allowed us to pay down debt and provide the capital we needed to fund our expected growth over the coming years. We want to thank our lenders and B. Riley for their assistance and look forward to growing the company in our current fiscal 2015 by more than 20 percent."

Advanced Photonix is a supplier of optoelectronic sensors, devices and instruments used by Test and Measurement, Process Control, Medical, Telecommunication and Homeland Security markets.

Finisar buys Aixtron MOCVD system

Finisar expands capacity for new tunable lasers and PICs

Finisar Corporation, the designer and manufacturer of optical communications components and subsystems, is expanding its capacity for making tunable lasers, high speed modulators, and photonic integrated circuits (PICs) with an AIX 2800G4-TM MOCVD system from German firm Aixtron SE.

To be used in Finisar's Swedish facility in Järfälla, near Stockholm, the new MOCVD depostition system will also support the company's focus on developing new, more highly integrated indium phosphide products, according to Patrik Evaldsson, Vice President and General Manager of Finisar Sweden.

Finisar Corporation already uses Aixtron's Planetary Reactor technology production for lasers and photodetectors.

Multi-tasking LNA from MACOM

Ultra-small packaged amplifier is ideal for space constrained customers looking for frequency cov erage up to 6 GHz

M/A-COM Technology Solutions (MACOM) has introduced a low noise, high gain amplifier for wireless infrastructure, WiFi and L- and S- band applications. The MAAL-011078 is a low noise amplifier that it is claimed to offer an ultra-low noise figure and high gain from a single stage. The Low Noise Amplifier (LNA) covers a bandwidth between 700MHz and 6GHz with good noise figure, OIP3 and gain. The return loss can be optimised over narrow bands by implementing simple external matching networks. The integrated active bias circuit allows direct connection to 3V or 5V voltage supply and minimises variations over temperature and process. The bias circuit voltage supply (VBIAS) can be utilized as an enable pin to power the device up and down during operation. "This LNA is a designed as a second generation of MAAL-011076 and MAAL-011075. It is designed using very low noise process and has more gain and bandwidth than any other LNA in the market," says Amer Droubi, Product Manager, MACOM. "Matching is done externally in order to enable customers to make the necessary compromise between return loss, gain, OIP and noise figure Production quantities and samples of MAAL-011078 are available from stock.

What now for RFMD and TriQuint merger?

The business combination is still subject to approval by both TriQuint's and RFMD's shareholders, other required regulatory approvals, and customary closing conditions

RF Micro Devices, Inc. and TriQuint Semiconductor, Inc. have announced that the applicable waiting period under the U.S. Hart-Scott-Rodino Antitrust Improvements Act of 1976 has expired.

The amended HSR Act, in the business combination between RFMD and TriQuint, expired on 11:59 p.m. EDT on June 13th 2014, with no action by the Federal Trade Commission or the Department of Justice.

On February 24th 2014, RFMD and TriQuint announced that it had entered into a definitive merger agreement under which the companies will combine under a new holding company in an all-stock, merger-of-equals transaction.

Upon completion of the transaction, RFMD shareholders will receive 0.25 of a share of common stock of the new holding company for each share of RFMD common stock, and TriQuint shareholders will receive 0.4187 of a share of common stock of the new holding company for each share of TriQuint common stock.

The companies anticipate that RFMD shareholders, on the one hand, and TriQuint shareholders, on the other hand, will each hold approximately 50 percent of the shares of common stock of the new holding company issued and outstanding immediately after completion of the transaction.

Completion of the HSR Act waiting period should

satisfiy one of the conditions required to finalise the transaction.

Emcore develops 40 GHz wideband RF splitter & redundancy switch

The firm will be showcasing the device at CommunicAsia 2014

Emcore's Optiva OTS-RFS-2 40 GHz device provides RF signal distribution for wideband satellite antenna applications up to 40 GHz for 1 x 1 RF fibre link redundancy applications.

Optiva OTS-RFS-2 and OTS-RSU-2, 40 GHz RF Splitter & Switch

The Optiva OTS-RSU-2 is optimised to perform in the 10 MHz to 40 GHz frequency range for 1 x 1 satellite signal transport link redundancy applications when integrated with Optiva RF fibre optic transmitters and receivers.

The switch also has automatic and manual redundancy modes, SNMP monitoring and control at 50 Ohm K.

Highest performing III-V metal-oxide FETs

III-V MOSFETs could lower power consumption for the next generation of servers

UCSB researchers say they have introduced the highest performing III-V metal-oxide semiconductor (MOS) field-effect transistors (FETs) at the 2014 Symposium on VLSI Technology.

The University of California, Santa Barbara (UCSB) research promises to help deliver higher semiconductor performance at lower power consumption levels for next-generation, high-performance servers.

The research is supported by the Semiconductor Research Corporation (SRC), a university-research consortium for semiconductors and related technologies.

UCSB says its III-V MOSFETs, for the first time in the industry, exhibit on-current, off-current and operating voltage comparable to or exceeding production silicon devices - while being constructed at small dimensions relevant to the VLSI (very-large-scale integration) industry.

For the past decade, III-V MOSFETs have been widely studied by a large number of research groups, but no research group had reported a III-V MOSFET with a performance equal to, let alone surpassing, that of a silicon MOSFET of similar size.

In particular, UCSB's transistors possess 25nm gate lengths, an on-current of 0.5mA and off-current of 100nA per micron of transistor width and require only 0.5 volt to operate.

"The goal in developing new transistors is to reach or beat performance goals while making the transistor smaller - it is no good getting high performance in a big transistor," says Mark Rodwell, professor of Electrical and Computer Engineering at UCSB. "In time, the UCSB III-V MOSFET should perform significantly better than silicon FinFETs of equal size."

To reach this breakthrough in performance, the UCSB team made three key improvements to the III-V MOSFET structure. First, the transistors use extremely thin semiconductor channels, some 2.5nm (17 atoms) thick, with the semiconductor being InAs. Making such thin layer improves the on-current and reduces the off-current. These ultra-thin layers were developed by UCSB Ph.D student Cheng-Ying Huang under the guidance of Arthur Gossard.

Next, the UCSB transistors use very-high-quality gate insulators, dielectrics between the gate electrode and the semiconductor. These layers are a stack of alumina (Al2O3, on InAs) and zirconia (ZrO2), and have a very high capacitance density. This means that when the transistor is turned on, a large density of electrons can be induced into the semiconductor channel.

Third, the UCSB transistors use a vertical spacer layer design. This vertical spacer more smoothly distributes the field within the transistor, avoiding band-to-band tunnelling. As with the very thin InAs channel design, the vertical spacer makes the leakage currents smaller, allowing the transistor's off-current to rival that of silicon MOSFETs. The overall design, construction and testing of the transistor was led by UCSB Ph.D student Sanghoon Lee under Rodwell's guidance.

"The UCSB team's result goes a long way toward helping the industry address more efficient computing capabilities, with higher performance but lower voltage and energy consumption," says Kwok Ng, Senior Director of Device Sciences at SRC. "This research is another critical step in helping ensure the continuation of Moore's Law - the scaling of electronic components."

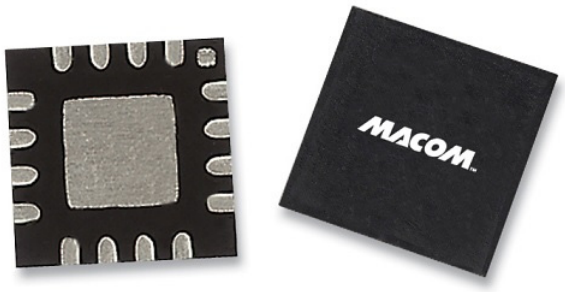
This article was adapted from an article by Semiconductor Research Corporation.

MA/COM introduces GaAs based LNA for 22-38 GHz applications

The low noise figure, and high gain amplifier is suited to in receiver applications

M/A-COM Technology Solution has launched a new three-stage low noise amplifier for point to point applications.

The MAAL-011111 is a low noise amplifier covering 22 - 38GHz in a small and low cost 3 x 3 mm QFN package. It offers 19dB of gain and less than 3dB of noise figure.



MAAL-011111 chip

The LNA is self-biased requiring only a single 3.3V voltage supply and there is no need for any external components. It is claimed to be easy to implement and takes up a small board area. The high gain and low noise figure makes it well suited as a first stage LNA in receiver applications covering multiple bands simultaneously.

"The MAAL-011111 offers excellent performance across the full band up to 38GHz in a small fully molded QFN package," says Amer Droubi, Product Manager, MACOM. "The low noise amplifier has an integrated ESD protection and by-pass capacitors and requires a single positive bias supply, making it an idea low cost and easy to implement solution for a wide range of applications."

The table below outlines typical performance:

Parameter	Units	MAAL-011111
Frequency	GHz	22-38
Small Signal Gain	dB	19
Input Return Loss	dB	10
Output Return Loss	dB	13
Noise Figure	dB	2.5
Supply Current	mA	55

Avago announces $0.29 interim dividend

The device supplier of analogue semiconductor devices with a focus on III-V based products and

complex digital and mixed signal CMOS based devices will be paid by June 30th

Avago Technologies Limited has announced that its Board of Directors has approved a quarterly, interim cash dividend of $0.29 per ordinary share.

The dividend is payable on June 30th, 2014 to shareholders of record at the close of business (5 pm) Eastern Time on June 19th, 2014.

Sumitomo Electric launches GaN HEMTs for space

The gallium nitride modules have a power added efficiency of 71.2 percent

Sumitomo Electric Device Innovations USA, Inc. (SEDU is to showcase next generation GaN devices for space applications at IMS2014.

GaN provides the benefits that space applications require such as operation at much higher temperatures, higher power added efficiency, wider bandwidth than GaAs all the while reducing overall operational cost.

“Sumitomo Electric is dedicated to offering a broad range of space qualified RF products over thirty years,” says John Wyatt, President of Sumitomo Electric Device Innovations USA. “The combination of high power, high gain and excellent efficiency performance makes our next generation GaN HEMTs for space very attractive design solution. For example ES/SGN15H150IV provides 150 W output power at 1.575 GHz with power added efficiency of 71.2 percent.”

The devices offer a high output power in single ended package and exhibit more than 70 percent power added efficiency. They have 18 dB gain at 1.5 GHz and operate at 50 V.

Samples for evaluation up to 150 W will be available in August 2014.

Hittite and Xilinx to demonstrate SiGe based radio Solutions

The complete 60GHz small cell backhaul demonstration will utiliseHittite’s 60GHz silicon germanium transceiver chip set

Hittite Microwave Corporation and Xilinx are to demonstrate complete radio solutions for 60 GHz millimetre wave small cell backhaul and 1024QAM microwave radio cellular backhaul at MTT-S. Tampa, June 3rd to 5th, 2014.

The Complete 60GHz Small Cell Backhaul Demonstration:

Hittite’s 60GHz SiGe transceiver chip set interfaces directly to the Xilinx 256 QAM Millimetre Wave ModemSmartCORE IP to support up to 750 Mbps data throughput capacity and configurable channel bandwidths from 50 to 250MHz with FDD and TDD modes to formulate an ideal lower power consumption small cell backhaul radio solution.

Hittite’s 60GHz transceiver chip set is a complete millimetre wave to baseband solution. The transceiver incorporates universal IQ interfaces for direct modulation and demodulation and chip set implements the entire transmitter and receiver chains with on-chip frequency synthesizers, frequency converters and the transmit power amplifier and receive low noise amplifier.

Hittite will release its next generation 60 GHz transmitter and receiver chipset later this year with increased output power (>15 dBm), a new frequency synthesizer with support for 64-QAM modulation and covering 57 - 66 GHz in 250 MHz step size, an integrated power detector, analogue or digital gain control, all in 4 x 6 mm surface mount packages.

Xilinx’s 256-QAM millimetre wave modem, part of Xilinx SmartCORE IP portfolio, is highly configurable point to point and point to multipoint capable modem. It consumes less than 5W of power at >1 Gbps data rates and incorporates all the key features and capabilities customers require to accelerate development of next generation backhaul solutions.

It supports RS and LDPC FEC, CPRI for front haul or 10GbE for backhaul, as well as the JESD204B interface for emerging data converter devices. The core can be extended to support also wider band supports such as 500MHz with up to 3.5Gbps throughput.

The 1024QAM Microwave Radio Split-Mount Outdoor Unit (ODU) Backhaul Demonstration:

Hittite's transceiver chip sets interfaces directly to the Xilinx QPSK to 1024QAM SmartCOREIP Modem to construct a fully functional Split-Mount Outdoor Unit (ODU) microwave radio. Hittite's 6 - 42GHz transceiver chip set is a simplified, cost effective solution consisting of highly integrated IF transceiver ICs, high linearity microwave IQ transmitter and receiver ICs, low phase noisemicrowave synthesisers ICs and the transmit power amplifier, all with industry leading performance and surface mount packaging.

The Xilinx modem implements all the features of a modern microwave radio backhaul including QPSK to 1024QAM modulation with software configurable bandwidths from 3.5 - 112MHz. The modem supports Gigabit Ethernet with software configurable features including closed loop digital pre-distortion, automatic correction of TX and RX IQ impairments, equalisation, XPIC and ATCP configuration support.

RF Electronics

European supply chain for advanced GaN technologies

Four year R&D project secures independent GaN production for military applications

A four-year research project guided by the European Defence Agency (EDA) has succeeded in establishing the entire supply chain for making GaN power components within Europe. The supply chain ranges from the availability of SiC substrates for the epitaxial growth of GaN, to the industrial manufacturing of hemts.

Project MANGA (Manufacturable GaN-SiC-substrates and GaN epitaxial wafers supply chain) was set up to ensure production of GaN devices for military applications without relying on international suppliers. Their high efficiency and robustness means GaN-based power electronic components are fast replacing established technologies in a broad spectrum of defence applications from advanced radar and communication antennas to electronic warfare. As such, the technology is regarded as critical.

MANGA involved research institutions, universities and defence companies from Germany, France, Italy, Sweden and the UK, working with the EDA. In the scope of the project, GaN-based transistor layers were grown epitaxially on newly developed, high quality SiC-substrates. Applying established foundry processing, these transistor layers were finally used to make state-of-the-art hemts.

In future projects, the EDA aims to further reduce the European defense industry's dependence on international trade regulations. In a follow-on project, the project partners want to achieve the qualification of an industrial European wafer supplier for state-of-the-art hemt structures.

High efficiency wireless power transfer demo boards

Featuring high frequency enhanced mode GaN fets

Efficient Power Conversion Corporation (EPC) has introduced two demo boards for resonant wireless power transfer. The EPC9506 and EPC9507 amplifier boards are based on the company's high frequency gallium nitride transistors, which enable wireless power systems with greater than 75 percent efficiency.

The EPC9506 and EPC9507 are A4WP compliant, Zero Voltage Switching (ZVS), Voltage Mode Class-D wireless power transfer amplifier boards capable of delivering up to 35W into a DC load while operating at up to 6.78MHz. The boards feature the 40V EPC2014 (EPC9506) and the 100V EPC2007 (EPC9507) eGaN FETs.

Both boards are configured to operate in either a half-bridge topology (for single-ended configuration)

or full-bridge topology (for differential configuration), and include the gate driver(s) and oscillator that ensure operation of the boards at a fixed frequency.

EPC makes enhancement-mode gallium-nitride-on-silicon (eGaN) FETs as power MOSFET replacements in applications such as DC-DC converters , wireless power transfer , envelope tracking, RF transmission, solar micro inverters, remote sensing technology (LiDAR), and class-D audio amplifiers.

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Analog Devices to acquire Hittite Microwave Corporation

Hittite's strength in RF, microwave, and millimeter wave technology complements ADI's RF and signal conversion expertise

Analog Devices, Inc (ADI) and Hittite Microwave Corporation have announced that the two companies have entered into a definitive agreement whereby ADI will acquire Hittite for $78 per share in cash. The closing price of Hittite's common stock on June 6, 2014 was $60.56 per share.

This agreement reflects a total enterprise value for Hittite of approximately $2 billion. ADI expects to fund the acquisition through a combination of cash on hand and short-term debt financing. The Boards of Directors of each company have approved the transaction, which is expected to close near the end of ADI's third fiscal quarter of 2014, subject to regulatory approvals and other customary closing conditions.

The transaction is expected to be accretive to ADI's non-GAAP earnings per share.

"Hittite's strength in RF, microwave, and millimeter wave technology complements ADI's RF and signal conversion expertise," said Vincent Roche, ADI President and CEO. "Our combined capabilities

will enable us to bring more complete solutions to our customers and address more of the industrial, communications infrastructure, and automotive markets."

"We welcome the very talented Hittite team, as we together leverage our strong product portfolios and customer relationships to create greater value for all our stakeholders," said Mr. Roche.

Rick D. Hess, President and Chief Executive Officer of Hittite added, "We are delighted to join forces with ADI, a premier company that shares Hittite's passion for solving complex challenges for customers. I look forward to joining Analog Devices and I am confident our combined efforts will accelerate the course of innovation throughout cellular and microwave communications infrastructure, automotive, industrial instrumentation, aerospace and defence."

ADI also reaffirmed financial guidance for its third quarter of fiscal year 2014, for revenue to increase in the range of 1% to 5%, and excluding any one-time items, for diluted earnings per share to be in the range of $0.60 to $0.64.

ABI: Wireless infrastructure drives RF power

The RF power semiconductor market is expected to top $1 billion in 2013. ABI Research says the market bridges the gap between two older technologies, exhibiting the high-frequency performance of GaAs combined with the power handling capabilities of silicon LDMOS

Spending on RF power seiconductors for the wireless infrastructure markets took another jump in 2013.

Other markets are seeing some moderation in growth as the global economic picture and political factors come into play but some sub-markets are showing a nice upside.

Also, according to a new study from ABI Research, gallium nitride - long seen as the likely promising new "material of choice" for RF power semiconductors - is continuing its march to capture share, especially in wireless infrastructure.

"Gallium Nitride (GaN) is delivering increasing market share in 2014 and is forecast to be a significant force by 2019," notes ABI Research Director Lance Wilson. "It bridges the gap between two older technologies, exhibiting the high-frequency performance of Gallium Arsenide combined with the power handling capabilities of silicon LDMOS. It is now a mainstream technology which has achieved meaningful market share and in future will capture a significant part of the market."

The vertical markets showing the strongest performance outside of wireless infrastructure in the RF power semiconductor business are the defence oriented segments, which Wilson describes as being now "a significant market" in total. Despite the poor press for defence oriented electronic hardware the actual performance in 2013 was better than originally thought for some sub-segments. "RF Power Semiconductors" examines RF power semiconductor devices that have power outputs of greater than 4 watts and operate at frequencies of up to 3.8 GHz, which represent the bulk of applications in use today.

The last study ABI Research published on this topic appeared late in 2013.

Lasers

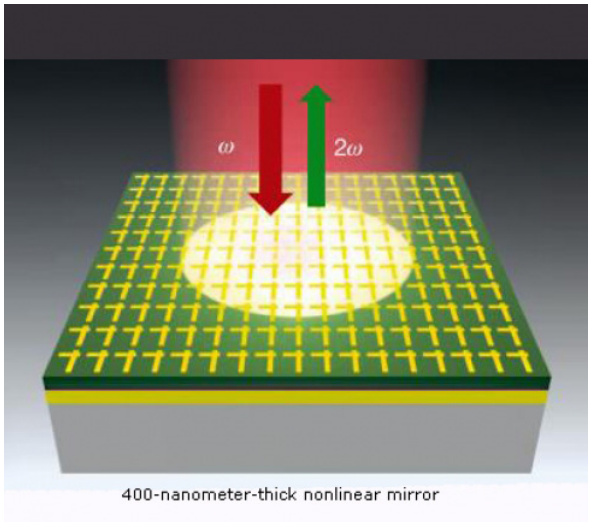
Non-linear metamaterials deliver compact lasers

Million times higher intensity frequency-doubled output

Using layers of indium, gallium and arsenic alternated with aluminum, indium and arsenic in a coupled quantum well structure, scientists at the Technische Universitaet Muenchen, Germany and the University of Texas, Austin, USA have developed a way of making compact lasers at wavelengths for which either no laser systems exist or at best only large and expensive ones.

About 100 of these InGaAs and ALInAs layers (each between one and twelve nanometers thick) were stacked on top of each other and sandwiched

between a layer of gold at the bottom and a pattern of asymmetrical, crossed gold nanostructures on top to make a 400nm thick nonlinear mirror. For a given input intensity and structure thickness, the new structure can produce approximately one million times higher intensity of frequency-doubled output, compared to the best traditional nonlinear materials, according to the researchers.



For the initial demonstration, the material converted light with a wavelength of 8000 nanometers to 4000 nanometers. “Laser light in this frequency range can be used in gas sensors for environmental technology,” says Frederic Demmerle, project member at the Walter Schottky Institute of the TU Muenchen.

