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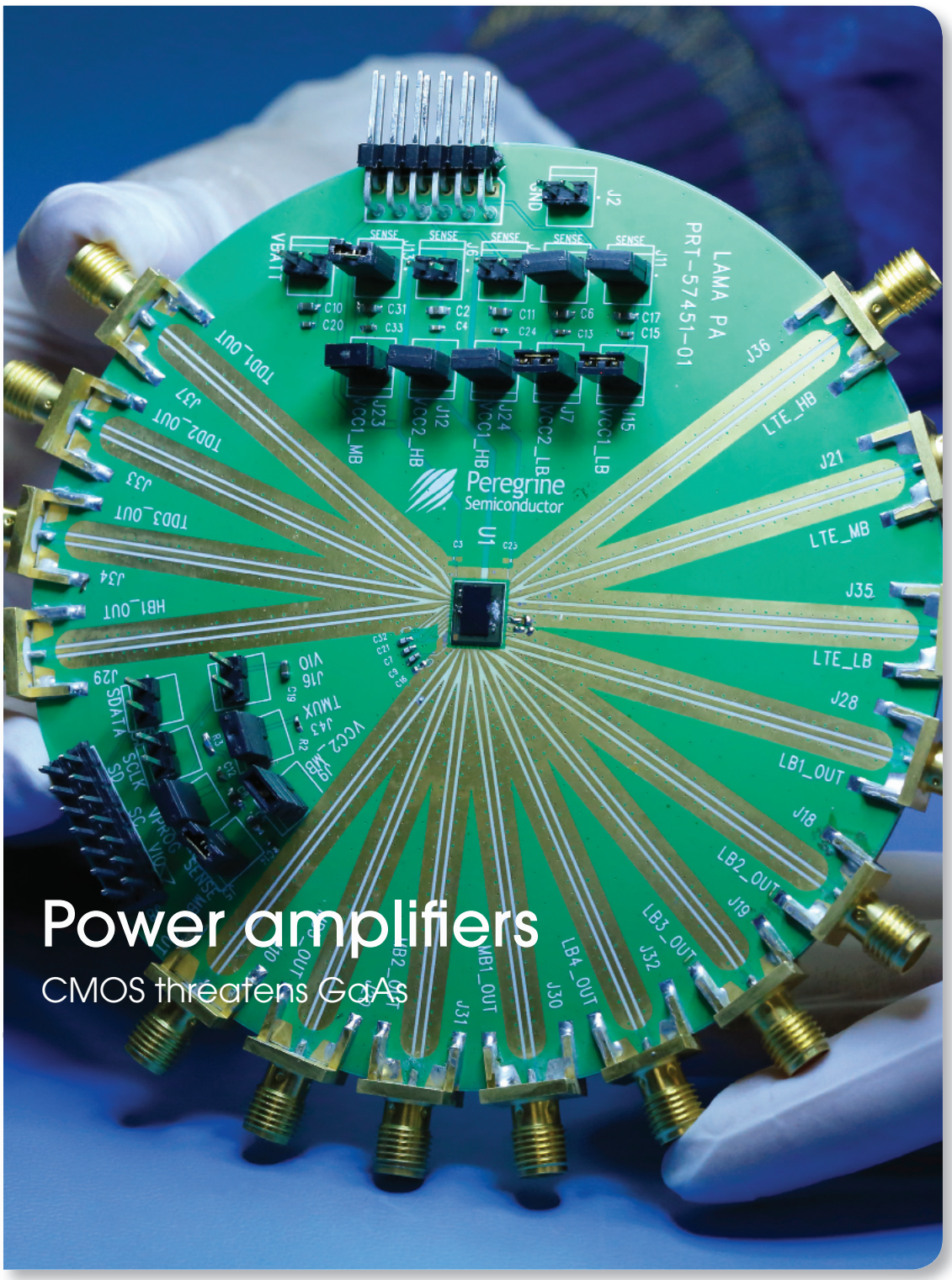

Power amplifiers

CMOS threatens GaAs

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ALWAYS ONE STEP AHEAD

editorial view

by Dr Richard Stevenson, Editor

Eyeing up the threats

BURYING YOUR HEAD IN THE SAND is rarely a good option. You might get away with it, but more often failure to act will backfire, with issues being harder to address as time goes on.

Applying this reasoning, I've commissioned a couple of features for this issue on silicon-based technologies for the front-end of mobiles. Power amplifiers deployed in front-ends have traditionally been built from GaAs, and while this material will definitely dominate for the next few years, it appears that the threat from silicon is now greater than ever, with this alternative technology tipped to take increasing market share.

One can argue, quite rightfully, that GaAs amps are better – there is no doubt that they have a far superior linearity. But a technology known as envelope tracking can address shortcomings in the linearity of silicon, arguably leaving little to choose between the two (see Nujira's feature on p.40 for details). Another attraction of turning to silicon, put forward by Peregine Semiconductor in *Building better RF front-ends with UltraCMOS* (see p.46), is that it could lead to a one-chip solution.

By helping to highlight these advances, I hope that everyone with a role to play within the GaAs industry can be aware of these threats and consider how to react.

One may also wonder if there are those within the silicon

industry that are failing to look over their shoulders, while arguing that silicon transistors will maintain the march of Moore's Law. IBM is not convinced, and has recently launched a $3 billion programme for new technologies. This firm is developing transistors with a III-V channel, as are several other groups that reported their advances at the recent VLSI Symposium (see p.50 for a report on this aspect of the conference).

What is clear is that as the boundaries blur between what silicon and the compound are good for, it's not a good time for anyone to stick their head in the sand – so instead, keep tabs on what is going on around you, and be ready to respond.

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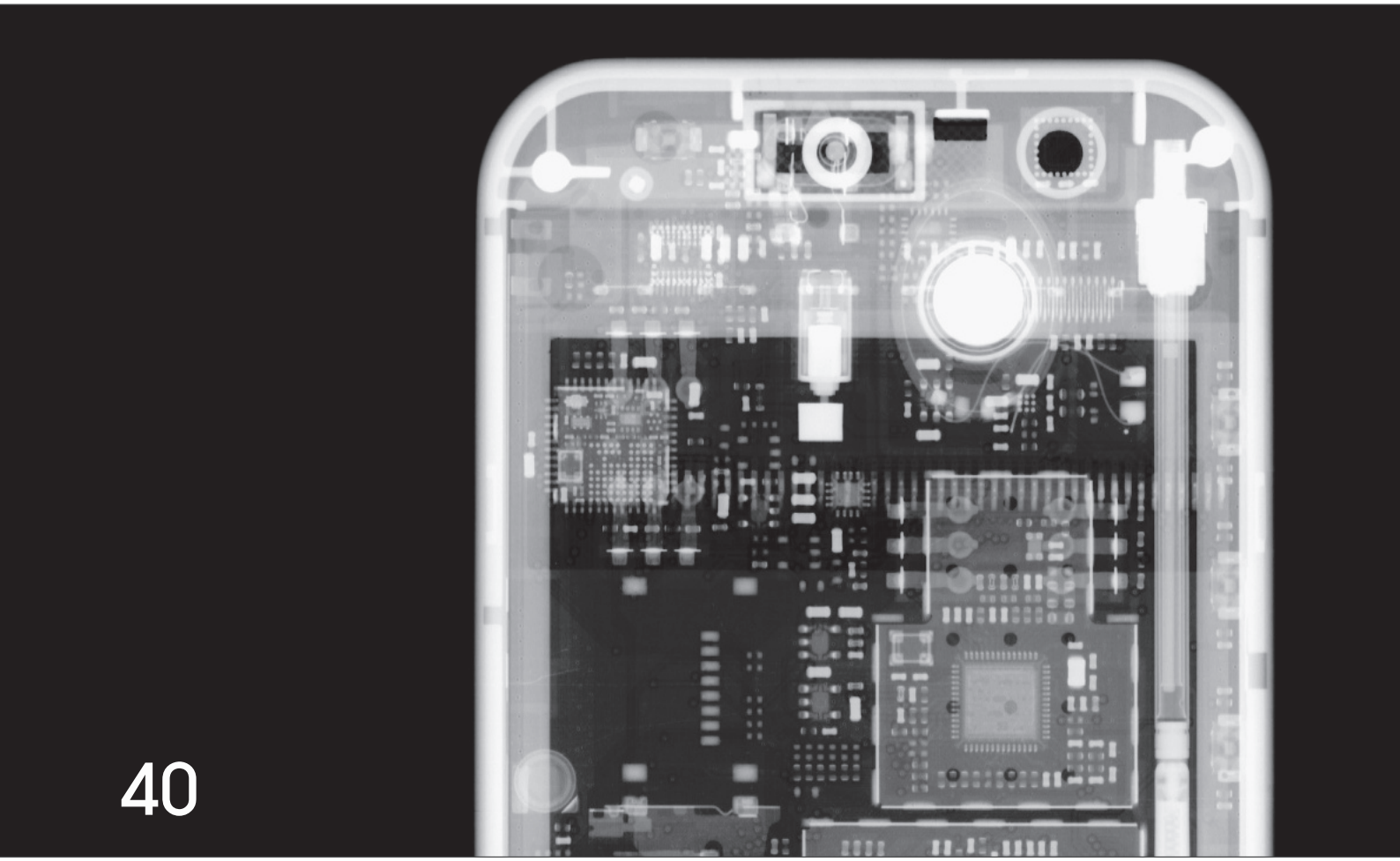

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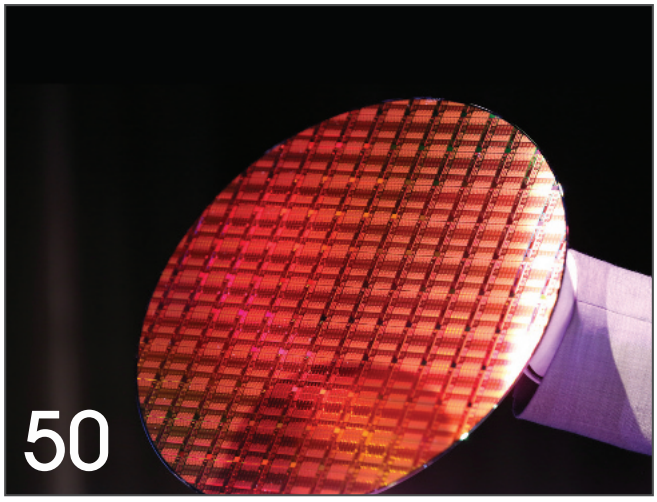

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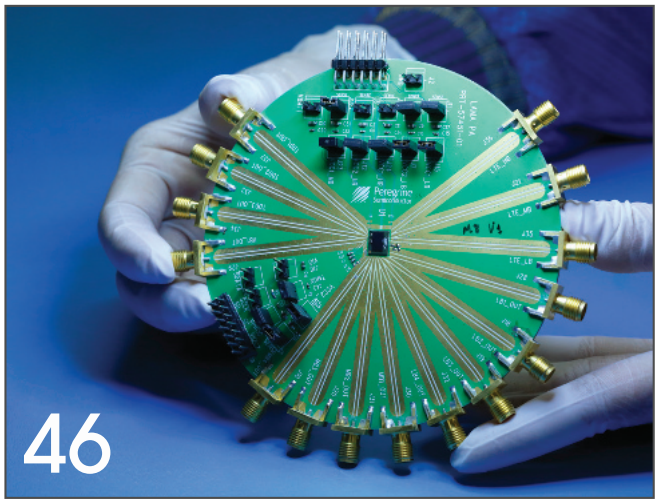


SiC to replace silicon power devices in cars by 2020

WIDE BANDGAP materials such as silicon carbide and gallium nitride are best positioned to address emerging power electronics performance needs in electric vehicles (EVs), with SiC displacing silicon as early as 2020, according to a new report by Lux Research.

As silicon struggles to meet higher performance standards, wide bandgap (WBG) materials are benefiting from evolving battery economics. On a Tesla Model S car, for example, a 20 percent power savings can result in gains of over $6,000 in battery cost, or 8 percent of the vehicle's cost.

"Efficient power electronics is key to a smaller battery size, which in turn has a positive cascading impact on wiring, thermal management, packaging, and weight of electric vehicles," said Pallavi Madakasira, Lux Research Analyst and lead author of the report 'Silicon vs. WBG: Demystifying Prospects of GaN and SiC in the Electrified Vehicle Market.'

"In addition to power electronic modules, opportunities from a growing number of consumer applications - such as infotainment and screens - will double the number of power electronic components built into a vehicle," she added.