Doubling the frequency of a beam of light in this way stems from the engineered electron states in the semiconductor material. When the semiconductor layers are only a few nanometers thick, the electrons can only occupy specific energy states and can be resonantly excited by the electromagnetic radiation.It is possible to adjust the structure to resonate optimally with the desired wavelengths by tuning the semiconductor layers’ thicknesses and the gold surface nanostructures geometry. The metallic structures ensure that the light is optimally coupled to the material. Their design also causes a strong increase in field strength at specific locations, which further amplifies the nonlinear response.

According to the researchers, because the frequency conversion happens over subwavelength scales, the nonlinear mirrors are free from the stringent requirement of matching the phase velocities of the input and output waves, which complicates nonlinear optical experiments with bulk nonlinear crystals.

The new structures can be tailored to work at various frequencies from near-infrared to mid-infrared to terahertz. In the future, the team thinks the structures could be used for other nonlinear effects. “Alongside frequency doubling, our structures may be designed for sum- or difference-frequency generation,” says graduate student Jongwon Lee, at the University of Texas, the lead author on the paper ‘*Giant nonlinear response from plasmonic metasurfaces coupled to intersubband transitions’* published today in Nature 2014, DOI: 10.1038/nature13455

Finisar buys Aixtron MOCVD system

Finisar expands capacity for new tunable lasers and PICs

Finisar Corporation, the designer and manufacturer of optical communications components and subsystems, is expanding its capacity for making tunable lasers, high speed modulators, and photonic integrated circuits (PICs) with an AIX 2800G4-TM MOCVD system from German firm Aixtron SE.

To be used in Finisar’s Swedish facility in Järfälla, near Stockholm, the new MOCVD depostition system will also support the company’s focus on developing new, more highly integrated indium phosphide products, according to Patrik Evaldsson, Vice President and General Manager of Finisar Sweden.

Finisar Corporation already uses Aixtron’s Planetary Reactor technology production for lasers and photodetectors.

Osram creates phasers for projectors

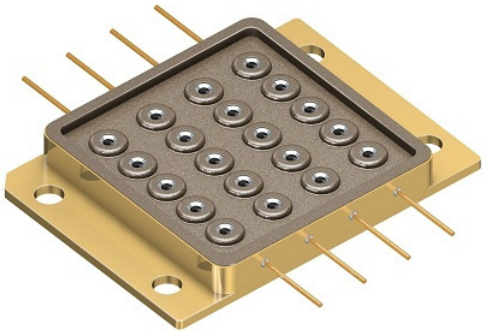
The company says this is the first compact laser module with a 50W optical output

Osram Opto Semiconductors can pack up to twenty blue laser chips in its new PLPM4 450 module.

Instead of taking the laborious approach and constructing a light source from individual laser diodes, it is now possible to reduce the complexity of laser projectors significantly.

The developers also succeeded in doubling the optical output of the individual chips, with the result that the new laser module now offers an overall output of 50W.

This means that professional laser projectors can achieve a brightness level of more than 2000 lumen with only one component.



Osram's multi die laser

Osram Opto Semiconductors is strengthening its leading position in light sources for laser projectors with its blue PLPM4 450 multi-chip package. Osram developers are the first to adapt the "butterfly" package for projection applications.

The result is a powerful laser module which can be more easily integrated in projectors. Its package measures 25.5 by 35mm and accommodates four copper bars with up to five blue laser chips connected in series and operated at 2.3A each.

This multichip product offers a light output of 50W from a typical electrical input of 165W, with wavelengths of 440 to 460nm. It achieves an efficiency of 30 percent.

Blue laser diodes in combination with a converter wheel, which converts part of the blue light into the two primary colours of red and green, are used as the light source for laser projectors.

Up to now, to achieve sufficient brightness for professional applications more than twenty individual laser diodes had to be combined. With its impressive optical output of 50 W the new laser module offers projection brightness levels of more than 2000 lumen from only one package.

If several modules are installed in a projector, brightness levels far in excess of 5000 lumen are then possible - for example for devices in large conference rooms.

To achieve the high optical output of the PLPM4 450, developers at Osram Opto Semiconductors optimised the chip parameters to double the single-chip output from 1.6 to 3.2 W and also improved the thermal resistance of the module.

This, says Osram Opto, offers unique technical performance is particularly attractive, and so too are the costs for the new laser module.

Thanks to the special design and the improved optical output power of the individual chip, the price per optical watt could be significantly reduced.

Another price benefit comes from the reduced production costs - installation and alignment of a multi-chip package involve less time and lower costs than for a large number of individual TO packages.

The radiation from all the laser chips can therefore be collimated with a single lens array. "The innovative package simplifies the integration of laser technology in projectors considerably, enabling a breakthrough in the projection market", says Stephan Haneder, Marketing Manager at Osram Opto Semiconductors.

Volume production of the PLPM4 450 will start at the end of 2014. Samples will be available from the summer.

The Osram Specialty Lighting Business Unit will also be integrating the multi-chip package in a new generation of phaser light modules for projection applications.

Phaser in this case is a hybrid word formed from phosphor and laser. Phaser light modules based on the multi-chip package will feature a particularly compact design and will be capable of being used

in combination, making them very easy to integrate in existing projector architectures.

Mitsubishi Electric touts GaAs based LD for projectors

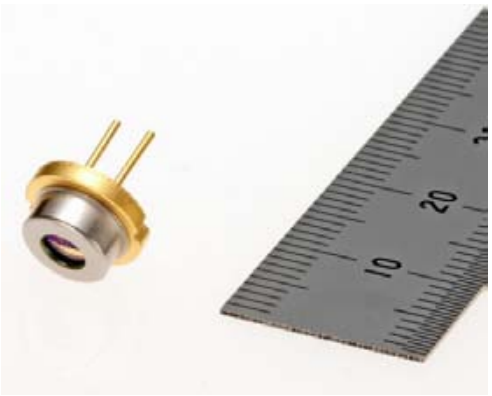
The gallium arsenide based 638nm laser diode will be showcased at LDC 2014 in Taiwan this week

Mitsubishi Electric has developed a GaAs based 638nm wavelength red laser diode (LD) offering an output power of 1.8 W at continuous-wave operation.

The company says this is the world's highest level among 638nm LDs in this package size used as light sources for projectors.

A commercial launch is targeted for the fiscal year ending in March 2016 at which time laser light sources for projectors are expected to take off.

The LD will be presented during the Laser Display Conference 2014 (LDC 2014) at National Chung Hsing University in Taichung, Taiwan on June 19th and 20th.



638nm wavelength red laser diode

Light sources for colour projectors, conventionally lamps, are being replaced with solid-state light sources offering higher energy efficiency, higher colour reproduction and longer life.

LDs deliver high output power while consuming low power because of their high power-conversion efficiency.

Mitsubishi Electric says that previously, the output power of red LDs with wavelengths shorter than 640nm was not sufficient for high-brightness projector applications at high temperatures.

As a first step to overcome this limitation, the firm applied specialised window-mirror structures and epitaxial growth technology to develop an LD capable of 0.5W power output at continuous-wave operation, which is packaged in a 5.6mm diameter transistor-outline can (TO-can).

After that, it applied a new LD structure in a 9.0mm TO-can package to achieve an output power of 1.8W at a 638nm lasing wavelength at continuous wave operation within an operating range of 0 to 45oC.

The device is also capable of emitting 1.3 W at continuous wave operation above 55oC and should meet the demands for bright projector systems.

Luminosity as a red light source exceeds 220 lumens due to lasing at a short wavelength and electrical conversion efficiency is 38 percent at 1.8 W at 25oC, helping to reduce power consumption.

QinetiQ acquires RIO semiconductor laser company

The acquisition should provide OptaSense, a wholly owned susidiary of QinetiQ, with secure access to an engineering team which develops coherent, low noise semiconductor lasers

QinetiQ Group plc has acquired Redfern Integrated Optics (RIO), a supplier of low noise semiconductor lasers, with a turnover of $5 million in 2013.

Based in San Francisco, California, RIO is a supplier to the sensing industry with over ten years' experience of delivering world class products to the fibre geophone, LiDAR and Distributed Acoustic Sensing (DAS) markets.

Backed by a consortium of venture capital funds led

by Southern Cross Ventures and Jolimont Capital, RIO says it was the first company to develop a commercially viable semi-conductor laser with sufficient stability for DAS applications.

Leo Quinn, QinetiQ Chief Executive Officer says, "This acquisition of RIO is an important step in ensuring that OptaSense realises its full potential as the global leader in distributed acoustic sensing. We are committed to supporting the high-growth businesses in our portfolio, accelerating their development as appropriate with acquisitions and partnerships. This acquisition has natural synergies with OptaSense and secures its access to a key supplier in the market."

Adds Magnus McEwen-King, OptaSense Managing Director, "We have been working with RIO for many years and are impressed with the technical capabilities of the team. Their products are ideally suited to the distributed fibre sensing market especially within the oil & gas sector where high performance and high reliability in harsh environments are essential."

"We see demand for RIO's laser products continuing to grow across the whole fibre sensing market and look forward to supporting their existing customer base. Through this acquisition we also gain the ability to shape the future developments of their products to further improve the technical performance of our DAS offerings especially in the seismic monitoring market. "

Larry Marshall, Chairman of RIO and Managing Director of Southern Cross Ventures comments, "OptaSense has made an excellent strategic acquisition and will greatly enhance RIO's ability to scale their unique technology across a broader range of markets and customers than would normally be accessible to a small start-up. Our team and investors are pleased that RIO secured such an exceptional partner who will support our customers."

RIO will be integrated with OptaSense but will continue to use the RIO brand name. The transaction is expected to complete within the first half of QinetiQ's financial year and is subject to normal regulatory approvals.

New compact microwave light sources

A new approach replaces the magnets with microwaves, and designers say it could be scaled to produce X-ray light

Stanford University scientists from the National Accelerator Lab (SLAC) have found a new way to produce bright pulses of light from accelerated electrons that could shrink light source technology used around the world since the 1970s to examine details of atoms and chemical reactions.

Traditionally this light is created by wiggling accelerated electrons with heavy magnets in a device called an undulator.

Undulators currently produce bright X-ray pulses for experiments at dozens of sites, including SLAC's Stanford Synchrotron Radiation Lightsource (SSRL) and Linac Coherent Light Source (LCLS) free-electron X-ray laser.

"This is a radical new design that can be used to create light sources that are more compact than can be achieved using a conventional undulator," says Sami Tantawi, a SLAC particle physics and astrophysics professor who led the development effort.

The microwave undulator can produce shorter wavelengths of light - using less driving energy from electrons than conventional undulators. This means the accelerator that feeds it electrons can shrink considerably, Tantawi adds.

A Step Toward Tabletop X-ray Lasers

"This brings us much closer to the dream of a tabletop X-ray free-electron laser," Tantawi says. "We have proved, in principle, that this is possible."

Electrons beamed into the undulator encounter rapidly alternating high-power microwave fields that cause the electrons to wiggle, emitting light at specific wavelengths. The wavelength and other properties of this light can be precisely tuned to suit many different types of experiments by adjusting the energy of the electrons and the microwave power.

Tantawi adds, “Because it doesn’t have any moving parts, the microwave undulator is amenable to scaling down to very short wavelengths.” Increasing its length and supplying more electron energy could allow it to produce X-ray pulses like those generated by the LCLS X-ray laser. Its scalability and rapid tuning sets it apart from other next-generation undulators, he notes.

A new source of tuneable light

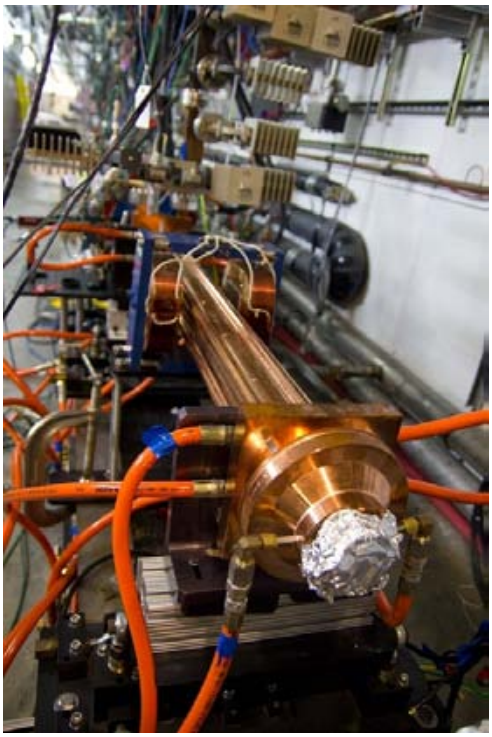
The new device could be used to provide more highly tailored light pulses that open new realms of experimental possibilities, particularly for studies of materials with exotic properties. It could be incorporated into next-generation lasers, synchrotrons and particle colliders and installed in existing facilities, such as SLAC’s LCLS and SSRL.

Tantawi says that next, he would like to pursue a superconducting version of the undulator that would require supercooling in order to produce a more continuous stream of light for experiments.

“This technology has vast potential to dynamically control the properties of the light for use in many scientific experiments,” comments Muhammad Shumail, a PhD student who is writing his thesis about the undulator.

Muhammad Shumail inspecting the microwave undulator that he worked to design and build (Credit: Fabricio Sousa/SLAC)

With further miniaturisation, it is conceivable that the microwave undulator could serve as a portable medical imaging source, Tantawi explains. “The next step of the research is to really make this technology more available.”



This microwave undulator, designed and built at SLAC, uses microwave power and electrons to produce shorter-wavelength pulses, and is highly tuneable compared to conventional undulators that use magnets (Credit: Glenn Roberts Jr./SLAC)

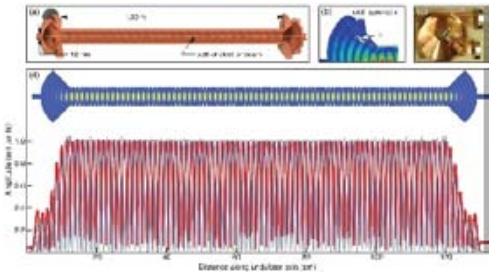
SLAC technologist Gordon Bowden says building the prototype device was challenging, requiring specialised tools to cut a series of tiny ribs from the inside of the copper pipe the undulator is made of. The ends of the device had to be precisely tapered to better trap the microwave energy in the device.

“No conventional undulator has the agility that this device can offer,” Bowden adds. “The unique properties of the light that emerges from the undulator are due to the precise comb-like pattern of the microwave fields trapped inside”.

Tantawi says SLAC’s historic and unique expertise in accelerators and microwave technology was well-suited to the development of the new device. “This is one of the few places on the planet we could have built this,” he said. The first magnetic undulator was built by Stanford researchers in the 1950s.

The pursuit of the microwave undulator was inspired by Tantawi’s conversations with X-ray free-electron laser pioneer Claudio Pellegrini and by Joachim Stöhr, SLAC photon science professor,

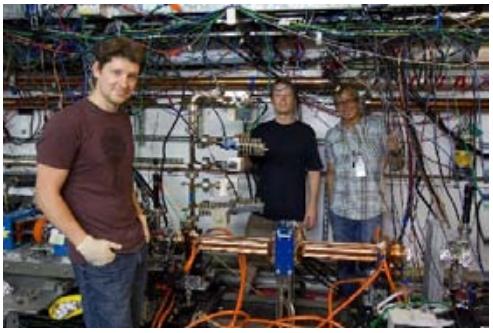
and the design stemmed from his work on a similar design for an antenna that could be used to explore the so-called cosmic microwave background radiation, which is believed to hold clues to the earliest origins of the universe.



A cutaway view of a microwave undulator designed and built at SLAC, with the path of the electron beam shown in white. (Bottom) Measurement of the electrical field travelling through the magnetic undulator (red), and a simulated view of the electromagnetic field created inside the undulator (blue) by the microwaves propagating through (Credit: Physical Review Letters/10.1103/ PhysRevLett.112.164802)

The work is described in detail in the paper, " Experimental Demonstration of a Tunable Microwave Undulator," by Sami Tantawi *et al in Physical Review Letters*, 112, 164802 (2014). DOI: 10.1103/PhysRevLett.112.164802.

The project was funded by the U.S. Department of Energy and the Defence Advanced Research Projects Agency AXiS program.

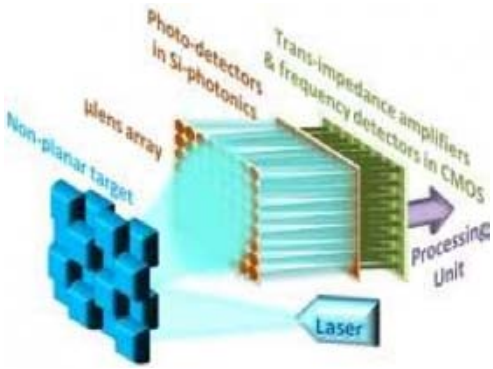


From left: Eric Hemsing, Michael Dunning, and Stephen Weathersby assisted with the microwave undulator project at SLAC (Credit: Glenn Roberts Jr./SLAC)

VCSELs and MEMS unite to enhance 3-D imaging

A new low power compact laser combining III-Vs and silicon could provide exceptional range for potential use in self-driving cars, smartphones and interactive video games

A new twist on 3-D imaging technology could one day enable your self-driving car to spot a child in the street half a block away, let you answer your smartphone from across the room with a wave of your hand, or play "virtual tennis" on your driveway.



A conceptual vision for an integrated 3D camera with multiple pixels using the FMCW laser source (Credit: Behnam Behroozpour)

The new system, developed by researchers at the University of California, Berkeley, can remotely sense objects across distances as long as thirty feet, ten times farther than what could be done with comparable current low-power laser systems.

With further development, the technology could be used to make smaller, cheaper 3-D imaging systems that offer exceptional range for potential use in self-driving cars, smartphones and interactive video games like Microsoft's Kinect, all without the need for big, bulky boxes of electronics or optics.

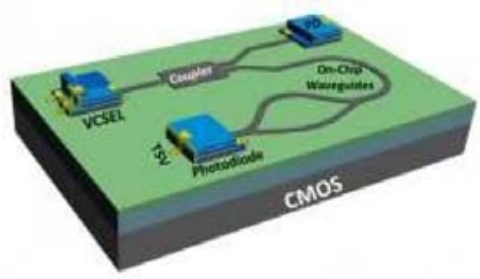
"While metre-level operating distance is adequate for many traditional metrology instruments, the sweet spot for emerging consumer and robotics applications is around ten metres," or just over thirty feet, says UC Berkeley's Behnam Behroozpour."This range covers the size of typical living spaces while avoiding excessive power dissipation and possible eye safety concerns."

The new system relies on LIDAR (light radar), a 3-D imaging technology that uses light to provide feedback about the world around it. LIDAR systems of this type emit laser light that hits an object, and then can tell how far away that object is by measuring changes in the light frequency that is reflected back. It can be used to help self-driving cars avoid obstacles halfway down the street, or to help video games tell when you are jumping, pumping your fists or swinging a racket at an imaginary tennis ball across an imaginary court.

In contrast, current lasers used in high-resolution LIDAR imaging can be large, power-hungry and expensive. Gaming systems require big, bulky boxes of equipment, and you have to stand within a few feet of the system for them to work properly, Behroozpour says. Bulkiness is also a problem for driverless cars such as Google's, which must carry a large 3-D camera on its roof.

The researchers sought to shrink the size and power consumption of the LIDAR systems without compromising their performance in terms of distance.

In their new system, the team used a type of LIDAR called frequency-modulated continuous-wave (FMCW) LIDAR, which they felt would ensure their imager had good resolution with lower power consumption, Behroozpour says. This type of system emits "frequency - chirped" laser light (that is, whose frequency is either increasing or decreasing) on an object and then measures changes in the light frequency that is reflected back.



3-D schematic showing MEMS-electronic-photonic heterogeneous integration (Credit: Niels Quack)

To avoid the drawbacks of size, power and cost, the Berkeley team exploited a class of lasers called MEMS tuneable VCSELs. MEMS (micro-electrical-mechanical system) parts are tiny micro-scale machines that, in this case, can help to change the frequency of the laser light for the chirping, while VCSELs (vertical-cavity surface-emitting lasers) are a type of inexpensive III-V integrable semiconductor lasers with low power consumption. By using the MEMS device at its resonance - the natural frequency at which the material vibrates - the researchers were able to amplify the system's signal without a great expense of power.

"Generally, increasing the signal amplitude results in increased power dissipation," Behroozpour says. "Our solution avoids this tradeoff, thereby retaining the low power advantage of VCSELs for this application."

The team's next plan includes integrating the VCSEL, photonics and electronics into a chip-scale package. Consolidating these parts should open up possibilities for "a host of new applications that have not even been invented yet," Behroozpour says - including the ability to use your hand, Kinect-like, to silence your ringtone from thirty feet away.