Lux Research analysts have evaluated system-level benefits WBG materials are bringing to the automotive industry, and predicted a timeline for commercial roll-outs of WBG-based power electronics.

Among their findings were that at 2 percent power savings, if battery costs fall below $250/kWh, SiC diodes will be the only economic solution in EVs requiring a large battery. For plug-in electric vehicles (PHEVs), the threshold power savings needs to 5 percent.

They also forecast that SiC diodes will attain commercialisation sooner than GaN, being adopted in vehicles by 2020. Government funding, they add, is driving WBG adoption. The US, Japan and the UK, among others, are funding research and development in power electronics.

The US Department of Energy's Advanced Power Electronics and Electric Motors is spending $69 million this year and defining performance and cost targets; the Japanese government funds a joint industry and university R&D program that includes Toyota, Honda and Nissan.

Mid-power LEDs account for 48 percent of 2014 market

THE GROWING LIGHTING end market in 2014 is now projected to account for 35 percent of all packaged LED dollars, according to the a new research note from Jamie Fox, for IHS Inc, providing information on packaged LEDs sold into the lighting market.

For the first time, this is more than all backlighting combined. In 2013, lighting and backlighting accounted for 31 percent of market revenue each. Mid-power devices are projected to represent 48 percent of packaged LED revenue in lighting applications in 2014 and 81 percent in terms of units. This represents a major change since 2010 when high-power LEDs, such as 1 watt devices, dominated.

In Western regions the mid-power percentage is lower, while in Asia it is higher. Many Chinese suppliers selling LEDs to their large domestic market predominantly produce mid-power LEDs. From 2011 to 2013, the market for mid-power LEDs grew rapidly, driven by the attractive dollar-per-lumen ratio and the availability of capacity previously used for backlighting. The trend was initially led by South Korean companies such as Seoul Semiconductor and Samsung.

However, mid-power LEDs have become an essential part of most global companies' portfolios, with other suppliers such as Lumileds and Cree following the trend. Nichia also has a competitive offering in mid-power.

IHS still ranks Cree as the largest provider of packaged LEDs in lighting applications, closely followed by Lumileds. Despite this, during the last few years the competition from Asian companies has increased in lighting applications.

During 2015 and beyond, IHS forecasts the share of mid-power will continue to increase. The share of chip-on-board (COB) is also growing and playing an increasingly important role as completed lighting products are being designed for a wider variety of target end markets. High-power LEDs are still popular in some areas such as street lighting and should retain a strong presence in the market.

Excluding lighting, the rest of the LED market is almost completely flat from year-to-year, and is forecast to stay that way to 2019 according to IHS's LED Intelligence Service. The lighting market, led by mid-power LEDs, will drive the growth.

Hanergy completes acquisition of GaAs solar firm Alta Devices

BEIJING–BASED Hanergy Holding Group, which makes thin-film solar devices, has completed the acquisition of Alta Devices, whose thin film gallium arsenide solar technology has a conversion efficiency of 30.8 percent, the highest among the solar energy technologies currently available.

Both companies' R&D teams will join forces to develop Alta Devices' technology. Hanergy plans to actively expand the application of Alta Devices' products in mobile and wearable power application areas, ranging from emergency charging of mobile phones, to the automotive sector and the Internet of Things.

Alta Devices' use of GaAs allows its dual- and single-junction solar cells to produce record-breaking conversion efficiencies of 30.8 percent and 28.8 percent respectively, as certified by the US National Renewable Energy Laboratory (NREL). On a same surface area basis, its cells produce a power output two to three times higher than standard flexible thin-film cells, 8 percent higher than mass-produced monocrystalline silicon cells, and 10 percent higher than multicrystalline silicon cells.

Chairman and CEO of Hanergy Li Hejun said: "Alta Devices' thin film solar technology allows more energy to be produced in lower light conditions than any other type of solar cell, giving it greater potential to power a wide r ange of mobile devices and equipment from phones to cars. It has the potential to change the way solar energy is used.

This acquisition advances Hanergy's goal to become the world leader in the solar technology of the future." Chris Norris, president and CEO of Alta Devices, said: "This successful acquisition is built upon Alta Devices' and Hanergy's shared belief that flexible, thin-film solar technology represents the future of the solar industry.

The combination of our world-class solar cell R&D capability and Hanergy's technology, research and capital resources will help us further improve the performance of our technology, increase production capacity and expand applications."

Alta Devices' single-junction GaAs thin-film solar cells are already in production. Following the acquisition, Alta Devices will continue to operate independently as a wholly-owned subsidiary of Hanergy. Hanergy will also work with Alta Devices to develop international markets and enhance its cooperation with key strategic customers.

LED lamp price down on July 2013

THE JULY 2014 release of the IHS Technology LED lamp Retail Price Tracker has found that the global average retail price of LED lamps was $22.31, indicating a fall of 1.6 percent in July 2014 from the prior month, and down 9.6 percent compared to the same time a year earlier in July 2013.

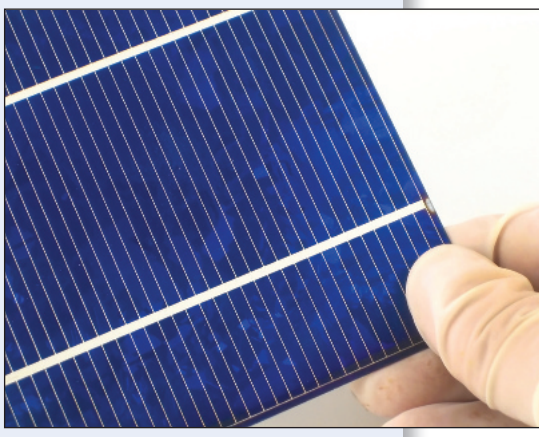
Over the past 12 months, the lumens-per-dollar ratio of LED lamps has increased by 17.6 percent to 34.3 lumens per dollar. IHS has been tracking LED lamp retail pricing trends for more than two and half years.

Each month IHS analyst's sample of 2,600 individual LED lamps sold in retailers across 15 countries globally.

Chinese lab makes step towards 'solar' fabric

SCIENTISTS at the State Key Laboratory of Molecular Engineering of Polymers, at Fudan University, Shanghai have made perovskite (a calcium titanium oxide mineral) solar cells with a flexible fibre structure, opening up the possibility of weaving them into textiles.