Behnam Behroozpour will describe the team's work at CLEO: 2014, in presentation AW3H.2, titled, "Method for Increasing the Operating Distance of MEMS LIDAR beyond Brownian Noise Limitation," which will take place on Wednesday, June 11th at 4:45 p.m. in Room 210H of the San Jose Convention Centre

Solar

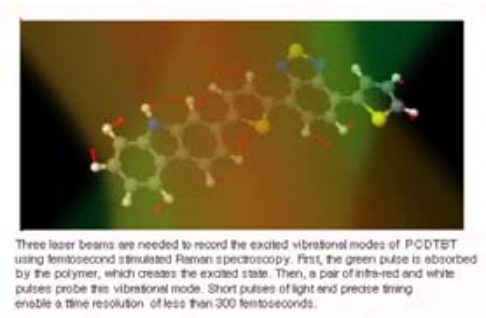
Scientists discover how plastic solar panels work

Findings are of key importance for all solar conversion systems

Scientists have determined exactly how light beams excite the chemicals in solar panels to produce charge. The findings, published today in Nature Communications, are of key importance for a fundamental mechanistic understanding, with molecular detail, of all solar conversion systems, according to lead author Françoise Provencher of the University of Montreal.

The researchers at University of Montreal, the

Science and Technology Facilities Council, Imperial College London and the University of Cyprus have been investigating the fundamental beginnings of the reactions that take place that underpin solar energy conversion devices, studying the new brand of photovoltaic diodes that are based on blends of polymeric semiconductors and fullerene derivatives. "In these and other devices, the absorption of light fuels the formation of an electron and a positive charged species. To ultimately provide electricity, these two attractive species must separate and the electron must move away. If the electron is not able to move away fast enough then the positive and negative charges simple recombine and effectively nothing changes. The overall efficiency of solar devices compares how much recombines and how much separates," explained Sophia Hayes of the University of Cyprus, last author of the study.



Three laser beams are needed to record the excited vibrational modes of PCDTBT using femtosecond stimulated Raman spectroscopy. First, the green pulse is absorbed by the polymer, which creates the excited state. Then, a pair of infra-red and white pulses probe this vibrational mode. Short pulses of light and precise timing enable a time resolution of less than 300 femtoseconds.

Two major findings resulted from the team's work. "We used femtosecond stimulated Raman spectroscopy," explained Tony Parker of the Science and Technology Facilities Council's Central Laser Facility. "Femtosecond stimulated Raman spectroscopy is an advanced ultrafast laser technique that provides details on how chemical bonds change during extremely fast chemical reactions. The laser provides information on the vibration of the molecules as they interact with the pulses of laser light." Calculations on these vibrations enabled the scientists to ascertain how the molecules were evolving. Firstly, they found that after the electron moves away from the positive centre, the rapid molecular rearrangement must be prompt and resemble the final products within around 300 femtoseconds. This promptness and speed enhances and helps maintain charge separation. Secondly, the researchers noted that any ongoing relaxation and molecular reorganisation processes following this initial charge separation, as visualised using the FSRS method, should be extremely small.

"Our findings open avenues for future research into understanding the differences between material systems that actually produce efficient solar cells and systems that should as efficient but in fact do not perform as well. A greater understanding of what works and what doesn't will obviously enable better solar panels to be designed in the future," said the University of Montreal's Carlos Silva.

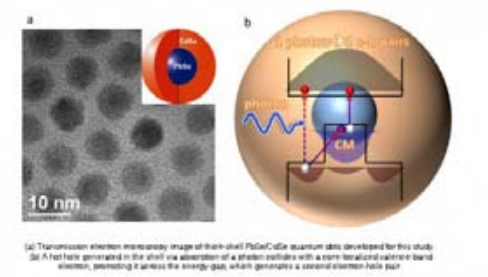
The article *‹Direct observation of ultrafast long-range charge separation at polymer-fullerene heterojunctions›* was published in Nature Communications on July 1, 2014.

Quantum dot solar cells show efficiency gains

Four fold carrier multiplication yield in nanoengineered quantum dots

Los Alamos researchers have demonstrated an almost four-fold boost of the carrier multiplication yield with nanoengineered quantum dots. Carrier multiplication is when a single photon can excite multiple electrons. Quantum dots are novel nanostructures that can become the basis of the next generation of solar cells, capable of squeezing additional electricity out of the extra energy of blue and ultraviolet photons.

Typical solar cells absorb a wide portion of the solar spectrum, but because of the rapid cooling of energetic (or 'hot') charge carriers, the extra energy of blue and ultraviolet solar photons is wasted through heat.



This energy can be recovered by converting it into additional photocurrent via carrier multiplication, in which collision of a hot carrier with a valence-band electron excites it across the energy gap. "In this way, absorption of a single photon from the high-

energy end of the solar spectrum produces not just one but two electron-hole pairs, which in terms of power output means getting two for the price of one, " explained Victor Klimov, director of the Center for Advanced Solar Photophysics (CASP) at Los Alamos National Laborator"

Carrier multiplication is inefficient in the bulk solids used in ordinary solar cells but is enhanced in quantum dots, as was first demonstrated by LANL researchers in 2004 (Schaller & Klimov, Phys. Rev. Lett. 92, 186601, 2004). In conventional quantum dots, however, carrier multiplication is not efficient enough to boost the power output of practical devices. A new CASP study demonstrates that appropriately engineered core/shell nanostructures made of lead selenide and cadmium selenide can increase the carrier multiplication yield four-fold over simple PbSe quantum dots.

Klimov explained, "This strong enhancement is derived primarily from the unusually slow phonon relaxation of hot holes that become trapped in high-energy states within the thick CdSe shell. The long lifetime of these energetic holes facilitates an alternative relaxation mechanism via collisions with core-localized valence band electron which leads to highly efficient carrier multiplication."

To realize the effect of slowed carrier cooling LANL researchers have fabricated PbSe quantum dots with an especially thick CdSe shell. Thick-shell PbSe/CdSe quantum dots have a fairly bright visible emission, from the shell, observed simultaneously with the infrared emission from the core. This shows that intraband cooling is slowed down dramatically, so that holes reside in the shell long enough to produce emission.

While the present CASP work is based on PbSe/CdSe quantum dots, the concept of "carrier-multiplication engineering" through control of intraband cooling is general, and should be realizable with other combinations of materials and/or nanostructure geometries.

Jeff Pietryga, lead CASP chemist says, "Further enhancement in carrier multiplication should be possible by combining this new approach with other demonstrated means for increasing multicarrier yields, such as by using shape-control (as in nanorods) and/or materials in which cooling is already naturally slower, like PbTe."

Applied together, these strategies might provide a practical route to nanostructures exhibiting carrier multiplication performance approaching the limits imposed by energy conservation.

A low-cost post-growth activation step for CdTe solar cells

Magenesium chloride could replace toxic cadmium chloride say researchers

Chemists at the University of Liverpool have shown that magnesium chloride, commonly used in bath salts, can replace a toxic, expensive chemical in the manufacture of cadmium telluride (CdTe) solar cells.

Cadmium telluride thin-film solar-cell technology has laboratory efficiencies approaching 20 percent, but a central part of its manufacturing process involves doping the polycrystalline thin-film CdTe with cadmium chloride, which costs around 30 cents per gram and is a toxic water-soluble source of cadmium ions.

Cadmium chloride is used to form the photovoltaic junction at the CdTe/CdS interface, and to passivate the grain boundaries, making it essential to achieving high device efficiencies. But as the rsearchers detailed in the Nature letter '*A low-cost non-toxic post-growth activation step for CdTe solar cells'* they have now demonstrated CdTe solar cells prepared using magnesium chloride, which is non-toxic and costs less than a cent per gram. Efficiencies of around 13 percent, they say, are identical to those of a cadmium chloride-processed control group.

Hole densities in the active layer are also similar and comparable impurity profiles for Cl and O, these elements being important *p*-type dopants for CdTe thin films. Contrary to expectation, cadmium chloride-processed and magnesium chloride-processed solar cells contain similar concentrations of magnesium; this is because of magnesium out-diffusion from the soda-lime glass substrates and is not disadvantageous to device performance. However, treatment with other low-cost chlorides such as NaCl, KCl and MnCl2 leads to the introduction of electrically active impurities that do

compromise device performance.

The team believes the results demonstrate that magnesium chloride can directly replace cadmium chloride in the existing process, both minimising the environmental risk and reducing the cost of CdTe solar-cell production.

Derived from, '*A low-cost non-toxic post-growth activation step for CdTe solar cells'* by JD Major et al, Nature (2014) doi:10.1038/nature13435

Proof of concept for high efficiency hot-carrier solar cell

Hot-carrier photocurrent from an InGaAs single quantum well solar cell

Researchers from Imperial College London and the US naval Research Laboratory in Washington DC have demonstrated hot-carrier photocurrent from an InGaAs single quantum well solar cell. Their work was detailed in a recent paper in *Applied Phys. Lett. 104, 231115 (2014)*.

A hot-carrier solar cell (HCSC) is a photovoltaic device with a carrier population that is hot relative to the semiconductor lattice. Such a design aims to reduce the energy lost through heat when a material absorbs photons with energies larger than its bandgap. To achieve this, the photo-generated carriers are collected through energy-selective contacts before they have time to lose their energy as heat. Within a narrow range of energy states, hot-carriers thermalize isoentropically, generating chemical potential with an efficiency approaching that of a Carnot engine. HCSCs thus have a substantially higher fundamental solar energy conversion efficiency limit.

But there are two major HCSC development challenges: hot-carrier absorbers and energy selective contacts. To reach efficiencies close to the maximum thermodynamic limit relies on slowing the rate of carrier cooling in the absorber long enough for them to be transmitted through the energy selective filter contacts.
A hot-carrier absorber requires restricted scattering between carriers and lattice phonons to prevent heat dissipation and generate a thermal gradient between these two populations and efficiently generate chemical potential. Slow carrier cooling in GaAs quantum wells (QWs) relative to bulk has been known about for many years, and in a recent study, a carrier-lattice thermal gradient >100K was characterized in a single InGaAs QW structure under illumination power density 1kW cm-2.

Several structures have been proposed for energy selective contacts including resonant tunneling structures and an all-optical contact. In this paper, the researchers demonstrate hot-carrier photocurrent extracted from an InGaAs QW via an energy selective barrier. A narrow energy selective contact is ideal for efficient generation of chemical potential but any structure with a narrower range of energy states than the absorber can generate some chemical potential isoentropically. The energy selective barrier used in this study is therefore a type of energy selective contact and can produce a partial hot carrier advantage.

The sample in this study used a GaAs pin structure grown by MOCVD on a GaAs substrate and a single strained InGaAs QW with thickness 107Å. The sample was initially cooled to 10K in a closed-cycle cryostat, and a bias of 1.2V applied. Under these conditions, photo-excited carriers in thermal equilibrium with the lattice are trapped in the QW. This allows hot-carrier photocurrent to be distinguished from equilibrium photocurrent.

Cryogenic temperatures are not necessary to hot carrier devices but were used in this study to create an energy selective barrier. Focused laser illumination, tuned below the GaAs band-edge (1.52eV at 10K), was used to resonantly excite a non-equilibrium hot-carrier population. The energy distribution of the resulting photoluminescence corresponds to that of the carriers, making it possible to determine the temperature of the population by fitting a Planck-like distribution to the high-energy tail of the emission.

In this study, the photoluminescence measurements show the InGaAs well region of the structure is a hot-carrier absorber. The GaAs barrier has a larger bandgap than the well and therefore a reduced range of energy states. Le Bris and Guillemoles have demonstrated that such a barrier provides the energy selectivity required of an HCSC contact and

therefore can generate some chemical potential isoentropically. Measurements in similar structures have demonstrated that this quantum well material can be used as a hot carrier absorber at room temperature.
While the proof of concept device has the two elements necessary for an HCSC, demonstration of a measurable hot-carrier efficiency enhancement would require significant improvement of both elements say the researchers. Further device development would include engineering hot carrier absorber material systems, with reduced carrier cooling lifetime, to generate a larger thermal gradient. In addition, the energy selective barrier would need to be designed to maximize the isoentropic generation of chemical potential, while maintaining good carrier transport.

This work is detailed in the paper *Experimental demonstration of hot-carrier photocurrent in an InGaAs quantum well solar* by LC Hirst et al, *Appl. Phys. Lett. 104, 231115 (2014)*

Ascent reaches financial agreement for Sugian project

Ascent is required to contribute to the JV manufacturing equipment, intellectual property assets, proprietary technology and know-how, and cash for its ownership share

CIGS Manufacturer Ascent Solar Technologies has announced the achievement of a milestone related to the Definitive Agreement signed in December of 2013 with the Government of the Municipal City of Suqian in Jiangsu Province, China ("Suqian").

As previously announced under the Definitive Agreement, Suqian will build a facility to manufacture Ascent's Copper-Indium-Gallium-Selenium (CIGS) photovoltaic modules on flexible thin films.

Ascent and Suqian will also form a joint venture entity (JV) in which Ascent's share will grow progressively up to 80% based on an ascribed value of Ascent's contributions to the JV.

Under the terms of the Definitive Agreement, in phase 1 and phase 2 of the project, Ascent is required to contribute to the JV manufacturing equipment, intellectual property assets, proprietary technology and know-how, and cash for its ownership share, and Suqian is required to contribute cash for its ownership share. Pursuant to the terms of the Definitive Agreement, Ascent's total contribution for phase 1 and phase 2 is required to be RMB 800 million (approximately $129M USD). Suqian's total contribution for phase 1 and phase 2 is required to be RMB 200 million (approximately $32M USD).

Pursuant to the terms of the Definitive Agreement, Ascent and Suqian are required to ascribe a dollar value to Ascent's noncash contributions. The major milestone noted above was the agreement by the Suqian government to credit RMB 480 million (approximately $77M USD) to Ascent's contribution of its proprietary technology, which represents 60% towards Ascent's total required contribution of $129M USD. In order to value Ascent's intellectual property assets, the parties jointly agreed to hire an independent appraisal company located in China. The appraisal company has now completed that review and has submitted the valuation report to each of the JV partners. This report valued Ascent's intellectual property assets at RMB 402 million (approximately $65M USD). The remaining 40% of Ascent's contribution will be in the form of some equipment from its Colorado plant and/or cash. The exact amounts of cash and equipment will be determined at a later date. These amounts of cash and equipment will depend, among other things, on an assessment of the contributed equipment by a Chinese appraisal firm mutually selected by Ascent and Suqian.

The actual contributions of cash and other assets into the JV by Ascent and Suqian will happen incrementally over time. In addition, under the Definitive Agreement, Suqian has agreed to provide rent-free use of the 331,000-square-foot manufacturing facility and office space that is currently being built for Ascent in the Suqian Economic and Industrial Development Science Park.

"We are pleased to have reached this agreement with Suqian regarding this important component of our JV," said Victor Lee, President & CEO of Ascent. "This agreement underscores the belief by the Suqian government that Ascent's CIGS on flexible thin-film technology has a bright future. We are delighted that Suqian has chosen Ascent

to anchor the Suqian Economic and Industrial Development Science Park. We plan to move quickly to next steps in the partnership, with the goal of achieving scaled manufacturing capacity enabling dramatic cost reduction of our CIGS modules."

Singulus wins €15 million contract for CIGS tool

This contractual agreement with the Chinese customer is an additional important expansion step for Singulus Technologies in the Solar segment

Singulus Technologies AG has signed an agreement with a Chinese customer for the supply of a production machine for wet-chemical coating processes.

This machine is a central component for the manufacturing of CIGS thin-film modules. The order volume exceeds €15 million. The order is still subject to the approval of the relevant boards.

For thin-film solar cells Singulus Technologies focuses on CIS/CIGS technology and offers machines for all of the relevant processing steps.

XsunX sales accelerate in Southern California

The company has added over 1 MW of commercial solar system proposals in June alone

XsunX, a solar energy solutions provider, has expanded its sales force and new financing options have resulted in accelerating the pace of sales and the number of solar system proposals in the company's sales pipeline.

"The level of interest we are seeing in commercial solar systems is quite extraordinary," states XsunX CEO, Tom Djokovich. "In June alone we added over 1-megawatt of commercial solar system proposals to our sales pipeline totalling over $3 million, and that's just the beginning of what we see as increasing business opportunities through the expansion of our commercial systems sales force."

Central to the company's sales efforts has been the addition of multiple financing programs designed to offer clients options tailored to their needs. Djokovich continues, "Initially, we offered a zero down loan program that worked for some customers, but we were seeing a substantial amount of potential business left on the table because we could not match clients' cash-flow needs with system finance options. To overcome this challenge, we now offer access to a range of programs in addition to our zero down loan program such as lease-to-own, PACE and Hero property tax assessment financing, and power purchase options for non-profits."

Helping to fuel the company's growing success in the commercial solar systems market are the increasing efforts of businesses to control and reduce their energy costs.

These efforts are fuelled by a number of factors, including:

The California Public Utility Commission's (CPUC) recent approval for rate increases of as much as 50 percent for large commercial users

Increasing cost for natural gas used to produce about 60% of power generated in California

The loss of 2.2 GW of power production from the shutdown of the San Onofre Nuclear Power Plant coupled with increasing competition and demand for power in the state

The anticipation of higher energy costs under California's new AB32 cap-and-trade laws known as the Global Warming Solutions Act

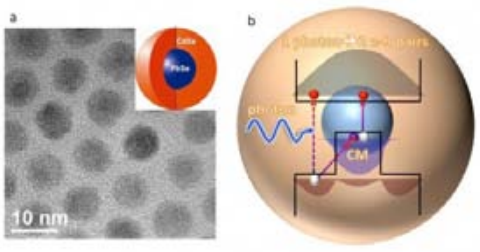
"With nearly all indicators pointing toward substantially higher electricity costs, it's only natural that businesses are beginning to see investments in solar energy as a wise decision with excellent returns," concludes Djokovich.

Quadrupling carrier multiplication yield in QDs

By nanoengineering PbSe/CdSe quantum dots, intraband cooling is slowed down so that holes reside in the shell long enough to produce emission

Los Alamos researchers say they have demonstrated an almost four-fold boost of the carrier multiplication yield with nanoengineered quantum dots.

Carrier multiplication is when a single photon can excite multiple electrons. Quantum dots are novel nanostructures that can become the basis of the next generation of solar cells, capable of squeezing additional electricity out of the extra energy of blue and ultraviolet photons.



Core/shell PbSe/CdSe quantum dots (a) and a carrier multiplication (CM) pathway (b) in these nano structures. (a) Transmission electron microscopy image of thick-shell PbSe/CdSe quantum dots developed for this study. (b) A hot hole generated in the shell via absorption of a photon collides with a core-localised valence-band electron, promoting it across the energy-gap, which generates a second electron-hole pair. In thick-shell PbSe/CdSe quantum dots this process is enhanced due to slow relaxation of shell-localised holes into the core

“Typical solar cells absorb a wide portion of the solar spectrum, but because of the rapid cooling of energetic (or ‘hot’) charge carriers, the extra energy of blue and ultraviolet solar photons is wasted in producing heat,” says Victor Klimov, director of the Centre for Advanced Solar Photophysics (CASP) at Los Alamos National Laboratory.

Getting two for the price of one

“In principle, this lost energy can be recovered by converting it into additional photocurrent via carrier multiplication. In that case, collision of a hot carrier with a valence-band electron excites it across the energy gap,” Klimov adds. “In this way, absorption of a single photon from the high-energy end of the solar spectrum produces not just one but two electron-hole pairs, which in terms of power output means getting two for the price of one.”

Carrier multiplication is inefficient in the bulk solids used in ordinary solar cells but is appreciably enhanced in ultra small semiconductor particles - also called quantum dots - as was first demonstrated by LANL researchers Schaller & Klimov in 2004.

In conventional quantum dots, however, carrier multiplication is not efficient enough to boost the power output of practical devices.

A new study conducted within the Centre for Advanced Solar Photophysics demonstrates that appropriately engineered core/shell nanostructures made of lead selenide (PbSe) and cadmium selenide (CdSe) can increase the carrier multiplication yield four-fold over simple PbSe quantum dots.

Klimov explains, “This strong enhancement is derived primarily from the unusually slow phonon relaxation of hot holes that become trapped in high-energy states within the thick CdSe shell. The long lifetime of these energetic holes facilitates an alternative relaxation mechanism via collisions with core-localised valence band electron which leads to highly efficient carrier multiplication.”

The nuts and bolts of slowing cooling

To realise the effect of slowed carrier cooling LANL researchers have fabricated PbSe quantum dots with an especially thick CdSe shell.

Qianglu Lin, a CASP student working on the synthesis of these materials says, “A striking feature of the thick-shell PbSe/CdSe quantum dots is fairly bright visible emission, from the shell, observed simultaneously with the infrared emission from the core. This shows that intraband cooling is slowed down dramatically, so that holes reside in the shell long enough to produce emission.”

“This slowed relaxation, which underlies the

observed enhancement of carrier multiplication, likely relates to the interplay between core- versus shell-localisation of valence-band states" explains Nikolay Makarov, a spectroscopist working on this project.

Istvan Robel, another CASP member adds, "Our modelling indicates that when the shell is thick enough, the higher-energy hole states lay primarily in the shell, while lower-energy states still remain confined to the core. This separation leads to electronic decoupling of higher- from lower-energy holes states, which is responsible for the observed slowed cooling."

What this could mean in the future

While the present CASP work is based on PbSe/CdSe quantum dots, the concept of "carrier-multiplication engineering" through control of intraband cooling is general, and should be realisable with other combinations of materials and/or nanostructure geometries.

Jeff Pietryga, lead CASP chemist says, "Further enhancement in carrier multiplication should be possible by combining this new approach with other demonstrated means for increasing multicarrier yields, such as by using shape-control (as in nanorods) and/or materials in which cooling is already naturally slower, like PbTe." Applied together, these strategies might provide a practical route to nanostructures exhibiting carrier multiplication performance approaching the limits imposed by energy conservation.

Funding for this research was provided by the Centre for Advanced Solar Photophysics (CASP), an Energy Frontier Research Centre funded by the Office of Science of the US Department of Energy.

This worked is further detailed in the paper, "Enhanced carrier multiplication in engineered quasi-type-II quantum dots" published in *Nature Communications* online.

Los Alamos National Laboratory, a multidisciplinary research institution engaged in strategic science on behalf of national security, is operated by Los Alamos National Security, LLC, a team composed of Bechtel National, the University of California, The Babcock & Wilcox Company, and URS for the Department of Energy's National Nuclear Security Administration.

Sharp develops ultra-efficient solar cells

A new technology could be twice as efficient at converting sunlight to electricity

Solar cells are still relatively inefficient at converting light to electricity. This is one of the main reasons solar can't compete with fossil fuels.

The best solar cells convert less than one-third of the energy in sunlight into electricity, although for decades researchers have calculated that sophisticated physics could allow them to convert far more.

Now researchers at Sharp have built a prototype that demonstrates one of these ideas.

If it can be commercialised, it would double the amount of power a solar cell can generate, offering a way to make solar power far more economical.

The researchers figured out a way around a bothersome phenomenon: when sunlight strikes a solar cell, it produces some very high-energy electrons, but within a few trillionths of a second, those electrons shed most of their energy as waste heat.

The Sharp team found a way to extract these electrons before they give up that energy, thereby increasing the voltage output of their prototype solar cell.

It's far from a practical device - it's too thin to absorb much sunlight, and for now it works only with a single wavelength of light. But the firm says it's the first time that anyone has been able to generate electrical current using these high-energy electrons. In theory, solar cells that exploit this technique could reach efficiencies over 60 percent.

The approach is one of several that could someday break open the solar industry and make fossil fuels expensive in comparison. High-efficiency solar cells would lower the cost of installation, which today is often more expensive than the cells themselves.

Exploiting exotic physics requires both understanding the behaviour of certain materials and figuring out how to make them with high precision. This is described in the articles, "Capturing More Light with a Single Solar Cell" and "Nanocharging Solar".

The Sharp device relies on the ability to make high-quality, nanometres-thick layers such as GaAs, which create a shortcut for high-energy electrons to move out of the solar cell.

Another way to achieve ultra-high efficiencies now is by stacking up different kinds of solar cells as described in the paper, "Exotic, Highly Efficient Solar Cells May Soon Get Cheaper", but doing so is very expensive. Meanwhile, MIT researchers are studying the transient behaviour of electrons in organic materials to find inexpensive ways to make ultra-efficient solar cells.

Each of the alternative approaches is at an early stage. James Dimmock, the senior researcher who developed the new device at Sharp, says he expects that his technique will initially be used to help boost the efficiency of conventional devices, not to create new ones.

Emcore rockets forward with extended contract

The company will supply its III-V multi-junction solar cells to SSL

Emcore has entered into a new long-term supply agreement with Space Systems/Loral, LLC (SSL) to manufacture and deliver high-efficiency, multi-junction solar cells for SSL's satellite programs.

This new contract follows several other earlier long-term supply agreements between SSL and Emcore.

The solar cells will be designed and produced at Emcore's manufacturing facility located in Albuquerque, New Mexico, USA.

Emcore has been supplying SSL with solar cells for its satellite programs for fifteen years. In early 2013 the firm reached a milestone of delivering its 1 millionth high-efficiency, multi-junction solar cell to SSL, which will ultimately represent more than a megawatt of power delivered into space.

Emcore's long-term business relationship with SSL has been an important component in the growth of the company's Photovoltaics division since 1998.

"After so many years of working together, Emcore is not just a trusted supplier, but also a part of the extended SSL team," says Vivian Mackintosh, Vice President, Supply Chain Management at SSL. "Emcore makes an important contribution to help SSL meet the demand for the world's highest power spacecraft."

"We are proud to continue our long-standing relationship with SSL through renewal of our long term supply agreement and appreciate SSL's continued confidence in Emcore," comments Brad Clevenger, Executive Vice President and General Manager of Emcore's Photovoltaics Division. "SSL has been a cornerstone of our satellite solar power business and we look forward to contributing to their success for many years to come."

"We value our long history as a key supplier of solar cells for SSL's space programs and are especially proud that our solar cells have continued to meet SSL's requirements for performance and reliability for fifteen years," adds Navid Fatemi, Vice President of Business Development of Emcore's Photovoltaics Division. "We now have a tremendous opportunity to build upon that successful legacy."

Emcore is a manufacturer of radiation-hard solar cells for space power applications. With a Beginning-Of-Life (BOL) conversion efficiency nearing 30 percent and the option for a patented, onboard monolithic bypass diode, Emcore's

multi-junction solar cells provide high levels of performance to interplanetary spacecraft and earth orbiting satellites.

Since 2001 Emcore solar cells or panels have supplied primary power to 130 space missions.

First Solar to build CdTe 150MW solar facility in California

The firms' Tenaska southern project will provide up to 800 construction jobs in the Imperial Valley Mainbody:

Tenaska Solar Ventures has selected First Solar to design and build the 150 megawatt (MW)AC Tenaska Imperial Solar Energy Centre West project near El Centro, California.

First Solar will provide full Engineering, Procurement and Construction (EPC) services on the project, employing its advanced thin film photovoltaic modules and single-axis tilt technology. The project sits on approximately 1,100 acres of previously disturbed land in Imperial County.

Tenaska Imperial West is the second solar project in Southern California's Imperial Valley developed, owned and managed by Tenaska.

In November of 2013, First Solar completed construction on the 130MWAC Tenaska Imperial Solar Energy Centre South power plant for Tenaska.

"We are pleased to continue our relationship with Tenaska," says Roger Bredder, First Solar's Managing Director for U.S. Business Development. "This project will provide up to 800 jobs in the Imperial Valley at construction peak, and make a significant economic contribution to the local community. It will also provide the residents of Southern California with a reliable source of clean, renewable energy."

Bredder explains that the local workforce that built Tenaska Imperial South over the past two years will provide a strong pool of experienced workers familiar with First Solar's technology and construction methods.

First Solar has already started engineering and expects to begin construction later in 2014, with full commercial operation anticipated in 2016. San Diego Gas & Electric Company holds a 25-year power purchase agreement (PPA) for all electricity generated by Tenaska Imperial West.

Stion to accelerate CIGS panel manufacturing capacity

The company also aims to continue to ramp up for increased 2015 demand precipitated by the news of the U.S. Department of Commerce's preliminary tariffs on Chinese solar modules shipped to the U.S.

US-based manufacturer Stion is to increase manufacturing capacity of its next generation Elevation Series CIGS solar modules for the second half of 2014.

This preliminary tariff will put a strain on the U.S. solar market as current major Chinese solar equipment supplier pricing increases from 18 to 35 percent, with the average Chinese supplier prices increasing by 27 percent.

Stion's Elevation Series CIGS thin-film modules are designed in San Jose, California and manufactured in Hattiesburg, Mississippi, with distribution in the U.S. and internationally.

The U.S. Commerce Department's announcement last week came after a lengthy countervailing duty investigation (CVD) for solar products imported into the U.S. from China to address an existing loophole that enabled an unfair pricing advantage to foreign manufacturers.

The decision will effectively raise prices on solar imports into the U.S. in the near term pending a final decision on August 18th, 2014.

This "anti-dumping" tariff will significantly increase prices for developers utilising Chinese-made products for solar installations in all major segments, Utility, Commercial and Residential. Many projects may subsequently be delayed or lose funding if Internal Rates of Return are adversely affected and the developers are unable to locate a cost-effective, non-Chinese-made technology alternative.

"We understand that this preliminary tariff will put a strain on the U.S. solar market as current major Chinese solar equipment supplier pricing increases from 18 to 35 percent, with the average Chinese supplier prices increasing by 27 percent," states Stion President and Chief Executive Officer Chet Farris. He adds, "Stion is committed to serving the U.S. market with the highest quality U.S. designed and U.S. manufactured solar technologies. We are ramping up our operations to meet the needs of our domestic customers in the near term and for the growing U.S. solar market over the years to come."

Adhesive bonding for mechanically stacked solar cells

GaAs and InGaAs solar cells in a stack have a combined efficiency of 25.2 percent

Researchers at the Tyndall National Institute, Ireland, have developed mechanically stacked solar cells (MSSC) using adhesive bonding of III-V cells.

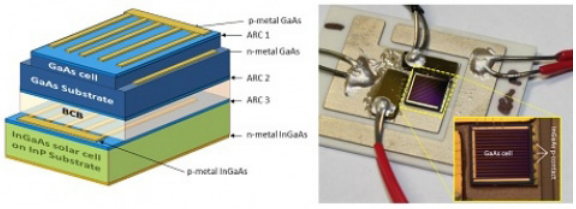
They aim to improve the annual energy yield of concentrator photovoltaic (CPV) systems.

BCB (Benzocyclobutene) was used to bond single-junction GaAs and InGaAs solar cells in a stack with a combined efficiency of 25.2 percent under 1-Sun conditions.

The lab efficiencies of current multi-junction solar cells are achieved by designing and testing cells according to tightly defined standard solar spectra to ensure current matching between the series-connected sub-cells.

These efficiencies are rare in commercial concentrator photovoltaic (CPV) systems as the incident solar spectrum varies with the time of day, geographical location and weather conditions where the sub-cells are no longer current matched and the photocurrent produced is reduced to the lowest of any cell in the device.

Mechanically stacked solar cells provide individual connections to sub-cells in a multi-junction device. The parallel-connections remove the current matching constraint of multi-junction solar cells and potentially facilitate increased efficiency and energy yield from CPV systems as maximum power is extracted from each sub-cell at all times, independent of the incident spectrum.



Left: Schematic outline of the prototype GaAs - InGaAs stacked solar cell with adhesive bonding layer

Right: Optical image of the fabricated and packaged GaAs - InGaAs stacked cell, the inset image shows the wire bonding to the cell bus bars

While mechanically stacked solar cells are not a new concept, the breakthrough presented by this work is the fabrication of cells using materials and process that lend themselves to wafer level processing.

BCB and Polyimide were both theoretically and experimentally investigated for solar cell bonding layers as both have been used for wafer level bonding in MEMS.

Single-junction GaAs and In0.53 Ga0.47 As solar cells with 1-Sun efficiencies of 20.6 percent and 9.3 percent were fabricated on GaAs and InP substrates respectively.

The GaAs cell was adapted for use in a stack by fabricating both *p* and *n* contacts on the front surface, to allow an insulating material to be used to bond the cells, as well as thinning the substrate to 140 μm to reduce free carrier absorption.

The InGaAs cells were fabricated with 3 μm absorber layers and featured a 100 nm thick InP window layer which helped to reduce lateral series resistance in the emitter/window region. Single cells were defined using chlorine based dry etching techniques with a SiN thin-film provided as a dual function passivation layer and anti-reflection coating.

Single-junction InGaAs cells had an open-circuit voltage of 357mV when measured under 1-sun conditions and a short-circuit current density of 38.2 mA/cm2. Benzocylobutene from the Cyclotene Advanced Electronics Resins range from Dow Corning was used as the interlayer adhesive.

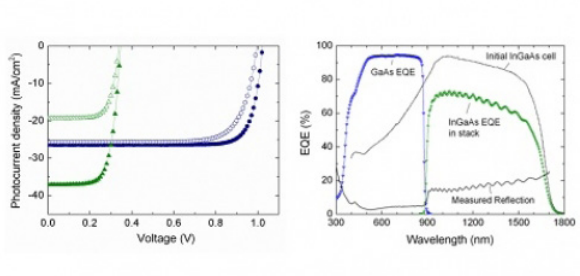
The GaAs top cell was bonded to InGaAs bottom cell using a Finetech Flip-Chip bonder. It should be noted that both cells did not have matching metallisation patterns, and some negative impact on bottom cell performance was expected because of excess shading by the top cell metallisation pattern.

The bonded cells were pre-cured at 150°C under a pressure of 4 N/cm2 before the chips were cured in an oven at 210°C for 2 hours.

The Voc and Jsc values of the InGaAs cell dropped to 339 V and 19.3 mA/cm2 respectively in stacked configuration. The cell contributed 4.6 percent to the efficiency of the stack leading to a total 1-sun of 25.2 percent for the dual-junction cell.

The work will be further progressed by developing a wafer scale process to investigate the commercial potential of this technique. Furthermore the concept can be extended to any solar cell type.

The next logical step for this work is the integration of III-V and Si solar cells where the silicon device will act as a low cost substrate/carrier for wide-bandgap thin-film III-V cells.



Left: Measured photocurrent density-voltage characteristics of a control GaAs cell (closed navy circles), top-contacted GaAs cell (open navy circles), stand alone InGaAs cell (green triangles) and stacked InGaAs cell (open green triangles) under 1-Sun conditions.

Right: Measured EQE of the GaAs (blue) and InGaAs (green) cells in stacked formation. Also shown is the measured reflection from the stack and the EQE of the InGaAs cell pre-bonding (black).

The details of the work described here can be found in an upcoming paper, “Adhesive bonding for mechanically stacked solar cells” by I. Mathews *et al*, accepted for *Progress in Photovoltaics: Research and Applications,* (2014).

QDs could change the face of solar cells

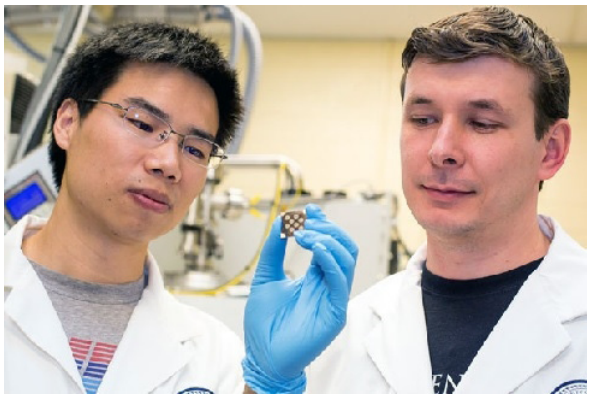
Lead sulphide quantum dots may be cheaper and brighter than current solar cells used outdoors

Are those flat, glassy solar panels on your neighbour’s roof the pinnacle of solar technology? Maybe not.

Researchers in the University of Toronto’s Edward S. Rogers Sr. Department of Electrical & Computer Engineering have designed and tested a new class of solar-sensitive nanoparticle that is said to outshine the current technology.

This new form of solid, stable light-sensitive nanoparticles, called colloidal quantum dots, could lead to cheaper and more flexible solar cells, as well as better gas sensors, infrared lasers, infrared LEDs and more.

The work, led by Zhijun Ning and Ted Sargent, was published this week in *Nature Materials.*



Co-authors Zhijun Ning (left) and Oleksandr Voznyy (right) examine a film coated with colloidal quantum dots (Credit: Roberta Baker)

Collecting sunlight using these tiny colloidal quantum dots depends on two types of semiconductors:*n*-type, which are rich in electrons; and *p*-type, which are poor in electrons. The problem? When exposed to air, *n*-type materials bind to oxygen atoms, give up their electrons, and turn into *p*-type.

Ning and his colleagues modelled and demonstrated a new colloidal quantum dot *n*-type material that does not bind to oxygen when exposed to air.

The main material used was PbS (lead sulphide), a IV-VI semiconductor.

Maintaining stable *n*- and *p*-type layers simultaneously not only boosts the efficiency of light absorption, but also opens up a world of new optoelectronic devices that capitalise on the best properties of both light and electricity.

This means more sophisticated weather satellites, remote controls, satellite communication or pollution detectors.

“This is a material innovation, that’s the first part, and with this new material we can build new device structures,” says Ning. “Iodide is almost a perfect ligand for these quantum solar cells with both high efficiency and air stability - no one has shown that before.”

Ning’s hybrid *n*- and *p*-type material achieved solar power conversion efficiency up to eight percent which they say is one of the best results reported to date.

But the researchers believe this improved performance is just a start for this new quantum-dot-based solar cell architecture. The QDs could be mixed into inks and painted or printed onto thin, flexible surfaces, such as roofing shingles, dramatically lowering the cost and accessibility of solar power for millions of people.

“The field of colloidal quantum dot photovoltaics requires continued improvement in absolute performance, or power conversion efficiency,” Sargent concludes. “The field has moved fast, and keeps moving fast, but we need to work toward bringing performance to commercially compelling levels.”

The study has been described in the paper, “Air-stable *n*-type colloidal quantum dot solids,” by Zhijun Ning *et al* in *Nature Materials* (2014). doi:10.1038/nmat4007

This research was conducted in collaboration with Dalhousie University, King Abdullah University of Science and Technology and Huazhong University of Science and Technology.

Avancis receives general building approval for CIS module

The firm says this is the first frameless copper-indium-selenide module with back-rails admitted for BIPV

Avancis has received from the German Institute for Building Technology (DIBt), the general building approval (abZ) for its frameless CIS thin-film module PowerMax SMART.

With this approval, the frameless modules can be installed on roofs, facades and building-integrated PV systems (BIPV).

“We are very delighted about this general building approval for our newest generation PowerMax SMART module, because this means a major milestone for Avancis,” explains Franz Karg, Managing Director and CTO of Avancis. “It shows that our quality standards have proven concerning performance, safety and building related applicability as well as the consistent further development of our frameless modules.“

With the approval by the German Institute for Building Technology (DIBt), a separate approval of the module for use on roofs and facades is no longer necessary. Obtaining individual licenses is also no longer necessary. “We give architects, designers and construction companies a building regulated thin-film module at hand which meets the highest standards of safety, efficiency, design and aesthetics,” adds Karg.

In January 2014, Avancis established a new efficiency record of 16.6 percent in CIS thin-film

modules confirmed by the research laboratory for renewable energy and energy efficiency of the U.S. Department of Energy (NREL).

First Solar to acquire skytron-energy

With an increased focus on integrated power solutions, CdTe cell manufacturer First Solar is expanding in Europe

First Solar has entered into an agreement to acquire skytron-energy.

This is a subsidiary of AEG Power Solutions, which provides utility-scale photovoltaic (PV) power plant management systems, Operations and Maintenance (O&M) services, data monitoring technology, and equipment to solar power plants throughout Europe.

Currently, skytron has installed monitoring and control systems in more than 600 plants across Europe with a total peak capacity of 5 gigawatts (GWp), more than doubling First Solar's global portfolio of monitored assets. The acquisition is subject to consent by the German merger control authorities (Bundeskartellamt).

Terms of the deal were not disclosed.

The acquisition supports First Solar's initiative to provide full, end-to-end energy solutions that vertically integrate solar services and solutions. It broadens First Solar's portfolio of energy assets operated and maintained by the company and establishes a strategic opportunity to offer additional value-added services to both existing and new customers in Europe.

"skytron has a high quality, operations-based foundation and a strong portfolio of valued customers," says Bob Callery, First Solar's Vice President of Operations and Maintenance. "They bring considerable strategic value to our global O&M offering, as well as a pathway to expand our services across the entire solar value chain. Our combined expertise enables power plants to operate with the reliability of conventional generation resources, further establishing solar as a given part of the global energy mix."

"This is a very positive move for skytron-energy," says Jeffrey Casper, Chief Restructuring Officer of AEG Power Solutions and member of the board of directors. "Joining First Solar assures that skytron will continue to provide customers leading-edge monitoring, supervision and plant control solution systems. skytron benefits from the reach of First Solar's powerful sales and service network, as well as its installed base. This deal opens a wealth of prospective growth and development for all parties."

Citing a GTM Research report, Callery said the O&M market size in Europe was 25 gigawatts (GW) in 2013, and is projected to grow to 35GW by 2017. skytron grew its monitored fleet by 37 percent in 2013, and First Solar grew its global monitored fleet by 176 percent in that same period. "There is clearly an opportunity for skytron and First Solar to provide innovative, reliable solutions and expertise to power plant owners," Callery adds.

According to Callery, skytron will operate as a subsidiary of First Solar, and will maintain its own brand identity, which has recognised value in its various markets. "skytron-energy employees will remain with the organization," he said, "and operations will continue without disruption."

Superior tunnel junctions for ultra-high concentration CPV

Substituting the GaAs-based cathode with a GaInP alloy in the tunnel-junction results in a 1.3 percent increase in solar cell efficiency in the triple junction cell and allows operation at 15,000 suns

Scientists from the Solar Energy Institute of the Technical University of Madrid have developed a high bandgap tunnel junction (TJ) for multi-junction cells that sets a new benchmark for current handling capability.