The technique, detailed in the journal *Angewandte Chemie*, involved continuously winding an aligned multiwalled carbon nanotube sheet electrode onto a fibre electrode. Photoactive perovskite materials were incorporated inbetween them through a solution process.



The fibre-shaped perovskite solar cell exhibits an energy conversion efficiency of 3.3 percent, which remained stable on bending.

The perovskite solar cell fibres may be woven into electronic textiles for large-scale application by well-developed textile technologies, according to the researchers, making them potentially useable in wearable and portable electronic devices.

Full details can be found in the paper 'Integrating Perovskite Solar Cells into a Flexible Fiber' by L. Qiu et al (2014), Angew. Chem. Int. Ed.. doi: 10.1002/anie.201404973

Cars playing increasing role in optoelectronics sector

WITH CAR OWNERSHIP increasing in less economically developed regions and vehicles becoming more advanced, the automotive sector is playing an increasingly important role across all the major opotoelectronic component product types, according to a research by Stewart Shinkwin at IHS Inc.

Following a new European Union Directive 2008/89/EC, which required after 2011 all new models of car to be fitted with daylight running lamps, adoption of LEDs in automotive exteriors has significantly increased. Due to the long lifetime and energy efficient nature of LEDs, penetration in this area of the market was high and has helped drive adoption of LEDs.

Use of LEDs specifically in headlamp units is still relatively low, with only 2 percent of car headlamps using LEDs in 2013 according to figures from IHS Automotive. As their popularity, performance and efficiency grow, this is set to increase to 17 percent in 2019. This will bring significant growth to the LED market, with packaged LEDs for automotive exterior lighting set to grow at a CAGR of over 8 percent.

Technological advancement in the automotive industry has increased the adoption of infrared components, with a wide range of automotive applications including auto headlamps, automatic windscreen wipers, gesture control, and night vision displays.

Infrared revenues in this sector are forecast to increase from $118 million in 2013 to $207 million in 2019. It is unlikely, says IHS, that these technologies will become standard features in lower cost models; however, their penetration in mid-tier models is constantly increasing.

The increase in sales of hybrid electric vehicles (HEV) and full electric vehicles (EV) is also promoting growth in the optocoupler market.

Australian researchers pioneer graphene process using epitaxial SiC

RESEARCHERS at Griffith University in Australia are fabricating graphene from silicon carbide on silicon wafers using a process they say is scalable to 300mm mass production wafers.

Dr Francesca Iacopi's team are using the Australian National Fabrication Facility's (ANFF) Silicon Carbide Epitaxial reactor located at the Queensland Micro and Nanotechnology Centre at Griffith. They have combined the production of low cost silicon carbide wafers (made through the deposition of a high quality SiC layer onto low cost Si wafers), with the ability to pattern and etch this material using a plasma and finally to use novel low-temperature technology to synthesise graphene on only the required pattern. The researchers say that the combination of a crystalline SiC core with a surface graphene coating is ideal for sensing devices. The exceptional mechanical properties of SiC (which is the second hardest material after diamonds) can be further enhanced by graphene, resulting in excellent fracture strength. Also graphene offers a wealth of surface chemistry approaches for targeting specific ions and molecules. This year, the team produced SiC micro-resonators by replacing the traditional metals with a one molecule thick, transparent, highly conductive graphene layer. This work was detailed in a paper called 'Microresonators with Q-factors over a million from highly stressed epitaxial silicon carbide on silicon' by A.R Kermany et al in Applied Physics Letters 104, 081901 (2014).

MACOM announces highest power GaN L-Band Radar HEMT

MACOM has introduced a new GaN on SiC HEMT power transistor which it claims offers the highest peak power in the industry for a single-ended power transistor optimised for pulsed L-Band radar.

The MAGX-001214-650L00 guarantees 650W of peak power with a typical 19.5 dB of gain and 60 percent efficiency. The device also has a high breakdown voltage which allow customers reliable and stable operation at 50V under more extreme load mismatch conditions.

The device is assembled in a ceramic flange package and has undergone MACOM's rigorous qualification and reliability testing.

"The MAGX-001214-650L00 is a clear leader in high pulsed power GaN technology with guaranteed 650 W of peak output power combined with excellent gain, efficiency and reliable performance," said Paul Beasly, product manager.

"The device is an ideal candidate for customers looking to combine two power transistors and realise over 1,000 W of peak power in a single pallet for next generation L-Band radar systems that require increased performance in smaller footprints."

Operating between the 1200 to 1400 MHz Frequency range, the MAGX-001214-650L00 has a mean time to failure (MTTF) of 5.3 x106 hours.

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Perovskite semiconductor shows promise for low cost LEDs

A HYBRID FORM OF PEROVSKITE - the same type of material which has recently been found to make highly efficient solar cells - has been used to make low-cost, easily manufactured LEDs, potentially opening up a wide range of applications such as flexible colour displays.

This class of semiconducting perovskites have generated excitement in the solar cell field over the past several years, after Henry Snaith's group at Oxford University found them to be remarkably efficient at converting light to electricity. In two years, perovskite-based solar cells have reached efficiencies of nearly 20 percent, a level which took conventional silicon-based solar cells 20 years to reach.

Now, researchers from the University of Cambridge, University of Oxford and the Ludwig-Maximilians-Universität in Munich have demonstrated a new application for perovskite materials, using them to make high-brightness LEDs. The results are published in the journal Nature Nanotechnology.

Perovskite is a general term used to describe a group of materials that have a distinctive crystal structure of cuboid and diamond shapes. They have long been of interest for their superconducting and ferroelectric properties. But in the past several years, their efficiency at converting light into electrical energy has opened up a wide range of potential applications.

The perovskites that were used to make the LEDs are known as organometal halide perovskites, and contain a mixture of lead, carbon-based ions and halogen ions known as halides. These materials dissolve well in common solvents, and assemble to form perovskite crystals when dried, making them cheap and simple to make.

"These organometal halide perovskites are remarkable semiconductors," said Zhi-Kuang Tan, a PhD student at the University of Cambridge's Cavendish Laboratory and the paper's lead author. "We have designed the diode structure to confine electrical charges into a very

thin layer of the perovskite, which sets up conditions for the electron-hole capture process to produce light emission."

The perovskite LEDs are made using a simple and scalable process in which a perovskite solution is prepared and spin-coated onto the substrate. This process does not require high temperature heating steps or a high vacuum, and is therefore cheap to manufacture in a large scale. In contrast, conventional methods for manufacturing LEDs make the cost prohibitive for many large-area display applications.

"The big surprise to the semiconductor community is to find that such simple process methods still produce very clean semiconductor properties, without the need for the complex purification procedures required for traditional semiconductors such as silicon," said Richard Friend of the Cavendish Laboratory, who has led this programme in Cambridge.

"It's remarkable that this material can be easily tuned to emit light in a variety of colours, which makes it extremely useful for colour displays, lighting and optical communication applications," said Tan. "This technology could provide a lot of value to the ever growing flat-panel display industry."

The team is now looking to increase the efficiency of the LEDs and to use them for diode lasers, which are used in a range of scientific, medical and industrial applications, such as materials processing and medical equipment. The first commercially-available LED based on perovskite could be available within five years.

Plessey expands its distribution network for GaN-on-Si LEDs

Plessey has announced that it has entered into a distribution agreement with Solid State Supplies Ltd, an electronics distributor headquartered in Redditch, UK, to expand its European network with coverage in the UK and Ireland market for its GaN-on-Si LED products.

John Macmichael, managing director of Solid State Supplies said: "Plessey's GaN-on-silicon technology looks set to cause major disruption in the LED lighting market. Our in-house lighting division is already geared up to support lighting and luminaire designers with these new LEDs. We look forward to a very bright future in partnership with Plessey."

David Owen, Plessey's regional sales director, added: "Plessey is very pleased to join forces with a distributor that has a focused lighting division already up and running, helping the significant number of lighting and luminaire makers in the UK. Solid State Supplies has a strong portfolio of products to support the lighting eco system which is now enhanced by the addition of the Plessey GaN-on-silicon LED product range. This will accelerate the time to market for Plessey LEDs in this region."

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

Revenues up at Rubicon

RUBICON TECHNOLOGY, a provider of sapphire substrates and products to the LED, semiconductor, and optical industries, has reported its Q2 financial results, ending June 30, 2014.
Q2 revenue was $14.5 million as compared with $14.3 million in Q1. Revenue from polished and patterned wafers increased by $1.8 million sequentially while revenue from cores declined by a similar amount.
The decline in core sales was due to more crystal production being directed into wafer products and because the company had exhausted its excess boule inventory in the first quarter.

Four-inch core pricing increased approximately 10 percent sequentially due to strong demand from the LED market and the result of LED chip manufacturers moving from two-inch to four-inch substrates in order to increase throughput from their existing facilities. Raja Parvez, President and CEO of Rubicon, commented, "Now that MOCVD utilisation rates are high, many LED chip manufacturers are looking for ways to increase throughput from existing operations, and moving to a larger substrate is one of the most effective ways to do that. We view the recent move to four-inch substrates as valid ation of our belief that we will soon see greater adoption of six-inch and even eight-inch substrates. This is important for Rubicon because of our strength and expertise in larger diameters."

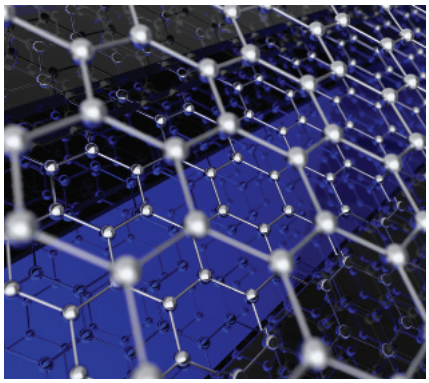
The company also reported progress with its patterned sapphire substrates (PSS) product introduction, an important part of Rubicon's go-forward strategy. Mr. Parvez said, "A significant development in the introduction of our PSS product came this quarter with the initial qualification of our four-inch and six-inch PSS wafers at three customers, two of which are major, international LED chip manufacturers. This is significant because we believe these customers have the potential to contribute significant revenue next year."
The company reported a per share loss of $0.39 in the second quarter as compared with a loss of $0.43 per share in the prior quarter. Wafer costs continued to be higher than normal due to the large number of PSS samples produced and the cost of establishing a four-inch polishing line. William Weissman, Rubicon's CFO, commented, "While idle plant and development costs at our wafering facility continued to be a drag on earnings in the second quarter, we are making progress in continuing to improve our overall cost position. Utilisation of our wafer operations is improving and we expect wafer costs to decline as we move from development to production in our new product lines."

Commenting on the outlook for the third quarter of 2014, Mr. Parvez said, "We expect continued progress in growing the wafer business in the third quarter with additional volumes in both polished and PSS wafers. However, we are seeing very limited demand for two-inch core in the third quarter as our polishing customers currently have excess inventory.

In addition, we believe that recent capacity additions in the sapphire market, which are primarily targeted at the developing mobile device market, are temporarily impacting the two-inch market. We expect third quarter revenue of between $8 and $12 million with an expected loss per share in the third quarter between $0.39 and $0.44. This relatively wide range of expected revenue is due to the near-term uncertainty in the two-inch market. We expect two-inch inventories at our polishing customers to be reduced over the course of the third quarter and for demand for that product to improve in Q4."

Finally, Mr. Parvez stated, "We continue to execute on our vertical integration strategy and are making good progress with the wafer business. The recent initial qualification of our PSS product at three new customers this quarter was an important step in the introduction of that new product line and qualification efforts continue with a number of other major LED manufacturers. With increasing volume and experience, and as customer specifications become better defined, we will reduce our idle plant costs and our wafer product cost. Furthermore, while pricing for certain product groups may take a step back from time to time for various reasons, we believe the general pricing trend for sapphire will continue to improve for some time. We believe that the market opportunities ahead of us are substantial and the work we are doing now will result in significant improvement in financial performance in the future."

The next graphene?



A TEAM OF ENGINEERING researchers from California has been awarded a $1.7 million grant from the US National Science Foundation (NSF) to characterise, analyse and synthesise a new class of ultra-thin film materials that could improve the performance of personal electronics, optoelectronic devices and energy conversion systems.

The potential of layering two-dimensional materials into novel heterostructures held together by weak van der Waals interactions is attracting increasing attention. Graphene has already been well studied but dozens of these one-atom- or one-molecule-thick crystals are known including monolayers of MoS2, hexagonal boron nitride, WSe2, graphane, fluorographene, mica and silicene.