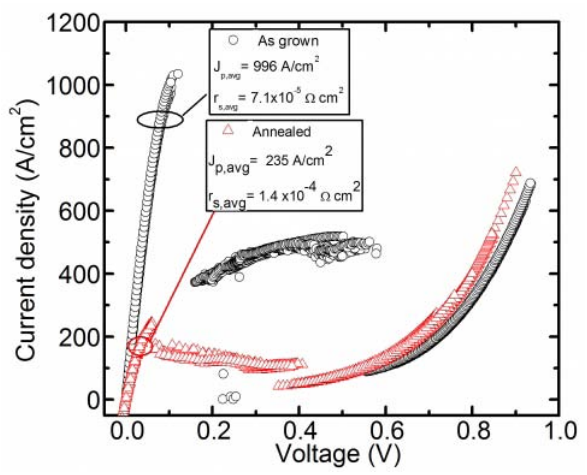
The team believes that these TJs, which also deliver increased transparency, will aid their quest to develop high efficiency solar cells operation at ultra-high concentrations.

Grown by MOCVD, the *p*++-AlGaAs/*n*++-GaInP tunnel junction (TJ) produced by the researchers displays an outstanding electrical performance.

The TJ is intended to interconnect the top (GaInP) and middle (GaInAs) subcells of concentrator triple junction solar cells. In as-grown tunnel diodes, an average peak tunnelling current density (Jp) of 996 A/cm2 and a specific resistance of 7 x 10-5 Ω cm2 were obtained, whilst record-performing devices exhibited Jp above 1050 A/cm2.

When introduced in multi-junction solar cell structures, tunnel diodes are known to suffer significant degradation. This results from the thermal load associated with the growth of the rest of the solar cell structure, which is deposited at much higher temperatures (for details, see I. Garcia *et al* in the*Journal of Physics D: Applied Physics*).

In order to simulate this effect, the researchers from Madrid annealed the samples. After the thermal load, these devices still exhibited high performance, although the average Jp reduced to 235 A/cm2 and specific resistance increased to 1 x 10-4 Ω cm2. Despite this drop, these values are still significantly high enough to allow the TJ to operate in the ohmic region up to about 15,000 suns with a negligible voltage drop (see figure below).



Left: Average J-V measurements of p++-AlGaAs:C/n++-GaInP : Te TJs fabricated with the as-grown structures (black circles) and after thermal annealing at 675oC for 30 min (red triangles)

Right: Magnification of left figure for low voltages where current densities equivalent to operation at 1000, 5000 and 10000 suns are drawn as references (dotted lines)

The design and manufacture of multi-junction solar cells - and accordingly tunnel junctions - for operation at ultra high concentration (i.e. several thousand suns) is one of the research goals of the III-V Semiconductor Group of the Solar Energy Institute in Madrid.

Progress by the III-V Semiconductor Group is seen by comparing work from 2008 to now. Back then, they reported in *Applied Physics Letters* a GaInP/GaAs dual-junction solar cell with a record efficiency of 32.6 percent at 1026 suns. The TJ employed in that case (a *p*++-AlGaAs:C/*n*++-GaAs:Te) showed peak current densities of 2000 A/cm2 and 300 A/cm2 for the as-grown and annealed devices, respectively.

The motivation for introducing the new TJ is to increase transparency. Success on this front also results in a gain in current around 0.56 A/cm2, implying an improvement of 1.3 percent (absolute) in the triple junction solar cell efficiency.

The details of the work described here can be found in the paper,"Highly conductive p++-AlGaAs/n++-GaInP tunnel junctions for ultra-high concentrator solar cells," by E. Barrigón et al in Progress in Photovoltaics: Research and Applications, 22, 4, pp.399 - 404. (April 2014). DOI: 10.1002/pip.2476

MKS branches out into vacuum with Granville-Phillips buyout

The acquisition strengthens MKS' position in the vacuum gauge market. The firm's primary served markets are manufacturers of capital equipment for semiconductor devices, and for other thin film applications including LEDs and solar cells

MKS Instruments has completed its acquisition of the assets of Granville-Phillips, formerly a division of Brooks Automation, Inc. for $87 million in cash

Granville-Phillips is a provider of vacuum measurement and control instruments to the semiconductor, thin film and general industrial markets, with sales of approximately $30 million.in 2013.

This acquisition further strengthens MKS' position in the vacuum gauge market. MKS is the market leader in direct pressure measurement and Granville-Phillips is a well-regarded leader in indirect vacuum gauges, with a premium brand and an excellent reputation for quality, reliability and performance.

The Granville-Phillips business will be operated as the Granville-Phillips division of MKS and will be integrated into MKS' Pressure Measurement business. The acquisition is not expected to have a material impact on second quarter revenue or non-GAAP earnings.

Management expects the acquisition to be accretive to non-GAAP earnings in fiscal 2014, and also expects future cash flow benefits due to the availability of tax amortisation on most of the purchase price.

Jerry Colella, CEO and President, says, "We are pleased to be able to offer our customers and existing Granville-Phillips customers an extended portfolio of quality products supported by our global sales and service infrastructure. We are also excited to welcome Granville-Phillips employees to MKS and look forward to their contribution to business synergies as we integrate Granville-Phillips into MKS."

TSMC Solar takes on CIGS & CdTe expert Noufi

The Taiwanese subsidiary has taken on US NREL veteran to push its CIGS development

TSMC Solar has engaged Rommel Noufi in a long-term consulting capacity, to augment its CIGS R&D program.

Noufi is a 33-year veteran of the US National Renewable Energy Laboratory (NREL) where he was Principal Scientist and lead the team driving CIGS and CdTe cell research. He has authored over 190 publications and has eight patents.

TSMC Solar has a track record of R&D achievement, having produced a TUV-SUD verified, 15.7 percent efficient module with production equipment on its production line in mid-2013. The company is currently expanding its capacity from 40MW to reach 120MW in Q4 of this year.

Commenting on the decision to engage Noufi, TSMC Solar President Ying-Chen Chao says, "Dr. Noufi played a key role in the development of CIGS as a leading photovoltaic material. The addition of his deep CIGS experience to our R&D effort puts us on solid footing to maintain our rapid improvement of module efficiency over the next several years."

Noufi sees great potential for CIGS efficiency improvements, "CIGS efficiencies in the lab have reached 20.9 percent, with a clear path to achieving 23 percent. With its strong R&D, manufacturing and equipment engineering skill set TSMC Solar is uniquely equipped to develop this potential and bring it into production."

Stabilising GaAs and GaP in solar fuel generators

Scientists have devised a method to protect materials such as gallium arsenide and gallium phosphide in a solar-fuel generator

Researchers around the world are trying to develop solar-driven generators that can split water, yielding hydrogen gas that could be used as clean fuel. Such a device requires efficient light-absorbing materials that attract and hold sunlight to drive the chemical reactions involved in water splitting.

Semiconductors like GaAs and silicon are excellent light absorbers - as is clear from their widespread use in solar panels. However, these materials rust when submerged in the type of water solutions found in such systems.

Now Caltech researchers at the Joint Centre for Artificial Photosynthesis (JCAP) have

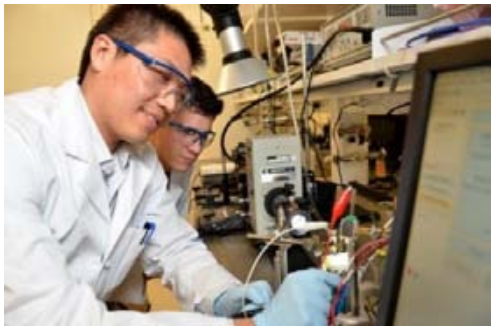
devised a method for protecting these common semiconductors from corrosion even as the materials continue to absorb light efficiently. The finding paves the way for the use of these materials in solar-fuel generators.

The research, led by Shu Hu, a postdoctoral scholar in chemistry at Caltech, appears in the May 30th issue of the journal *Science*.

“For the better part of a half century, these materials have been considered off the table for this kind of use,” says Nate Lewis, the George L. Argyros, professor of chemistry at Caltech, and the principal investigator on the paper. “But we didn’t give up on developing schemes by which we could protect them, and now these technologically important semiconductors are back on the table.”

In the type of integrated solar-fuel generator that JCAP is striving to produce, two half-reactions must take place - one involving the oxidation of water to produce oxygen gas; the other involving the reduction of water, yielding hydrogen gas.

Each half-reaction requires both a light-absorbing material to serve as the photoelectrode and a catalyst to drive the chemistry. What’s more, the two reactions must be physically separated by a barrier to avoid producing an explosive mixture of their products.

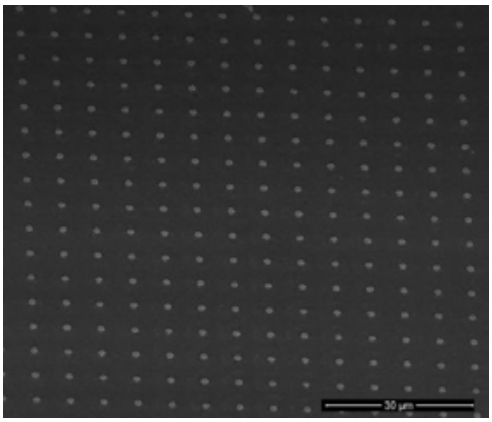


Postdoctoral scholar Shu Hu (foreground) demonstrates how to make photoelectrochemical measurements of a solar-fuels cell (Credit: Robert Paz)

Historically, it has been particularly difficult to come up with a light-absorbing material that will robustly carry out the oxidation half-reaction. Researchers have tried, without much success, a variety of materials and numerous techniques for coating the common light-absorbing semiconductors.

The problem has been that if the protective layer is too thin, the aqueous solution penetrates through and corrodes the semiconductor. If, on the other hand, the layer is too thick, it prevents corrosion but also blocks the semiconductor from absorbing light and keeps electrons from passing through to reach the catalyst that drives the reaction.

At Caltech, the researchers used a process called atomic layer deposition to form a layer of titanium dioxide (TiO2) - a material found in white paint and many toothpastes and sunscreens - on single crystals of GaAs, GaP or silicon.



Scanning electron microscope (SEM) image of nickel islands on silicon protected by a titanium dioxide film (Credit: Shu Hu/Caltech)

The key was that they used a form of TiO2 known as “leaky TiO2” - because it leaks electricity. First made in the 1990s as a material that might be useful for building computer chips, leaky oxides were rejected as undesirable because of their charge-leaking behaviour.

However, leaky TiO2 seems to be just what was needed for this solar-fuel generator application. Deposited as a film, ranging in thickness between 4 and 143nm, the TiO2 remained optically transparent on the semiconductor crystals - allowing them to absorb light - and protected them from corrosion but allowed electrons to pass through with minimal resistance.

On top of the TiO2, the researchers deposited 100nm-thick “islands” of an abundant, inexpensive nickel oxide material that successfully catalyzed the oxidation of water to form molecular oxygen.

The work appears to now make a slew of choices

available as possible light-absorbing materials for the oxidation side of the water-splitting equation. However, the researchers emphasise, it is not yet known whether the protective coating would work as well if applied using an inexpensive, less-controlled application technique, such as painting or spraying the TiO2 onto a semiconductor. Also, thus far, the Caltech team has only tested the coated semiconductors for a few hundred hours of continuous illumination.

"This is already a record in terms of both efficiency and stability for this field, but we don't yet know whether the system fails over the long term and are trying to ensure that we make something that will last for years over large areas, as opposed to weeks," says Lewis. "That's the next step."

The work is described in the paper, "Amorphous TiO2 Coatings Stabilize Si, GaAs, and GaP Photoanodes for Efficient Water Oxidation," by Hu *et al* in *Science*, 344 (6187), pp. 1005-1009. DOI: 10.1126/science.1251428

The research was supported by the Office of Science of the U.S. Department of Energy through an award to JCAP, a DOE Energy Innovation Hub. Some of the work was also supported by the Resnick Sustainability Institute and the Beckman Institute at Caltech.

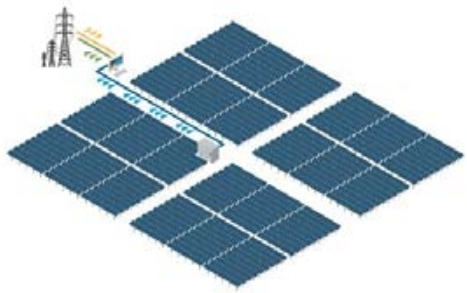
First Solar to introduce pre-engineered CdTe plant products

The new offerings focus on customers' need for enhanced, reliable energy output and will be introduced at Intersolar Europ

First Solar has launched its modular AC Power Block solar power plant solution and its next generation First Solar Series 4 thin film photovoltaic (PV) module.

Purpose-built for power plant owners and developers seeking to minimise project risk and maximise energy production and revenue, the AC Power Block is a configurable system solution that can be scaled to address a wide range of project conditions.

The pre-engineered system is available in modular units ranging from 800 kilowatts (kW) to 3.8 megawatts (MW). Based on First Solar's PV plant design and energy prediction model, the AC Power Block is backed by a first year energy performance guarantee and a 25-year capacity warranty.



AC Power Block solution

First Solar's new Series 4 PV module offers up to eight percent more energy than conventional crystalline silicon modules with the same power rating, and is compatible with advanced 1500-volt plant architectures. The Series 4A variant features a new anti-reflective coated glass, which enhances energy production. The module is backed by First Solar's 25-year Linear Performance Warranty.

"What matters most to our customers is reliable energy output achieved through proven technology," says Thomas Kuster, First Solar Senior Vice President of Product Management. "The AC Power Block and the Series 4 module are designed to deliver on those expectations. As solar energy secures its place in the global energy mix, these offerings demonstrate First Solar's ability to deliver solutions that address our customers' specific needs. We are confident that our commitment to innovation and continuous improvement position First Solar as a leading provider of comprehensive solar energy solutions."

"The underlying principle behind these new offerings and our existing power systems portfolio is an unwavering focus on a goal that we share with our customers in Europe and around the world: reliable generation of solar energy that is competitive within the framework of the region's energy generation portfolio," Christopher Burghardt, Vice President for Europe at First Solar, explains. "Showcasing our industry-leading range of solutions at the region's premier solar energy exhibition underscores the market's importance to our growth

strategy."

First Solar will also spotlight its Modules Plus System at Intersolar. This offering features fixed-tilt and single-axis tracker designs that are optimised for installation ease, project value, and operational reliability with First Solar's advanced thin film PV modules.

Power Electronics

Annealing accelerates electron mobility

In-situ annealing nearly doubles electron mobility in InGaAs MISFETs

A team of researchers from Japan has almost doubled electron mobility in InGaAs MISFETs by performing an annealing step prior to the deposition of a HfO2 gate dielectric.

These efforts by engineers from the National Institute of Advanced Industrial Science and Technology and Sumitomo Chemical will help to enhance the credentials of III-V channels as alternatives to silicon for maintaining the march of Moore's Law. Higher mobilities allow a reduction in operating voltage of the transistor while maintaining its current, thus enabling ICs to maintain performance while consuming less power.

Traditionally, researchers have paired InGaAs MISFETs with an Al2O3 dielectric to create transistors with high mobility and a low interface state density. But the dielectric constant of this oxide is just 9, which is half that of HfO2, the gate dielectric used within the silicon industry today.

A higher dielectric constant is preferred, because it should make it easier to shrink transistor dimensions while maintaining performance. However, replacing Al2O3 with HfO2 has been hampered by a reduction in inversion electron mobility.

The team from Japan has overcome this by loading the epiwafers in an atomic layer deposition tool, and prior to deposition of the dielectric, annealing them in an argon atmosphere for 30 minutes at 300 degC. After this, a film of HfO2 is deposited using a 50-cycle process, before gates are patterned using a standard reactive-ion etching process and metal contacts are added.

X-ray photoelectron spectroscopy measurements on this device, and also on a control that had not been annealed, revealed that the former structure produced a stronger signal at an energy associated with gallium oxides. This occurred because annealing is estimated to increase the thickness of the GaOx from 0.15 nm to 0.20nm.

A series of different electrical measurements by the team showed that the annealed device had a much smaller frequency dispersion around the threshold voltage, which was the result of a decrease in the density of border traps in the HfO2 dielectric.

Mobility in the annealed sample peaked at about 1250 cm2 V-1 s-1 for a surface carrier density of around 2.5 x 1012 cm-2. In comparison, the mobility for the control was just shy of 700 cm2 V-1 s-1 for a surface carrier density of around 3.5 x 1012 cm-2.

The team attributes superior mobility to effective GaOx passivation at the interface between InGaAs and HfO2

Reference: M. Oda et al. Appl. Phys. Express 7 061202 (2014)

High voltage GaN HEMTs on large diameter silicon substrates

Enkris demonstrates high voltage GaS HEMT structures on 200mm silicon with Aixtron MOCVD tool

Enkris Semiconductor has reported producing high voltage GaN HEMT materials on 200mm silicon with excellent uniformity and low buffer leakage combined with thickness uniformity of below 0.5 percent without edge exclusion. Under special conditions the uniformity value can be improved

even further, says the company.

GaN-on-Si power devices have attracted much attention because of their potential applications in power electronics but due to the defective nature of heteroepitaxial GaN layers grown on silicon, GaN-on-Si power devices have suffered from high buffer leakage. Using GaN on large size silicon substrates is viewed as a cost-effective way to achieve high-volume production of GaN power devices but a large wafer bow combined with a high buffer leakage has hindered the further development of the GaN-on-Si technology so far.

"Our process on 200mm silicon substrates shows that high breakdown voltage (less than 1600V) GaN power devices with low leakage currently can be achieved with relatively thin buffer layers of 4µm. They simplify the growth process, minimize the wafer bow and reduce the epi-cost significantly. Based on our processes which were applied on an Aixtron system, GaN-on-Si power devices may reach even higher voltages in the near future," commented Cheng Kai, co-founder of Enkris.

Frank Wischmeyer, Aixtron's vice president of power electronics says: "Enkris' remarkable success in achieving excellent layer quality and material properties show the capability of our technology for high-voltage GaN HEMT applications. Our MOCVD technology is enabling the integration of wide-bandgap semiconductors on large diameter silicon substrates."

Nanowin upgrades its GaN substrate production

High volume 2in GaN substrates with reduced dislocation densities

Benefiting from an upgraded HVPE system and improved growth technology, Suzhou Nanowin is announcing mass production of 2 inch GaN substrates with improved dislocation densities. Its production capacity has been increased by around five times this year. Dislocation density will be reduced from around 5x106cm-2 to less than 5x105cm-2.

Suzhou Nanowin has been providing 2 inch freestanding GaN substrates since 2010, mainly for manufacturing UHB-LED and blue laser diodes. Since 2012, Nanowin has been able to grow undoped GaN substrates with carrier concentration of the order of 3x1015cm-3 to to 5 x1016cm-3, and dislocation density as low as in 104cm-2, which is suitable for fabricating switch devices.

Now, Nanowin can provide most customer-defined GaN substrates, including polar (Ga-face or N-face) and non-polar (a-plane and m-plane) substrate, GaN and AlN templates on sapphire or SiC substrates.

European supply chain for advanced GaN technologies

Four year R&D project secures independent GaN production for military applications

A four-year research project guided by the European Defence Agency (EDA) has succeeded in establishing the entire supply chain for making GaN power components within Europe. The supply chain ranges from the availability of SiC substrates for the epitaxial growth of GaN, to the industrial manufacturing of hemts.

Project MANGA (Manufacturable GaN-SiC-substrates and GaN epitaxial wafers supply chain) was set up to ensure production of GaN devices for military applications without relying on international suppliers. Their high efficiency and robustness means GaN-based power electronic components are fast replacing established technologies in a broad spectrum of defence applications from advanced radar and communication antennas to electronic warfare. As such, the technology is regarded as critical.

MANGA involved research institutions, universities and defence companies from Germany, France, Italy, Sweden and the UK, working with the EDA. In the scope of the project, GaN-based transistor layers were grown epitaxially on newly developed, high quality SiC-substrates. Applying established foundry processing, these transistor layers were finally used to make state-of-the-art hemts.

In future projects, the EDA aims to further reduce the European defense industry's dependence on international trade regulations. In a follow-

on project, the project partners want to achieve the qualification of an industrial European wafer supplier for state-of-the-art hemt structures.

High efficiency wireless power transfer demo boards

Featuring high frequency enhanced mode GaN fets

Efficient Power Conversion Corporation (EPC) has introduced two demo boards for resonant wireless power transfer. The EPC9506 and EPC9507 amplifier boards are based on the company's high frequency gallium nitride transistors, which enable wireless power systems with greater than 75 percent efficiency.

The EPC9506 and EPC9507 are A4WP compliant, Zero Voltage Switching (ZVS), Voltage Mode Class-D wireless power transfer amplifier boards capable of delivering up to 35W into a DC load while operating at up to 6.78MHz. The boards feature the 40V EPC2014 (EPC9506) and the 100V EPC2007 (EPC9507) eGaN FETs.

Both boards are configured to operate in either a half-bridge topology (for single-ended configuration) or full-bridge topology (for differential configuration), and include the gate driver(s) and oscillator that ensure operation of the boards at a fixed frequency.