Researchers at Vienna University of Technology, for instance, recently reported developing a new compound semiconductor structure combining tungsten diselenide with molybdenum disulphide to create a 'designer' optoelectronic material.

The Californian team is led by Alexander Balandin, University of California, who is founding chair of the materials science and engineering program at UC Riverside's Bourns College of Engineering. (A group led by Balandin at UC Riverside previously discovered the unusually high thermal conductivity of graphene.)

Other members of the team are Roger Lake, a UC Riverside professor, Alexander Khitun, a UC Riverside research professor, and Tina Salguero, an assistant professor at the University of Georgia.

This project will investigate novel electrical, optical, and thermal phenomena in such materials and heterostructures. The research is expected to produce new material synthesis techniques and enable practical applications of ultra-thin film materials in electronic switches, optical detectors, low-power information processing and direct energy conversion. Each member of the NSF-funded team will cover different aspects of the research and application of the van der Walls materials. Balandin will conduct materials characterization, fabrication and experimental testing of nanodevices, Lake will perform the first principal theoretical analysis and computer simulation of the properties of new materials and devices. Khitun will design circuits and systems based on two-dimensional materials and atomic heterostructures. Salguero will synthesize new materials using chemical approaches.

The NSF funding was awarded via the Emerging Frontiers in Research and Innovation (EFRI-2014) program called Two-Dimensional Atomic-layer Research and Engineering (2-DARE).

Intel patent to reduce parasitic leakage current

THE US PATENT AND TRADEMARK OFFICE (USPTO) has published a patent application filed by Intel process engineers describing a deep gate semiconductor device that uses either germanium or group III-V active layers. The idea is to reduce parasitic leakage current in small feature-size devices.

Shrinking transistor size allows more functions on a chip but it presents increasing difficulties - in particular the growing need to optimise the performance of each transistor to reduce leakage current and power consumption. Multi-gate devices, such as tri-gate transistors, have become one answer. In a tri-gate, by stacking a single gate on two vertical ones, there is more surface area for electrons to travel. In conventional processes, tri-gate transistors are generally made on bulk silicon or silicon-on-insulator substrates, which offer reduced leakage. Bulk silicon substrates are preferred as they are cheaper and tri-gate fabrication is easier, but it is often difficult to align the base of the metal gate electrode with the source and drain extension tips at the bottom of the transistor body. Proper alignment is needed for optimal gate control and to reduce short-channel effects: if the source and drain extension tips are deeper than the gate electrode, punch-through may occur; alternately, if the gate electrode is deeper than the source and drain extension tips, the result may be an unwanted gate capacitance parasitics.

Intel's patent application describes a solution in the form of a deep gate-all-around device, which it says is particularly suited for germanium or III-V material-based FETs with nanowire or nanoribbon channels. III-V materials are receiving a deal of interest as possible channel materials for future mainstream logic chips due to their high bulk electron mobility, which can improve the power / performance tradeoff.

Gate-all-around transistors are similar to FinFETs and Omega-FETs, which have their conducting channel wrapped with silicon, which forms the body of the device. The thickness of the silicon 'wrapper' determines the channel length. The method provides better electrical control over the channel and helps reduce leakage current. A gate-all-around differs from in that the gate material surrounds the channel region on all sides.

The device described in the patent application and illustrated above comprises: a buffer layer on a substrate; an active layer on the buffer layer; a gate electrode stack on and completely surrounding a channel region of the active layer, and also within a trench in the buffer layer; and source and drain regions positioned in the active layer and in the buffer layer either side of the gate electrode stack. The gate electrode stack is located to a depth in the buffer layer sufficiently below the source and drain regions to block a substantial portion of leakage from the source region to the drain region. The full details are described in US Patent Application 20140203327.

Japanese group reduces defects in SiC transistors

A RESEARCH GROUP at the University of Tokyo Graduate School of Engineering, has found a way to reduce defects in silicon carbide devices to improve performance.

SiC devices offer the potential for lower energy loss than conventional silicon devices, but SiC transistors suffer from high resistance and low reliability, mainly due to defects formed at the interface between SiC gate dielectric film.

Such defects, caused by impurities and atomic excess or deficiency at the interface, need to be reduced to improve the performance.

The Tokyo University group led by Koji Kita found that the density of interface defects is significantly reduced by employing reaction conditions where the by product carbon is ejected as carbon monoxide when creating the gate dielectric film.

The group achieved the lowest defect density in a metal-oxide-semiconductor test structure employing these conditions. This technique provides a high quality SiC interface without any extra processes such as addition of nitrogen-containing gases, assuring the easy industrial application of this method.

This technique is expected to improve the performance and accelerate the spread of SiC power devices, contributing to energy saving in a variety of applications, including electric power transmission, electric vehicles, and factory machines.

The work was published as "Fabrication of SiO^2/4H-SiC (0001) Interface with Nearly-Ideal Capacitance-Voltage Characteristics by Thermal Oxidation" by Richard Heihachiro Kikuchi and Koji Kita, in Applied Physics Letters **105,** 032106 (2014).

Vishay orders Aixtron system

VISHAY SEMICONDUCTOR GMBH has acquired an MOCVD system from Aixtron to expand its infrared LED production capacities. The company aims to substantially extend its product portfolio in this area. The system was delivered to Vishay at the end of March.

"We opted for Aixtron's planetary reactor, as it deposits high-quality layers and offers very high production stability, long operating times, and high throughput rates. Not only that, Aixtron will support us with process expertise, thus enabling us to rapidly and efficiently expand our gallium arsenide-based infrared LED production," commented Heinz Nather, senior VP or Vishay's Opto division.

"We are delighted to have convinced Vishay Semiconductor, one of the world's leading producers of semiconductors and power electronics, with our range of technologies and services," remarked Frank Schulte, Vice President of Aixtron Europe. "We have great expectations of our ongoing cooperation with Vishay."

Vishay Semiconductor GmbH forms part of Vishay Intertechnology, Inc, based in Malvern, Pennsylvania, USA, one of the world's largest manufacturers of discrete semiconductor elements (diodes, rectifiers, transistors, optoelectronic components, integrated circuits) and passive electronics components (resistors, capacitors, inductors, sensors, transformers).

First Solar surpass CdTe thin film efficiency again

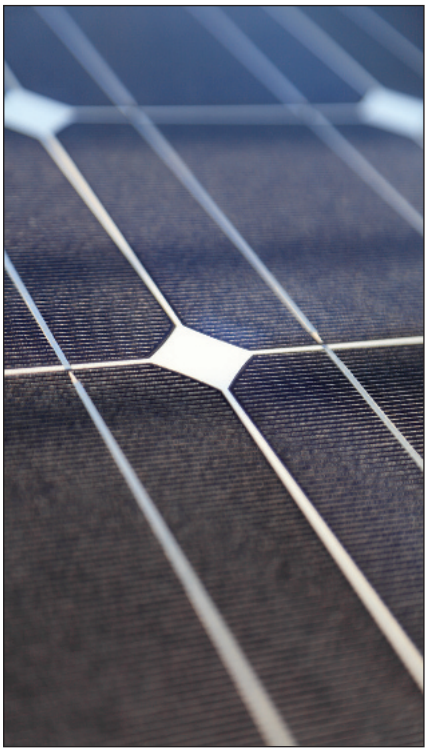
FIRST SOLAR has announced it has set a world record for cadmium-telluride (CdTe) photovoltaic (PV) research cell conversion efficiency, achieving 21 percent efficiency certified at the Newport Corporation's Technology and Applications Centre (TAC) PV Lab. The record-setting cell was constructed at the company's Perrysburg, Ohio manufacturing factory and Research & Development Centre, using processes and materials designed for commercial-scale manufacturing.

The record has been documented in the US Department of Energy's National Renewable Energy Laboratory (NREL) "Best Research Cell Efficiencies" reference chart.

This certified result bests the previous CdTe record of 20.4 percent conversion efficiency, which was set by First Solar in February of 2014, and represents the seventh substantial update to CdTe record efficiency since 2011. The achievement also places First Solar's CdTe research cell efficiency above copper indium gallium diselenide based solar cells (CIGS) at 20.9 percent, and well above multicrystalline silicon (mSi), which peaked at 20.4 percent in 2004.

"We have just begun to reveal the true unrealized potential of CdTe PV," said Raffi Garabedian, First Solar's Chief Technology Officer. "Our Advanced Research team continues to deliver extraordinary results by creating practical devices capable of commercial scale production. Not only have we have now demonstrated the highest single junction thin film cell on record, but just as important, our record cells are based on the same scalable manufacturing processes and commodity materials that we have proven through years of volume production."

Garabedian noted that while competing technologies are using increasingly costly materials and cell processes in order to deliver moderate performance gains, First Solar is establishing a rapid path to industry-leading energy densities, while simultaneously improving manufacturing metrics.



"Our significant investment in development of CdTe thin-film technology has enabled a rapid rate of improvement and gives us tremendous confidence in the future," said Markus Gloeckler, First Solar Vice President for Advanced Research. "We have made outstanding improvements in all aspects of our thin-film solar cells and are aggressively pursuing the commercialization of these advanced technologies in our product."

At an analyst briefing last March, First Solar presented a technology roadmap anticipating a 22 percent research cell efficiency milestone in 2015. This announcement indicates First Solar is steadily tracking to achieve that goal ahead of schedule.

First Solar has continued to transfer its success in the R&D lab into its commercially produced modules, increasing its average production module efficiency to 14 percent in the second quarter of 2014, up 0.5 percent from the first quarter of the year, and up 0.7 percent from FY2013. The company's lead line was producing modules with 14.1 percent average efficiency at the end of the second quarter of 2014.

GaAs IC Market to reach $8 billion in 2017

A NEW MARKET research report 'The GaAs IC Market' by Information Network forecasts that the GaAs IC market will reach $8 billion in 2017.

The most important driver of the GaAs RF IC market is power amplifiers (PAs) and switches in the front-end of the handsets. 3G handsets often contain up to five PAs, and GaAs makes up 100 percent of the market, which is close to $5 billion.

According to the report, the number of PAs per handset is growing because of: complex 3G systems, global roaming support, and data roaming support.

Pricing for PAs has increased from $0.80 per handset to $2.90 currently and is projected to increase to greater than $3.50 once Long Term Evolution (LTE) and Advanced Wireless Services (AWS) spectrum emerge in advanced handsets in the marketplace.

While industrialised countries are using 3G networks, today's world is a mixture of 2/2.5G and 3G networks, the heavy majority of subscribers are actually on 2G-based networks - and predicted to remain so for a number of years.

Between 70 to 80 percent of Skyworks' and RF Micro Device's GaAs business is in PAs. 2G handsets contain one PA, so it represents a sizable market.

Because they aren't as technologically advanced as 3G cell phones, particularly smartphones, silicon is making inroads in the GaAs domain. For 2013, only 90 percent of PAs were made in GaAs, 5 percent in silicon CMOS, and 5 percent in silicon LDMOS.

In the article "Understanding imperfections in GaN HEMTs", it was stated that Petra Specht was at the University of Santa Barbara, California.

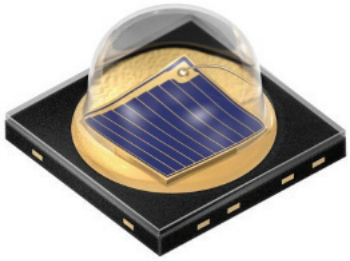
This is incorrect: Specht is at The University of Berkeley, California.

Osram introduces 940nm IR LED with 150 degree beam angle

OSRAM OPTO SEMICONDUCTORS is launching the SFH 4726S, a high-power member of its IR Oslon Black product family with a wide beam angle of 150degrees.

When integrated in reflector-based optics, the infrared LED (IRED) pre-shapes the light beam, concentrates it and can then focus it efficiently via other optics. As a result, smaller optics can be used, permitting generally more compact lighting solution designs.

This system will replace the current conventional approach, which requires optics with a much larger optical aperture. Customers also stand to benefit, for the smaller dimensions offer much greater design freedom for lighting solutions. Another advantage of the new IRED is its high optical performance of 990mW at a current of 1A.



Like its sister IRED product, the SFH 4725S, the new Oslon Black has a wavelength of 940nm. This long-wave radiation at the red end of the spectrum is barely visible to the human eye. Even the slight red glow which can be perceived at a wavelength of 850nm rarely occurs with this version. Infrared LEDs are hence suited for discreet surveillance applications; for instance in the main hall of a bank or at border crossings.