EPC makes enhancement-mode gallium-nitride-on-silicon (eGaN) FETs as power MOSFET replacements in applications such as DC-DC converters , wireless power transfer , envelope tracking, RF transmission, solar micro inverters, remote sensing technology (LiDAR), and class-D audio amplifiers.

SiC market growing at 42 percent CAGR

SiC semiconductor market worth $3182.89 million by 2020

According to a new report, the silicon carbide semiconductor market is expected to reach $3182.89 million by 2020, growing by around 42 percent CAGR.
Silicon carbide has a band-gap and thermal coefficient three times higher than silicon based semiconductors, making it attractive for solar power applications, harsh environments, and military and defence systems. Huge competition from the development of gallium nitride is one factor restraining its growth, according to the report published by Markets and Markets.

Covering technology, product, application and geography, the report also includes a brief description of major SiC players including CREE, Fairchild Semiconductor, Genesic Semiconductor, Infineon Technologies, Microsemi Corporation, Norstel, Renesas Electronics, ROHM, STMicroelectronics, and Toshiba and their recent developments.

'Silicon Carbide (Sic) In Semiconductor Market By Technology, Product, And Application (Automotive, Defense, Computers, Consumer Electronics, ICT, Industrial, Medical, Railways, And Solar), By Geography - Forecast And Analysis To 2013 - 2020'. Publlished by marketsandmarkets.com (June 2014).

Equipment and Materials

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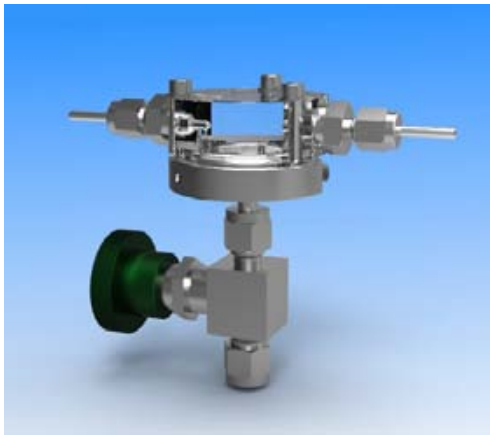
Hiden enhances inlet mass spectrometer series

New features support measurement of dissolved gases and vapours

The Hiden HPR-40 MIMS membrane inlet mass spectrometer series now features an extended range of submersible insertion probes and flow-through cuvette-style interfaces specifically engineered for measurement of dissolved gases and vapours in aqueous solution. All incorporate a semi-permeable membrane interface selected for operation in diverse environments with optimum transition rate for the gaseous species of interest.



The systems provide real-time analysis of biological and physical processes within aquatic and marine processes, with interfaces refined for specific applications including bio-fuel development, soil analysis, water quality determination, fermentation culture monitoring and photo-responsive processes.

The compact mass spectrometer module is bench-top and cart-mounting compatible, with comprehensive control and data analysis programs for both automated and manual operation. Multiple sampling lines can be accommodated for automated sequential multi-media sampling, the QIC BioStream variant currently operating with up to 80 sample streams. A custom-design service is available to assist with interface design for specific research and development projects.

Researchers to share insights into sub 10nm chip design

III-V layers as next generation channel materials

At the SEMICON West 2014 conference in San Francisco next week, the newly merged SUNY College of Nanoscale Science and Engineering/ SUNY Institute of Technology based in Albany, USA, will be detailing some of the research underway at its technology development centres including the use of III-V compounds in next generation chip technology.

In his presentation '*Driving Transistor Technology Sub-10nm: Process and Equipment Direction' o*n the 9th July 2014, Christopher Borst, associate professor of nanoengineering at Suny CNSE, will explain how in parallel with work developing Si nanowire devices on 300 mm wafers, CNSE researchers are evaluating III-V layers as channel materials for next generation devices. CNSE has established an ecosystem for collaborative III-V work with industrial and research partner institutions. It is committed to developing modules for III-V gate stack, contact and source-drain engineering that are compliant with environmental guidelines while driving to device performance targets.

Beyond III-V, CNSE is working closely with partners from academia, industry and federal research programs on 2D materials including the growth, device design, and integrated module development for these layers with a view to their introduction into mainstream processing. Initial successes have been made in graphene growth and transfer onto 300 mm wafer substrates for clean, repeatable processing through the CNSE development facility.

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In future projects, the EDA aims to further reduce the European defense industry's dependence on international trade regulations. In a follow-on project, the project partners want to achieve the qualification of an industrial European wafer supplier for state-of-the-art hemt structures.

Avantor to showcase new cleaning chemistries at SEMICON West

NMP-free organic film stripper for LEDs

Avantor Performance Materials will be showing a number of new products for photoresist and post-etch residue removal during SEMICON West 2014 in San Francisco next week. These include the new J.T.Baker ALEG-368 NMP-free organic film stripper and residue remover for LED applications

For lines, via, and bond pad cleaning, ALEG-368 is developed for technologies containing aluminum interconnects. The ALEG-368 formulation removes ash residue, sidewall polymers, and bulk photoresist, and is NMP-free in response to environmental and regulatory concerns.

The ALEG-368 material supports the integration of Environmental, Health, and Safety (EH&S) roadmaps, and allows for process optimisation and cost reduction programs.

New multi-gauge controller

Displays pressure measurements from ten vacuum gauges

The Kurt J. Lesker Company has introduced a new multi-gauge controller to its pressure measurement product line that can display pressure measurements from up to ten different vacuum gauges simultaneously.

The MGC4000 multi-gauge controller is able to provide pressure measurements from 1000 Torr to 2x10-11 Torr, can be configured to display up to six gauges in a single screen or any number of gauges can be assigned to various screens for auto scrolling of display.

Customers can configure the MGC4000 to their specifications on the company's website by specifying the number of gauges, set points, and AI/AO they need. This allows them to only purchase the level of functionality requirred.

The Kurt J. Lesker Company (KJLC), founded in 1954, is a global manufacturer and distributor of vacuum components and systems for the high- and ultra-high vacuum equipment market.

Morgan Advanced Materials make advances in materials

Improved CVD growth capability enables 300+ mm components

Morgan Advanced Materials has announced advances in its range of materials grown using chemical vapour deposition processes. Morgan's CVD silicon carbide and pyrolytic boron nitride materials are for use in rapid thermal processing and plasma etch process chamber components, as well as metalorganic CVD tools for high-brightness white LED manufacturing using the indium gallium nitride process.

Morgan's improved CVD SiC growth capability enables the manufacture of 300+ millimeter diameter components with thicknesses of more than 10mm at production volumes for plasma etch applications. With access to ultrasonic machining capability, Morgan offers high tolerance CNC machining and precision hard grinding, as well as the patented Rmax process for producing focus CVD SiC ring shapes.

Morgan's high purity (99.999 percent+) SiC material has high thermal conductivity, is resistant to chemical erosion, and features minimal particulate generation, making it suitable for chlorine and fluorine plasma etch processes. The material can also be used in producing gas distribution plates. Ultrasonic drilling can provide holes with diameters as small as 0.5mm, ideal for custom etch applications.

High purity (99.99 percent+) PBN materials have a working temperature in excess of 1500degC, and feature high electrical resistivity and high dielectric strength. Low out-gassing, non-wetting, and non-toxic, the PBN materials are inert to most acids,

alkalis and organic solvents and have high thermal conductivity in the “a” direction. The advanced materials are a good choice for manufacturers of PBN coated graphite heaters and PBN effusion cell components.

Semiconductor quantum dots with single-atom precision

Another step towards a new generation of atomic and molecular electronic integrated circuits

Scientists at NTT Basic Research Laboratories in Japan, the Paul-Drude-Institute in Germany, and the Naval Research Laboratory in America have developed quantum dot and combined artificial molecules with single-atom precision in terms of position and configuration. They achieved this on a clean surface of semiconductor single crystal thin film manufactured by MBE using a low-temperature Scanning Tunneling Microscope (STM) to integrate atoms one-by-one.

According to the researchers, this technology has made it possible to implement quantum dots with identical properties, like natural atoms, and do this flexibly at the semiconductor substrate for the first time at this level of precision. As a result, they say, it should be possible to manufacture quantum devices with atomic-level reproducibility e.g. a single photon source with a uniform wavelength, or an array of quantum bits with uniform functions, which has not been possible before. These results will be published in the Nature Nanotechnology on 29th, June 2014.

If the fabrication and characterization of quantum structures with atomic precision is possible at the semiconductor substrate surface, this will be a major leap toward being able to make a new types of integrated circuits that combine wafer-level semiconductor technology and atomic and molecular electronics.

For the base of the atom manipulation, the team used an (111)A-oriented surface of indium arsenide crystal. The (111)A surface has periodic hollow sites caused by a specific atomic structure of compound semiconductors. The structure formation can be exactly controlled by placing each atom at each hollow site. The high quality InAs thin film has been grown at NTT-BRL on the (111)A-oriented substrate with atomically controlled thickness. After the grown InAs surface was covered by a protection film (amorphous As), the sample was transferred from NTT to PDI.

Atom-by-atom quantum structure fabrication
When the sample was loaded into STM instruments at PDI, the protection film was removed in an ultra-high-vacuum to recover the clean (111)A surface, on which it is feasible to perform atom manipulation. The indium atom is self-ionized at the InAs surface to be +1 charged ion with releasing an electron. By using the low-temperature STM, we can not only observe surface atomic arrangement but also form nanostructures by atom manipulation of these ions as building blocks. Artificial atoms (6 ≤ the number of atoms ≤ 25) have been manufactured by arranging each In atom one-by-one in a line at the (111)A surface. The row of such ions behaves as a ‹core› of an artificial atom and electronic states at the semiconductor surface are confined to the induced local potential well.

Future Plans
The team expect that the present achievements will open the door to developing new electronic technology by combining atomic and molecular electronics with semiconductor thin film technology. By exploring novel properties of many integrated atoms and the interaction with semiconductor heterostructures, they plan to develop architectures for quantum computers and high-performance semiconductor devices composed of well-defined semiconductor nanostructures with robust fidelity. Further study will bring many benefits to a broad range of science and technology fields.

Publication information: *Quantum dots with single-atom precision* by S. Fölsch etc al, Nature Nanotechnology (2014).DOI: 10.1038/NNANO.2014.129

A low-cost post-growth activation step for CdTe solar cells

Magenesium chloride could replace toxic cadmium chloride say researchers
Chemists at the University of Liverpool have shown that magnesium chloride, commonly used in bath salts, can replace a toxic, expensive chemical in the manufacture of cadmium telluride (CdTe) solar cells.

Cadmium telluride thin-film solar-cell technology has laboratory efficiencies approaching 20 percent, but a central part of its manufacturing process involves doping the polycrystalline thin-film CdTe with cadmium chloride, which costs around 30 cents per gram and is a toxic water-soluble source of cadmium ions.

Cadmium chloride is used to form the photovoltaic junction at the CdTe/CdS interface, and to passivate the grain boundaries, making it essential to achieving high device efficiencies. But as the rsearchers detailed in the Nature letter '*A low-cost non-toxic post-growth activation step for CdTe solar cells'* they have now demonstrated CdTe solar cells prepared using magnesium chloride, which is non-toxic and costs less than a cent per gram. Efficiencies of around 13 percent, they say, are identical to those of a cadmium chloride-processed control group.

Hole densities in the active layer are also similar and comparable impurity profiles for Cl and O, these elements being important *p*-type dopants for CdTe thin films. Contrary to expectation, cadmium chloride-processed and magnesium chloride-processed solar cells contain similar concentrations of magnesium; this is because of magnesium out-diffusion from the soda-lime glass substrates and is not disadvantageous to device performance. However, treatment with other low-cost chlorides such as NaCl, KCl and MnCl2 leads to the introduction of electrically active impurities that do compromise device performance.

The team believes the results demonstrate that magnesium chloride can directly replace cadmium chloride in the existing process, both minimising the environmental risk and reducing the cost of CdTe solar-cell production.

Derived from, '*A low-cost non-toxic post-growth activation step for CdTe solar cells'* by JD Major et al, Nature (2014) doi:10.1038/nature13435

SiC market growing at 42 percent CAGR

SiC semiconductor market worth $3182.89 million by 2020

According to a new report, the silicon carbide semiconductor market is expected to reach $3182.89 million by 2020, growing by around 42 percent CAGR.

Silicon carbide has a band-gap and thermal coefficient three times higher than silicon based semiconductors, making it attractive for solar power applications, harsh environments, and military and defence systems. Huge competition from the development of gallium nitride is one factor restraining its growth, according to the report published by Markets and Markets.

Covering technology, product, application and geography, the report also includes a brief description of major SiC players including CREE, Fairchild Semiconductor, Genesic Semiconductor, Infineon Technologies, Microsemi Corporation, Norstel, Renesas Electronics, ROHM, STMicroelectronics, and Toshiba and their recent developments.

'Silicon Carbide (Sic) In Semiconductor Market By Technology, Product, And Application (Automotive, Defense, Computers, Consumer Electronics, ICT, Industrial, Medical, Railways, And Solar), By Geography - Forecast And Analysis To 2013 - 2020'. Publlished by marketsandmarkets.com (June 2014).

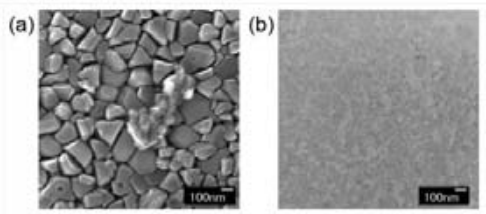
Researchers make full-colour InGaN LEDs using LCD-type process

Low cost pulsed sputtering technique shows promise for large area InGaN LED displays

InGaN-based LEDs are now widely accepted as highly efficient light sources that can replace incandescent bulbs. But so far they been limited to small devices. Now a team from the University of Tokyo has shown that InGaN LEDs could form large area displays on amorphous substrates using a manufacturing technique frequently used for making liquid-crystal displays (LCD).

To date, most InGaN-based LEDs have been fabricated using expensive MOCVD processes on single-crystal substrates such as sapphire and SiC. In contrast, the Tokyo team used a pulsed sputtering deposition process to grow GaN and InGaN films on amorphous SiO2. They made working red, green, and blue InGaN LEDs.

Figure 1: SEM images of a GaN film grown on an amorphous SiO_2 substrate (a) without and (b) with a multilayer graphene buffer layer.



Many attempts have been made to replace single-crystal substrates for the growth of group-III nitrides with low-cost, large-area materials such as glass and metal. Glass is the ideal substrate for large-area, low-cost LEDs because of its transparency and compatibility with existing LCD fabrication processes. But GaN films grown on glass have been impractical due to a low softening temperature (500-700degC) for glass substrates, and the amorphous nature of glass, which leads to poor crystalline quality of the overlaid nitride semiconductor layer.

By introducing multilayer graphene as a highly oriented crystalline buffer layer between the substrate and nitride film, the team overcame the first problem (large-area graphene films like these can be easily deposited by conventional chemical vapour deposition). As for the low softening temperature, recent progress in the epitaxial growth techniques based on pulsed sputtering deposition enables the growth of high-quality group III nitride crystals even at room temperature. The successful reduction in the growth temperature was achieved because of the high kinetic energy and pulsed supply of group III atoms, which assist the surface migration of film precursors at substrate surfaces, Recently, successful fabrication of 640 nm InGaN LEDs by PSD at a maximum process temperature of 480degC has been reported (Nakamura et al Appl. Phys. Lett. 104, 051121 (2014)).

By demonstrating that full-color LEDs can be fabricated on amorphous substrates, the researchers think that since sputtering is frequently used in the LCD industry, it could be adapted to fabricate large-area inorganic LED displays on glass substrates including flexible glass foils.

This work is detailed in the paper *Fabrication of full-colour InGaN-based Light-emitting diodes on amorphous substrates by pulsed sputtering* by *Jeong woo Shon et al in Nature Scientific Reports 4, Article number 5325*

IQE wins new multi million pound volume manufacturing agreement

The order with an existing client is worth in excess of £1m a year for epitaxial wafers

IQE plc has entered into a new multi-year volume manufacturing agreement expected to be worth in excess of £1m a year for epitaxial wafers for use in optical communications applications.

The new supply agreement is with an existing key strategic customer that already has a significant presence in the Asia Pacific region and includes the rapidly growing market for photonics in China. The new contract increases IQE's share with a guaranteed minimum of 80% of the customer's business, which is expected to be worth more than £1m in additional annual revenues to IQE's photonics business unit.

Customers are increasingly seeking to ensure security of supply through entering into long-term supply agreements to support products and devices for LTE backbone communications for base stations, Gigabit Passive Optical Networks (GPON) and Fibre to the Home (FTTH) at 2.5G and 10G, migrating to 100G over the coming years.

The agreement also includes scope for adding

new products which are currently undergoing qualification, such as Avalanche Photo Detectors (APDs) for high-speed, long-reach detectors.

The new contract takes the form of a "Vendor Managed Inventory" (VMI) agreement which enables IQE to optimise production efficiency and manage any short-term fluctuations in demand.

Dr Drew Nelson, IQE CEO, said:

"IQE provides the key enabling technology that is helping to meet the ever increasing demands on optical communications driven by trends such as 'Big Data' and 'The Internet of Things.'

"As the importance of photonic applications continues to grow, customers increasingly need to ensure security of supply to meet the needs of their technology roadmaps and are seeking to enter into volume manufacturing agreements.

"IQE is the global leader in wafer outsourcing and is seen by its customers as their key strategic partner to support this rapidly growing industry sector."

Finisar buys Aixtron MOCVD system

Finisar expands capacity for new tunable lasers and PICs

Finisar Corporation, the designer and manufacturer of optical communications components and subsystems, is expanding its capacity for making tunable lasers, high speed modulators, and photonic integrated circuits (PICs) with an AIX 2800G4-TM MOCVD system from German firm Aixtron SE.

To be used in Finisar's Swedish facility in Järfälla, near Stockholm, the new MOCVD depostition system will also support the company's focus on developing new, more highly integrated indium phosphide products, according to Patrik Evaldsson, Vice President and General Manager of Finisar Sweden.

Finisar Corporation already uses Aixtron's Planetary Reactor technology production for lasers and photodetectors.

Entegris Opens new $55 million innovation facility

The flagship innovation centre is designed for solving difficult materials science

Entegris Inc has inaugurated its new i2M Centre for Advanced Materials Science («The i2M Centre») in Bedford, Massachusetts. The facility is the company's flagship innovation centre for developing filtration and specialty coatings technologies, which are used to maximize production yields in a microelectronics manufacturing environments.

Representing an investment of more than $55 million, the i2M Centre aims to be one of the world's leading R&D and manufacturing centres for filtration media, metal membranes, electrostatic clamps (E-Chucks) and proprietary advanced, low-temperature coatings.

Bertrand Loy, President and CEO of Entegris, said: "i2M stands for 'ideas to market' and we intend for this facility to be our flagship innovation centre for solving very difficult materials science challenges. Our customers run extremely complex manufacturing processes and the i2M Centre reflects our commitment to developing truly innovative solutions to support their process advancements. As a global company serving global customers, we evaluated a number of locations for this new building. We chose Massachusetts because it is at the epicentre of some of the best engineering talent in the world."

Approximately 100 professionals will work at i2M Centre, many of whom hold doctorates and advanced degrees in material/separation science and chemical engineering. Entegris has approximately 350 employees in Massachusetts and approximately 3,500 employees worldwide. The Company reported on April 30, 2014 that it completed the acquisition of Danbury-based ATMI for $1.1 billion.

MicroSense ships LED measurement tool

The systems will be used for sapphire wafer process control

MicroSense, LLC has announced multiple shipments of its new, next-generation automated sapphire wafer metrology tool, the MicroSense UltraMap C200 (pictured below).

Designed specifically for high throughput dimensional measurement of sapphire wafers for LED manufacturing, the UltraMap C200 provides throughput of ninety 6” diameter sapphire wafers per hour with lowest cost of ownership (CoO).

The UltraMap C200 utilises MicroSense’s novel two sided capacitive sensing technology to measure sapphire wafer geometry including thickness, TTV (total thickness variation), bow, warp, and LTV (local site thickness variation).

“LED manufacturers typically don’t make their own sapphire wafers, so incoming quality control has become a requirement for LED chip makers as the industry continues to migrate from primarily 2” wafers to 4”, 6” and 8” wafers,” according to David Kallus, Director of Dimensional Wafer Metrology at MicroSense. “LED manufacturers have found high sapphire wafer bow strongly correlates to LED yield loss. The UltraMap C200 utilizes our proprietary capacitive sensing technology and advanced high density wafer mapping algorithms to provide world leading measurement repeatability and throughput.”

“Sapphire has become a break out substrate material, and sapphire factories are scaling to capacities unheard of before, driven by the LED and smartphone component markets,” continues Kallus. “In order to improve sapphire wafer yields and drive down wafer cost, wafer manufacturers need to measure at more steps in the wafering process. Unlike metrology tools based on optical methods, the MicroSense UltraMap C200 measures sapphire wafers and substrates with any surface finish - as cut, lapped, ground, polished, textured and patterned sapphire substrates (PSS) - without sacrificing wafer throughput or measurement repeatability. Wafer surface condition has no effect on measurement performance.”

The UltraMap C200 is available in three versions including tools with robotic loading, robotic loading with cassette sorting and a bench top tool. The UltraMap C200 handles wafers ranging from 2” to 8” in diameter.

Plessey orders Ferrotec metallisation tool

The UEFC-4900 will bring the Auratus deposition process enhancement methodology benefits to Plessey’s MaGIC LED production line

Ferrotec Corporation has confirmed that the first Temescal UEFC-4900 will be delivered to Plessey Semiconductors.

Plessey’s proprietary MaGIC process produces a unique, thin layer of GaN-on-Silicon and the UEFC-4900 offers the benefits of the Auratus deposition process to attain near-perfect uniformity and reduction in material consumption.

UEFC-4900 system

"At only 2.5 µm for both buffer and epitaxial layer, our MaGIC process uses a much thinner GaN layer compared to the 8 µm thickness typical on most other LED processes," says Mike Snaith, operations director at Plessey. "When you're working with this level of precision, the uniformity and efficiency that you can achieve with a Temescal system is essential. The UEFC-4900 will be an excellent upgrade from our FC-2800 platform with its Auratus enhancements such as increased capacity, faster throughput and reduced cost of operations."

"Plessey is making tremendous inroads into reducing the cost of high brightness LEDs with its unique GaN-on-Silicon process. By producing high performance GaN LED structures on standard silicon substrates, Plessey is able to deliver industry-standard performance at a dramatically reduced cost of manufacture," Gregg Wallace, managing director of Ferrotec's Temescal division, comments.

"With the UEFC-4900, our most advanced Auratus process enhancements and our excellent local support, this tool will help Plessey achieve larger batch sizes and improved efficiencies, all while maintaining the critically precise process parameters," Wallace adds.

Aerotech unveils small linear encoder precision stage

The system can be used for compound semiconductor characterisation

Aerotech's compact MPS75SLE linear positioning stage which travels to 100 mm, features smooth travel which combines accuracy, repeatability and positioning resolution capability to 25 nm.

Ideal applications include optics positioning, z-axis positioning of sensors in surface metrology, and in general purpose high-precision alignment.

One of its potentials is in semiconductor characterisation.

Quick and straightforward multi-axis configurations are made easily with other MPS linear and rotary stages using the adapter brackets and mounting compatibility inherent in the entire MPS stage family.

Precision Design for Precision Results

The precision ground, preloaded ball-screw coupled with a low thermal expansion linear encoder provides an accuracy of ± 0.75 µm and a repeatability of ± 0.1 µm. Anti-creep, crossed-roller bearings provide smooth travel and high-load capacity in a compact package.

The low thermal expansion (3.3 ppm/˚C) precision glass scale encoder results in high-accuracy and repeatable positioning over long periods of time. The linear encoder is available with amplified sine (1 Vpp) or 50 nm TTL digital outputs for easy integration with all standard controllers.

Highly Configurable for Flexibility

MPS75SLE motor options include a DC servomotor with a high-resolution rotary encoder or a stepper motor. Just like the MPS75SL, the SLE is available with and without optional bellows way covers. An optional mounting plate provides direct mounting to both English and metric optical breadboards, while the inherent mounting compatibility between all MPS stages results in simple development of multi-axis arrangements.

Ferrotec flaunts electron beam metallisation tool

Suited for compound semiconductor applications, the firm's deposition process provides methodology benefits to 100 and 150mm wafer production lines

Ferrotec Corporation has unveiled the Temescal UEFC-4900, a mid-sized ultra-high efficiency electron beam metallisation system for lift-off compound semiconductor applications.

A smaller system that's optimised for 100 and 150mm production wafer processes, the UEFC-4900 offers all of the benefits of the Auratus Deposition Process Enhancement Methodology, producing near-perfect uniformity while delivering up to 40% reduction in material consumption, resulting in significant cost savings on process materials like gold and platinum compared to traditional box coaters.

The Temescal UEFC-4900 is designed for active compound semiconductor production environments that use electron beam evaporation and lift-off coating processes. The UEFC-4900 features a conical shaped vacuum chamber that doubles the wafer capacity of the system compared to the similarly sized Temescal FC-2800. The system also features a patent-pending High-Uniformity Lift-off Assembly (HULA) design that uses a dual-axis motion to optimise collection efficiency.

"With the UEFC-4900, we're bringing our most advanced Auratus process enhancements to customers operating 100 and 150mm production lines traditionally served by our FC-2800 system. From its unique chamber design to the HULA for wafer handling, the UEFC-4900 pumps down faster, coats more wafers, and runs more batches per day than the comparably sized FC-2800," says Gregg Wallace, managing director of Ferrotec's Temescal division. "But the real power of this system is its precision, producing near-perfect uniformity while reducing process material consumption by up to 40%. For IDMs and foundries, this equates to better quality devices that cost less. "

The Temescal UEFC-4900 features significantly increased wafer production capacity. The system can process up to twenty-five 150mm wafers in a batch, more than double the capacity of the Temescal FC-2800 system with a similar footprint and power consumption.

With its unique conical shaped chamber and multiple cryopumps, the UEFC-4900 pumps down to process pressure significantly faster than conventional box coaters. With 39,000 L/sec pumping capacity, the system can reach 5E-07 Torr faster than the FC-2800, reducing production time lost waiting for the system to get to process pressure and increasing the number of batches that can be run per day.

The system incorporates Temescal's Auratus deposition process enhancement methodology. Auratus is a proprietary optimization methodology for lift-off electron beam evaporative coating that incorporates patent pending technology to achieve unprecedented levels of uniformity, precision, and collection efficiency.

Auratus enables Temescal system users to coat wafers with near perfect uniformity, resulting in more consistent, better quality products and fewer defects. Temescal's Auratus methodology also has the capability to increase the effective deposition rate, enabling customers to increase throughput.

Sumitomo expands GaN-on-SiC capacity

The company will use the Aixtron reactor to grow gallium nitride on silicon carbide RF power devices

Sumitomo Electric Device Innovations, Inc. (SEDI), Japan, has ordered an Aixtron CRIUS MOCVD system to be delivered with 4-inch wafer configuration.

The reactor will be used to boost production of GaN on SiC devices for RF data transfer applications.

The purchase was made in the first quarter of 2014 for delivery at SEDI's Electron Devices Division in Yokohama in the third quarter.

SEDI is preparing for a ramp-up in demand expected to begin in 2015 and chose the Aixtron system due to its reputation for 4-inch wafer uniformity and precise process control, which is especially important for device production on cost-intensive SiC wafers.

The new reactor will be equipped with optional features such as dynamic gap adjustment, ARGUS *in-situ* temperature control, and EpiCurve TT metrology system. The ARGUS monitoring device provides full wafer mapping in real time for optimum control of the growth process. Extended flexibility is enabled by allowing the adjustment of the process gap between the showerhead and the substrate.

MKS branches out into vacuum with Granville-Phillips buyout

The acquisition strengthens MKS' position in the vacuum gauge market. The firm's primary served markets are manufacturers of capital equipment for semiconductor devices, and for other thin film applications including LEDs and solar cells

MKS Instruments has completed its acquisition of the assets of Granville-Phillips, formerly a division of Brooks Automation, Inc. for $87 million in cash

Granville-Phillips is a provider of vacuum measurement and control instruments to the semiconductor, thin film and general industrial markets, with sales of approximately $30 million.in 2013.

This acquisition further strengthens MKS' position in the vacuum gauge market. MKS is the market leader in direct pressure measurement and Granville-Phillips is a well-regarded leader in indirect vacuum gauges, with a premium brand and an excellent reputation for quality, reliability and performance.

The Granville-Phillips business will be operated as the Granville-Phillips division of MKS and will be integrated into MKS' Pressure Measurement business. The acquisition is not expected to have a material impact on second quarter revenue or non-GAAP earnings.

Management expects the acquisition to be accretive to non-GAAP earnings in fiscal 2014, and also expects future cash flow benefits due to the availability of tax amortisation on most of the purchase price.

Jerry Colella, CEO and President, says, "We are pleased to be able to offer our customers and existing Granville-Phillips customers an extended portfolio of quality products supported by our global sales and service infrastructure. We are also excited to welcome Granville-Phillips employees to MKS and look forward to their contribution to business synergies as we integrate Granville-Phillips into MKS."

Palomar Technologies joins NCDMM alliance

The provider of optoelectronic packaging systems, along with NCDMM and its alliance members, is aiming to reduce manufacturing and machining costs

Palomar Technologies has been approved as an Alliance Partner by the National Centre for Defence Manufacturing and Machining (NCDMM).

The firms was approved as a member at the NCDMM Board of Directors' meeting which was held on May 6th, 2014.

Palomar was welcomed by NCDMM to a select group of organisations interested in working with the Centre to implement advanced manufacturing technology within the U.S. Department of Defence (DoD) and its supply base.

The NCDMM's mission is to promote the use of cost-effective manufacturing solutions by current, as well as future, U.S.- based producers of Department of Defence (DoD) systems by assisting with the ongoing identification and implementation of, and transition to, state-of-the-art manufacturing and technology solutions.

"On behalf of all of us at NCDMM, we are proud to welcome MAYA Design, Navista, Palomar Technologies, The Lucrum Group, and UPS into the ranks of our distinguished team of Alliance Partners," says Randy Gilmore, NCDMM Vice President and Chief Technology Officer. "The ongoing collaboration between our Alliance Partners, Manufacturing Consortium, and internal staff is essential to supporting our industry and

providing our customers with the most innovative and effective technologies available today."

Alliance Partners at NCDMM take an active role in identifying, developing, demonstrating, and deploying new solutions in partnership with the NCDMM. NCDMM is aiming to reduce manufacturing and machining costs, enabling more critical hardware and supplies to be available for US defence troops.

Palomar Technologies, a former subsidiary of Hughes Aircraft, is a provider of automated high-accuracy, large work area die attach and wire bond equipment and precision contract assembly services. Customers utilise its products, services and solutions to meet their needs for optoelectronic packaging. complex hybrid assembly and micron-level component attachment.

Novel Devices

Voids boost LED light emission

Higher light extraction efficiency results from a novel architecture formed by laser drilling and photochemical etching

A partnership between researchers in the US and China has increased LED output power by more than one-fifth via the creation of air gaps within the device.To deliver the increase in extraction efficiency, the researchers from National Chung Hsing University and Yale University drilled holes with a laser, before etching a heavily doped GaN layer beneath the LED structure.

Fabrication of these novel LEDs began with growth of an epistructure on sapphire that had a low-temperature buffer, an 1.2μm-thick undoped GaN layer, a heavily doped 0.2μm -thick GaN layer and a 0.2μm-thick undoped GaN layer. On top of this they deposited a relatively conventional device structure, which was capped with a 250 nm-thick layer of the transparent conductive material indium tin oxide.

Engineers employed a 355 nm laser to drill 10μm -diameter holes down to the heavily doped n-type layer, and used an electrochemical wet-etching process to create disk-shaped voids with a diameter of 40μm.

Driven at 20 mA, the etched LED delivered a light output power that was 22 percent higher than that of the control. However, this gain in the output came at the expense of a small increase in operating voltage from 3.12 V to 3.19 V, due to the slightly reduced emission area and the increased resistance of the treated LED structure.

Ref. C. -F. Lin et. al. Appl. Phys. Express 7 076501 (2014)

Annealing accelerates electron mobility

In-situ annealing nearly doubles electron mobility in InGaAs MISFETs

A team of researchers from Japan has almost doubled electron mobility in InGaAs MISFETs by performing an annealing step prior to the deposition of a HfO2 gate dielectric.

These efforts by engineers from the National Institute of Advanced Industrial Science and Technology and Sumitomo Chemical will help to enhance the credentials of III-V channels as alternatives to silicon for maintaining the march of Moore's Law. Higher mobilities allow a reduction in operating voltage of the transistor while maintaining its current, thus enabling ICs to maintain performance while consuming less power.

Traditionally, researchers have paired InGaAs MISFETs with an Al2O3 dielectric to create transistors with high mobility and a low interface state density. But the dielectric constant of this oxide is just 9, which is half that of HfO2, the gate dielectric used within the silicon industry today.

A higher dielectric constant is preferred, because it should make it easier to shrink transistor dimensions while maintaining performance. However, replacing Al2O3 with HfO2 has been hampered by a reduction in inversion electron mobility.

The team from Japan has overcome this by loading

the epiwafers in an atomic layer deposition tool, and prior to deposition of the dielectric, annealing them in an argon atmosphere for 30 minutes at 300 degC. After this, a film of HfO2 is deposited using a 50-cycle process, before gates are patterned using a standard reactive-ion etching process and metal contacts are added.

X-ray photoelectron spectroscopy measurements on this device, and also on a control that had not been annealed, revealed that the former structure produced a stronger signal at an energy associated with gallium oxides. This occurred because annealing is estimated to increase the thickness of the GaOx from 0.15 nm to 0.20nm.

A series of different electrical measurements by the team showed that the annealed device had a much smaller frequency dispersion around the threshold voltage, which was the result of a decrease in the density of border traps in the HfO2 dielectric.

Mobility in the annealed sample peaked at about 1250 cm2 V-1 s-1 for a surface carrier density of around 2.5 x 1012 cm-2. In comparison, the mobility for the control was just shy of 700 cm2 V-1 s-1 for a surface carrier density of around 3.5 x 1012 cm-2.

The team attributes superior mobility to effective GaOx passivation at the interface between InGaAs and HfO2

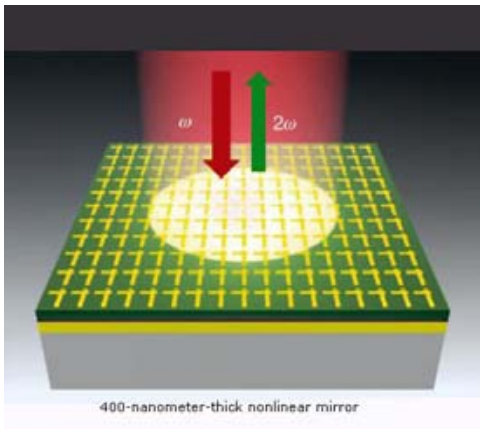
Reference: M. Oda et al. Appl. Phys. Express 7 061202 (2014)

Non-linear metamaterials deliver compact lasers

Million times higher intensity frequency-doubled output

Using layers of indium, gallium and arsenic alternated with aluminum, indium and arsenic in a coupled quantum well structure, scientists at the Technische Universitaet Muenchen, Germany and the University of Texas, Austin, USA have developed a way of making compact lasers at wavelengths for which either no laser systems exist or at best only large and expensive ones.

About 100 of these InGaAs and ALInAs layers (each between one and twelve nanometers thick) were stacked on top of each other and sandwiched between a layer of gold at the bottom and a pattern of asymmetrical, crossed gold nanostructures on top to make a 400nm thick nonlinear mirror. For a given input intensity and structure thickness, the new structure can produce approximately one million times higher intensity of frequency-doubled output, compared to the best traditional nonlinear materials, according to the researchers.



For the initial demonstration, the material converted light with a wavelength of 8000 nanometers to 4000 nanometers. “Laser light in this frequency range can be used in gas sensors for environmental technology,” says Frederic Demmerle, project member at the Walter Schottky Institute of the TU Muenchen.

Doubling the frequency of a beam of light in this way stems from the engineered electron states in the semiconductor material. When the semiconductor layers are only a few nanometers thick, the electrons can only occupy specific energy states and can be resonantly excited by the electromagnetic radiation.It is possible to adjust the structure to resonate optimally with the desired wavelengths by tuning the semiconductor layers’ thicknesses and the gold surface nanostructures geometry. The metallic structures ensure that the light is optimally coupled to the material. Their design also causes a strong increase in field strength at specific locations, which further amplifies the nonlinear response.

According to the researchers, because the frequency conversion happens over subwavelength scales, the nonlinear mirrors are free from the stringent requirement of matching the phase velocities of the input and output waves, which

complicates nonlinear optical experiments with bulk nonlinear crystals.

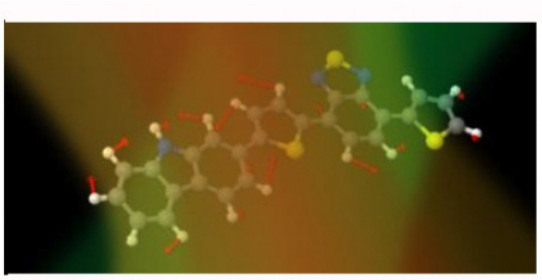
The new structures can be tailored to work at various frequencies from near-infrared to mid-infrared to terahertz. In the future, the team thinks the structures could be used for other nonlinear effects. “Alongside frequency doubling, our structures may be designed for sum- or difference-frequency generation,” says graduate student Jongwon Lee, at the University of Texas, the lead author on the paper ‘*Giant nonlinear response from plasmonic metasurfaces coupled to intersubband transitions’* published today in Nature 2014, DOI: 10.1038/nature13455

Scientists discover how plastic solar panels work

Findings are of key importance for all solar conversion systems

Scientists have determined exactly how light beams excite the chemicals in solar panels to produce charge. The findings, published today in Nature Communications, are of key importance for a fundamental mechanistic understanding, with molecular detail, of all solar conversion systems, according to lead author Françoise Provencher of the University of Montreal.

The researchers at University of Montreal, the Science and Technology Facilities Council, Imperial College London and the University of Cyprus have been investigating the fundamental beginnings of the reactions that take place that underpin solar energy conversion devices, studying the new brand of photovoltaic diodes that are based on blends of polymeric semiconductors and fullerene derivatives. “In these and other devices, the absorption of light fuels the formation of an electron and a positive charged species. To ultimately provide electricity, these two attractive species must separate and the electron must move away. If the electron is not able to move away fast enough then the positive and negative charges simple recombine and effectively nothing changes. The overall efficiency of solar devices compares how much recombines and how much separates,” explained Sophia Hayes of the University of Cyprus, last author of the study.



Three laser beams are needed to record the excited vibrational modes of PCDTBT using femtosecond stimulated Raman spectroscopy. First, the green pulse is absorbed by the polymer, which creates the excited state. Then, a pair of infra-red and white pulses probe this vibrational mode. Short pulses of light and precise timing enable a time resolution of less than 300 femtoseconds.

Two major findings resulted from the team’s work. “We used femtosecond stimulated Raman spectroscopy,” explained Tony Parker of the Science and Technology Facilities Council’s Central Laser Facility. “Femtosecond stimulated Raman spectroscopy is an advanced ultrafast laser technique that provides details on how chemical bonds change during extremely fast chemical reactions. The laser provides information on the vibration of the molecules as they interact with the pulses of laser light.” Calculations on these vibrations enabled the scientists to ascertain how the molecules were evolving. Firstly, they found that after the electron moves away from the positive centre, the rapid molecular rearrangement must be prompt and resemble the final products within around 300 femtoseconds. This promptness and speed enhances and helps maintain charge separation. Secondly, the researchers noted that any ongoing relaxation and molecular reorganisation processes following this initial charge separation, as visualised using the FSRS method, should be extremely small.

“Our findings open avenues for future research into understanding the differences between material systems that actually produce efficient solar cells and systems that should as efficient but in fact do not perform as well. A greater understanding of what works and what doesn’t will obviously enable better solar panels to be designed in the future,” said the University of Montreal’s Carlos Silva.

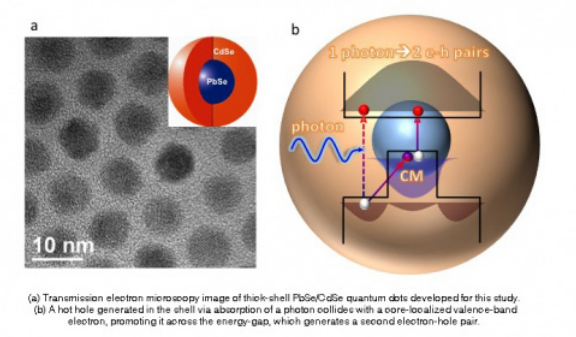
The article *‹Direct observation of ultrafast long-range charge separation at polymer-fullerene heterojunctions›* was published in Nature Communications on July 1, 2014.

Quantum dot solar cells show efficiency gains

Four fold carrier multiplication yield in nanoengineered quantum dots

Los Alamos researchers have demonstrated an almost four-fold boost of the carrier multiplication yield with nanoengineered quantum dots. Carrier multiplication is when a single photon can excite multiple electrons. Quantum dots are novel nanostructures that can become the basis of the next generation of solar cells, capable of squeezing additional electricity out of the extra energy of blue and ultraviolet photons.

Typical solar cells absorb a wide portion of the solar spectrum, but because of the rapid cooling of energetic (or 'hot') charge carriers, the extra energy of blue and ultraviolet solar photons is wasted through heat.



(a) Transmission electron microscopy image of thick-shell PbSe/CdSe quantum dots developed for this study. (b) A hot hole generated in the shell via absorption of a photon collides with a core-localized valence-band electron, promoting it across the energy-gap, which generates a second electron-hole pair.

This energy can be recovered by converting it into additional photocurrent via carrier multiplication, in which collision of a hot carrier with a valence-band electron excites it across the energy gap. "In this way, absorption of a single photon from the high-energy end of the solar spectrum produces not just one but two electron-hole pairs, which in terms of power output means getting two for the price of one, " explained Victor Klimov, director of the Center for Advanced Solar Photophysics (CASP) at Los Alamos National Laborator"

Carrier multiplication is inefficient in the bulk solids used in ordinary solar cells but is enhanced in quantum dots, as was first demonstrated by LANL researchers in 2004 (Schaller & Klimov, Phys. Rev. Lett. 92, 186601, 2004). In conventional quantum dots, however, carrier multiplication is not efficient enough to boost the power output of practical devices. A new CASP study demonstrates that appropriately engineered core/shell nanostructures made of lead selenide and cadmium selenide can increase the carrier multiplication yield four-fold over simple PbSe quantum dots.

Klimov explained, "This strong enhancement is derived primarily from the unusually slow phonon relaxation of hot holes that become trapped in high-energy states within the thick CdSe shell. The long lifetime of these energetic holes facilitates an alternative relaxation mechanism via collisions with core-localized valence band electron which leads to highly efficient carrier multiplication."

To realize the effect of slowed carrier cooling LANL researchers have fabricated PbSe quantum dots with an especially thick CdSe shell. Thick-shell PbSe/CdSe quantum dots have a fairly bright visible emission, from the shell, observed simultaneously with the infrared emission from the core. This shows that intraband cooling is slowed down dramatically, so that holes reside in the shell long enough to produce emission.

While the present CASP work is based on PbSe/CdSe quantum dots, the concept of "carrier-multiplication engineering" through control of intraband cooling is general, and should be realizable with other combinations of materials and/or nanostructure geometries.

Jeff Pietryga, lead CASP chemist says, "Further enhancement in carrier multiplication should be possible by combining this new approach with other demonstrated means for increasing multicarrier yields, such as by using shape-control (as in nanorods) and/or materials in which cooling is already naturally slower, like PbTe." Applied together, these strategies might provide a practical route to nanostructures exhibiting carrier multiplication performance approaching the limits imposed by energy conservation.

Semiconductor quantum dots with single-atom precision

Another step towards a new generation of atomic and molecular electronic integrated circuits

Scientists at NTT Basic Research Laboratories in Japan, the Paul-Drude-Institute in Germany, and the Naval Research Laboratory in America have developed quantum dot and combined artificial molecules with single-atom precision in terms of position and configuration. They achieved this on a clean surface of semiconductor single crystal thin film manufactured by MBE using a low-temperature Scanning Tunneling Microscope (STM) to integrate atoms one-by-one.

According to the researchers, this technology has made it possible to implement quantum dots with identical properties, like natural atoms, and do this flexibly at the semiconductor substrate for the first time at this level of precision. As a result, they say, it should be possible to manufacture quantum devices with atomic-level reproducibility e.g. a single photon source with a uniform wavelength, or an array of quantum bits with uniform functions, which has not been possible before. These results will be published in the Nature Nanotechnology on 29th, June 2014.

If the fabrication and characterization of quantum structures with atomic precision is possible at the semiconductor substrate surface, this will be a major leap toward being able to make a new types of integrated circuits that combine wafer-level semiconductor technology and atomic and molecular electronics.

For the base of the atom manipulation, the team used an (111)A-oriented surface of indium arsenide crystal. The (111)A surface has periodic hollow sites caused by a specific atomic structure of compound semiconductors. The structure formation can be exactly controlled by placing each atom at each hollow site. The high quality InAs thin film has been grown at NTT-BRL on the (111)A-oriented substrate with atomically controlled thickness. After the grown InAs surface was covered by a protection film (amorphous As), the sample was transferred from NTT to PDI.

Atom-by-atom quantum structure fabrication
When the sample was loaded into STM instruments at PDI, the protection film was removed in an ultra-high-vacuum to recover the clean (111)A surface, on which it is feasible to perform atom manipulation. The indium atom is self-ionized at the InAs surface to be +1 charged ion with releasing an electron. By using the low-temperature STM, we can not only observe surface atomic arrangement but also form nanostructures by atom manipulation of these ions as building blocks. Artificial atoms (6 ≤ the number of atoms ≤ 25) have been manufactured by arranging each In atom one-by-one in a line at the (111)A surface. The row of such ions behaves as a ‹core› of an artificial atom and electronic states at the semiconductor surface are confined to the induced local potential well.

Future Plans
The team expect that the present achievements will open the door to developing new electronic technology by combining atomic and molecular electronics with semiconductor thin film technology. By exploring novel properties of many integrated atoms and the interaction with semiconductor heterostructures, they plan to develop architectures for quantum computers and high-performance semiconductor devices composed of well-defined semiconductor nanostructures with robust fidelity. Further study will bring many benefits to a broad range of science and technology fields.

Publication information: *Quantum dots with single-atom precision* by S. Fölsch etc al, Nature Nanotechnology (2014).DOI: 10.1038/NNANO.2014.129

A low-cost post-growth activation step for CdTe solar cells

Magenesium chloride could replace toxic cadmium chloride say researchers

Chemists at the University of Liverpool have shown that magnesium chloride, commonly used in bath salts, can replace a toxic, expensive chemical in the manufacture of cadmium telluride (CdTe) solar cells.

Cadmium telluride thin-film solar-cell technology has laboratory efficiencies approaching 20 percent, but a central part of its manufacturing process involves doping the polycrystalline thin-film CdTe with cadmium chloride, which costs around 30 cents per gram and is a toxic water-soluble source of cadmium ions.

Cadmium chloride is used to form the photovoltaic junction at the CdTe/CdS interface, and to passivate the grain boundaries, making it essential to achieving high device efficiencies. But as the rsearchers detailed in the Nature letter '*A low-cost non-toxic post-growth activation step for CdTe solar cells'* they have now demonstrated CdTe solar cells prepared using magnesium chloride, which is non-toxic and costs less than a cent per gram. Efficiencies of around 13 percent, they say, are identical to those of a cadmium chloride-processed control group.

Hole densities in the active layer are also similar and comparable impurity profiles for Cl and O, these elements being important *p*-type dopants for CdTe thin films. Contrary to expectation, cadmium chloride-processed and magnesium chloride-processed solar cells contain similar concentrations of magnesium; this is because of magnesium out-diffusion from the soda-lime glass substrates and is not disadvantageous to device performance. However, treatment with other low-cost chlorides such as NaCl, KCl and MnCl2 leads to the introduction of electrically active impurities that do compromise device performance.

The team believes the results demonstrate that magnesium chloride can directly replace cadmium chloride in the existing process, both minimising the environmental risk and reducing the cost of CdTe solar-cell production.

Derived from, '*A low-cost non-toxic post-growth activation step for CdTe solar cells'* by JD Major et al, Nature (2014) doi:10.1038/nature13435

Researchers make full-colour InGaN LEDs using LCD-type process

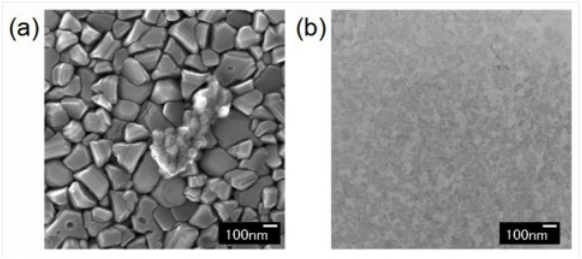
Low cost pulsed sputtering technique shows promise for large area InGaN LED displays

InGaN-based LEDs are now widely accepted as highly efficient light sources that can replace incandescent bulbs. But so far they been limited to small devices. Now a team from the University of Tokyo has shown that InGaN LEDs could form large area displays on amorphous substrates using a manufacturing technique frequently used for making liquid-crystal displays (LCD).

To date, most InGaN-based LEDs have been fabricated using expensive MOCVD processes on single-crystal substrates such as sapphire and SiC. In contrast, the Tokyo team used a pulsed sputtering deposition process to grow GaN and InGaN films on amorphous SiO2. They made working red, green, and blue InGaN LEDs.

Figure 1: SEM images of a GaN film grown on an amorphous SiO_2 substrate (a) without and (b) with a multilayer graphene buffer layer.

From
Fabrication of full-color InGaN-based light-emitting diodes on amorphous substrates by pulsed sputtering
Jeong Woo Shon, Jitsuo Ohta, Kohei Ueno, Atsushi Kobayashi & Hiroshi Fujioka
Scientific Reports 4, Article number: 5325 | doi:10.1038/srep05325
Received 24 April 2014 | Accepted 28 May 2014 | Published 23 June 2014



Many attempts have been made to replace single-crystal substrates for the growth of group-III nitrides with low-cost, large-area materials such as glass and metal. Glass is the ideal substrate for large-area, low-cost LEDs because of its transparency and compatibility with existing LCD fabrication processes. But GaN films grown on glass have been impractical due to a low softening temperature (500-700degC) for glass substrates, and the amorphous nature of glass, which leads to poor crystalline quality of the overlaid nitride semiconductor layer.

By introducing multilayer graphene as a highly oriented crystalline buffer layer between the substrate and nitride film, the team overcame the first problem (large-area graphene films like these can be easily deposited by conventional chemical vapour deposition). As for the low softening temperature, recent progress in the epitaxial growth techniques based on pulsed sputtering deposition enables the growth of high-quality group III nitride

crystals even at room temperature. The successful reduction in the growth temperature was achieved because of the high kinetic energy and pulsed supply of group III atoms, which assist the surface migration of film precursors at substrate surfaces, Recently, successful fabrication of 640 nm InGaN LEDs by PSD at a maximum process temperature of 480degC has been reported (Nakamura et al Appl. Phys. Lett. 104, 051121 (2014)).

By demonstrating that full-color LEDs can be fabricated on amorphous substrates, the researchers think that since sputtering is frequently used in the LCD industry, it could be adapted to fabricate large-area inorganic LED displays on glass substrates including flexible glass foils.

This work is detailed in the paper *Fabrication of full-colour InGaN-based Light-emitting diodes on amorphous substrates by pulsed sputtering* by *Jeong woo Shon et al in Nature Scientific Reports 4, Article number 5325*

Proof of concept for high efficiency hot-carrier solar cell

Hot-carrier photocurrent from an InGaAs single quantum well solar cell

Researchers from Imperial College London and the US naval Research Laboratory in Washington DC have demonstrated hot-carrier photocurrent from an InGaAs single quantum well solar cell. Their work was detailed in a recent paper in *Applied Phys. Lett. 104, 231115 (2014)*.

A hot-carrier solar cell (HCSC) is a photovoltaic device with a carrier population that is hot relative to the semiconductor lattice. Such a design aims to reduce the energy lost through heat when a material absorbs photons with energies larger than its bandgap. To achieve this, the photo-generated carriers are collected through energy-selective contacts before they have time to lose their energy as heat. Within a narrow range of energy states, hot-carriers thermalize isoentropically, generating chemical potential with an efficiency approaching that of a Carnot engine. HCSCs thus have a substantially higher fundamental solar energy conversion efficiency limit.

But there are two major HCSC development challenges: hot-carrier absorbers and energy selective contacts. To reach efficiencies close to the maximum thermodynamic limit relies on slowing the rate of carrier cooling in the absorber long enough for them to be transmitted through the energy selective filter contacts.

A hot-carrier absorber requires restricted scattering between carriers and lattice phonons to prevent heat dissipation and generate a thermal gradient between these two populations and efficiently generate chemical potential. Slow carrier cooling in GaAs quantum wells (QWs) relative to bulk has been known about for many years, and in a recent study, a carrier-lattice thermal gradient >100K was characterized in a single InGaAs QW structure under illumination power density 1kW cm-2.

Several structures have been proposed for energy selective contacts including resonant tunneling structures and an all-optical contact. In this paper, the researchers demonstrate hot-carrier photocurrent extracted from an InGaAs QW via an energy selective barrier. A narrow energy selective contact is ideal for efficient generation of chemical potential but any structure with a narrower range of energy states than the absorber can generate some chemical potential isoentropically. The energy selective barrier used in this study is therefore a type of energy selective contact and can produce a partial hot carrier advantage.

The sample in this study used a GaAs pin structure grown by MOCVD on a GaAs substrate and a single strained InGaAs QW with thickness 107Å. The sample was initially cooled to 10K in a closed-cycle cryostat, and a bias of 1.2V applied. Under these conditions, photo-excited carriers in thermal equilibrium with the lattice are trapped in the QW. This allows hot-carrier photocurrent to be distinguished from equilibrium photocurrent.

Cryogenic temperatures are not necessary to hot carrier devices but were used in this study to create an energy selective barrier. Focused laser illumination, tuned below the GaAs band-edge (1.52eV at 10K), was used to resonantly excite a non-equilibrium hot-carrier population. The energy distribution of the resulting photoluminescence

corresponds to that of the carriers, making it possible to determine the temperature of the population by fitting a Planck-like distribution to the high-energy tail of the emission.

In this study, the photoluminescence measurements show the InGaAs well region of the structure is a hot-carrier absorber. The GaAs barrier has a larger bandgap than the well and therefore a reduced range of energy states. Le Bris and Guillemoles have demonstrated that such a barrier provides the energy selectivity required of an HCSC contact and therefore can generate some chemical potential isoentropically. Measurements in similar structures have demonstrated that this quantum well material can be used as a hot carrier absorber at room temperature.
While the proof of concept device has the two elements necessary for an HCSC, demonstration of a measurable hot-carrier efficiency enhancement would require significant improvement of both elements say the researchers. Further device development would include engineering hot carrier absorber material systems, with reduced carrier cooling lifetime, to generate a larger thermal gradient. In addition, the energy selective barrier would need to be designed to maximize the isoentropic generation of chemical potential, while maintaining good carrier transport.

This work is detailed in the paper *Experimental demonstration of hot-carrier photocurrent in an InGaAs quantum well solar* by LC Hirst et al, *Appl. Phys. Lett. 104, 231115 (2014)*

3-D cadmium arsenide emulates graphene

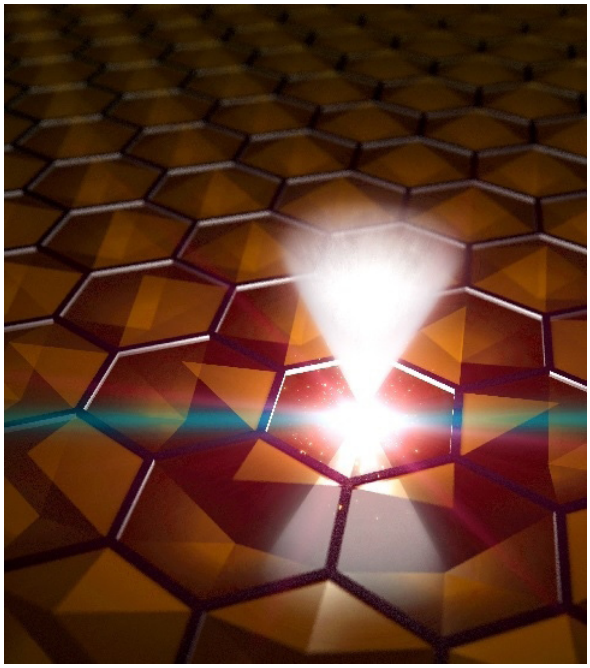
Researchers say a II-V semiconductor could yield practical devices with the same electronic properties as 2-D graphene

Scientists have discovered a material that has the same extraordinary electronic properties as 2-D graphene, but in a sturdy 3-D form that should be much easier to shape into electronic devices such as very fast transistors, sensors and transparent electrodes.

Cadmium arsenide (Cd3As2) is an inorganic, crystalline compound semiconductor with a tetragonal structure in the II-V family.

Cd3As2 is being explored independently by three groups, one of which includes researchers at the University of Oxford, SLAC, Stanford and Lawrence Berkeley National Laboratory who described their results in a paper published May 25th in *Nature Materials.*

“Now more and more people realize the potential in the science and technology of this particular material. This growing interest will promote rapid progress in the field - including the exploration of its use in functional devices and the search for similar materials,” says Yulin Chen of the University of Oxford, who led the research.



Scientists at Oxford, SLAC, Stanford and Berkeley Lab have discovered that a sturdy 3-D material, cadmium arsenide, mimics the electronic behavior of 2-D graphene. This illustration depicts fast-moving, massless electrons inside the material. The discovery could lead to new and faster types of electronic devices (Image: Greg Stewart/SLAC)

The group’s work builds on its earlier studies of a sodium bismuth compound that also mimics graphene but turns to powder when exposed to air. Both compounds had been predicted by co-authors Zhong Fang and Xi Dai, theoretical physicists from the Chinese Academy of Sciences, who suggested that cadmium arsenide, which is used in detectors and sensors, would provide the same properties in

a much more stable form.

Their prediction proved correct, says Zhongkai Liu, the paper's first author and a graduate student at SIMES, the Stanford Institute for Materials and Energy Sciences at SLAC. "The environmental stability of cadmium arsenide allows us to explore it very systematically, and makes it easier to study," he comments.

Graphene is a one-atom-thick sheet of carbon atoms peeled from a piece of graphite, which is familiar as the lead in pencils. One of its hallmarks is the weird behaviour of its electrons: When confined to this thin layer of regularly spaced atoms, these lightweight particles act as if they have no mass at all.

This allows them to zip through the material much faster than usual. The scientists who first isolated graphene in 2004 were awarded the Nobel Prize in Physics; and researchers have been racing to explore its properties and find practical uses for it ever since.

One such quest has been to find graphene-like materials that are three-dimensional, and thus much easier to craft into practical devices. Two other international collaborations based at Princeton University and in Dresden, Germany, have also been pursuing cadmium arsenide as a possibility. One published a paper on its results in the May 7th issue of *Nature Communications*, and the other has posted an unpublished paper on the preprint server *arXiv*.

Chen's group made samples of cadmium arsenide at Oxford and tested them at the Diamond Light Source in the United Kingdom and at Berkeley Lab's Advanced Light Source.

"We think this family of materials can be a good candidate for everyday use," Chen says, "and we're working with theorists to see if there are even better materials out there. In addition, we can use them as a platform to create and explore even more exotic states of matter; when you open a door, you find there are many

A state of matter known as a three-dimensional Dirac semimetal has latterly garnered significant theoretical and experimental attention. Using angle-resolved photoelectron spectroscopy, it is shown that Cd3As2 is an experimental realisation of a three-dimensional Dirac semimetal that is stable at ambient conditions.

This work is described in detail in the paper, " A stable three-dimensional topological Dirac semimetal Cd3As,"by Z. K. Liu *et al*, published online on 25th May 2014. doi:10.1038/nmat3990.

QMC starts mass production ahead of schedule

The firm has begun volume production CdSe tetrapod quantum dots

Quantum Materials Corporation (QMC) has received its increased capacity equipment and is launching mass production of advanced materials several months ahead of schedule.

QMC specialises in CdSe tetrapod Quantum Dots (QDs).

As an emerging provider of quantum dots, nanoparticle materials and related platform technologies, Quantum Materials Corp.'s (QMC) production phase equipment is capable of producing 250 kilograms of quantum dots per annum.

The company's proprietary high volume process technology produces quantum dots with superior uniformity to those created via manual processes. Additionally, QMC is executing its strategic plan to broaden the product line to a variety of tetrapod quantum dots including cadmium and previously announced Cadmium-Free Non-Heavy Metal Quantum Dots and size-optimised nanoscale metallic compounds including metal oxides. QMC recently added thick shell technology to its product offerings that possess many optoelectronic and photovoltaic advantages.

Looking beyond this achievement, Quantum Materials Corp. Chairman and CEO Stephen B. Squires stated that "Quantum Materials' next larger system, expected to be rapidly deployed later this year, will place us far ahead of the competition in the ability to supply reliable industrial quantities of quantum dots. We plan to quadruple production output by January 15th, 2015, and have engineered

plans in place to deploy short-lead-time parallel systems to meet ever increasing market demand."

David Doderer, Vice President of Research and Development for QMC, further detailed, "mass production affords the ability to quickly negate cost constraints and enable quantum dot penetration into newer applications such as security, defense, filtration, and product-ID packaging as well as our immediate opportunities in the display, lighting and energy sectors."

"With this accomplishment, our team has taken a significant step toward our goal of evolving quantum dots from an esoteric technological novelty to a core component commodity." Explaining his vision of the technology market, Squires continues, "The consumer expects the 'next big thing'.

Our quantum dots are a strong part of technological innovations that enable products that can be simply incredible. We are very focused and highly motivated to provide these key building blocks to a wide range of product innovators so that their dreams become reality in superior next-generation products for these markets."

In addition to manufacturing Tetrapod Quantum Dots (TQD) engineered to specific lighting, display and medical applications for leading manufacturers worldwide, QMC is also developing TQD-infused films for medical devices, solid state lighting applications, electronic displays and quantum dot solar cells.