The launch of the SFH 4726S now provides customers with another Osram product for discreet security surveillance. Other fields of application for the IR Oslon Black family include optical vehicle security systems or gesture detection for computer games.

Earlier this month, the company also announced the 850nm Oslon Black SFH 4715A, which boasts a typical electro-optical efficiency of 48 percent.

Commenting on the the SFH 4715A, Jörg Heerlein, senior manager for product marketing at Osram Opto Semiconductors said: “We are not aware of any other opto-electronic component with an optical efficiency to rival this one.

Thanks to a boost in output to 800mW (previously 630mW) the new Osram IRED can illuminate objects over 100m away depending on the application and type of external optics.

What’s more, this higher output generates more light, improving the image in the process.”

Skyworks opens doors for tier one automotive firm

SKYWORKS SOLUTIONS, which makes high performance analogue semiconductors, has announced that a tier-one automotive supplier is using its products for in-vehicle garage door openers across several car manufacturers.

The control system enables drivers to remotely activate garage door openers, entry door locks, home lighting, security systems and entry gates. Currently offered in all automotive brands, the platform is compatible with more than 99 percent of garage door opening systems as well as a wide variety of home safety and convenience products.

The three-button interface is located as an easy-to-install module in automobile rearview mirrors for a convenient, battery-free, programmable solution that eliminates the need for traditional clip-on transponders.

"Skyworks' advanced analogue and RF solutions are being leveraged across multiple in-vehicle applications that are enhancing safety and the overall driving experience," said John O'Neill, vice president of broad markets marketing at Skyworks. "As wireless technology in automobiles continues to rise, we are capitalising on the increasing number of addressable semiconductor opportunities that add value, minimise OEM costs and complexity, and improve time to market."

According to a report by Transparency Market Research entitled 'Connected Car Market: Global Industry Analysis, Size, Share, Growth, Trends and Forecast', the global connected car market is expected to reach $131.9 billion by 2019, growing at a compound annual growth rate of 34.7 percent.

The global connected car market is driven by safety and security services along with gaming, entertainment, traffic information, weather and location services.

US lab offers insights into new class of semiconductors

A PAPER PUBLISHED in the August 10th edition of the journal Nature Photonics by researchers at the University of Notre Dame in Indiana, describes their investigations into the fundamental optical properties of a new class of semiconducting materials known as organic-inorganic 'hybrid' perovskites. They conclude that the materials offer the best compromise between cost and performance for light harvesting.

'Perovskites' refers to the structural order these materials adopt upon drying and assembling in the solid state. In solid-state thin film solar cells, hybrid perovskites have recently shown light-to-electricity conversion efficiencies approaching 20 percent, rivaling that of commercial solar cells based on polycrystalline silicon. More importantly, these materials are easy and cheap to process using coating and or printing in contrast to solar technologies that typically require high purity materials, especially for silicon solar cells, and high-temperature processing.

However, the scientific community does not yet fully know how these unique materials interact with light on a fundamental level. In this study, Joseph Manser under the direction of Prashant Kamat, present insights into the excited-state properties of hybrid methylammonium lead iodide ($CH_3NH_3PbI_3$) thin films through a technique 'transient absorption pump-probe spectroscopy'. This approach was used to examine the events that occur trillions of a second after light absorption in the hybrid methylammonium lead iodide. They analysed both the relaxation pathway and spectral broadening in photoexcited hybrid methylammonium lead iodide and found that the excited state is primarily composed of separate and distinct electrons and holes known as free carriers.

"The fact that these separated species are present intrinsically in photoexcited hybrid methylammonium lead iodide provides a vital insight into the basic operation of perovskite solar cells," Manser said. "Since the electron and hole are equal and opposite in charge, they often exist in a bound or unseparated form known as an 'exciton.' Most next-generation photovoltaics based on low-temperature, solution-processable materials are unable to perform the function of separating these bound species without intimate contact with another material that can extract one of the charges."

This separation process siphons energy within the light-absorbing layer and restricts the device architecture to one of highly interfacial surface area. As a result, the overall effectiveness of the solar cell is reduced. "However, from our study, we now know that the photoexcited charges in hybrid perovskites exist in an inherently unbound state, thereby eliminating the additional energy loss associated with interfacial change separation," Manser said. "These results indicate that hybrid perovskites represent a 'best of both worlds' scenario, and have the potential to mitigate the compromise between low-cost and high-performance in light-harvesting devices."

Although the research was on the fundamental optical and electronic properties of hybrid perovskites, it does have direct implications for device applications. Manser and Kamat's research was supported by the Department of Energy's Office of Basic Energy Science.

The paper 'Band filling with free charge carriers in organometal halide perovskites' by J Manser et al, appears in Nature Photonics (2014) doi:10.1038/nphoton.2014.171

China lights up global LED industry

CHINA LED MANUFACTURER, MLS Electronics, has penetrated the packaged LED top ten. What could this mean for the rest of the world, asks Rebecca Pool?

AS PRICES FALL and consumer acceptance rises, the demand for packaged LEDs is climbing fast. US-based analysis business, IHS, predicts global revenue for these devices, in lighting applications, will grow from $3.6 billion in 2013 to a mighty $7.1 billion in 2016.

As suppliers worldwide chase the eagerly-anticipated 96 percent hike in revenue, China-based packaged LED manufacturers are already muscling in on the action. MLS Electronics recently cracked the top ten packaged LED rankings, a first for Chinese suppliers, and as IHS analyst Jamie Fox says: "MLS's ascent into the market's upper ranks represents a clear signal that Chinese firms will soon become major competitors in the global LED business."

As Fox, highlights, most of the new LED production capacity added worldwide since 2011 has come from China, and these massive investments are at last paying off. According to the analyst, worldwide number one supplier, Nichia, holds a 11.8 percent share of the global packaged LED market, while lead suppliers such as Osram Opto, Samsung Electronics, Seoul Semiconductor, Lumileds, Cree and LG Innotek have market share between 4.5 percent to 7 percent.

"But now MLS has around 2.4 percent share of the global market," he says. "China has built up a vast manufacturing capacity and its suppliers are already starting to compete internationally, so a key question is, how long until suppliers outside of China really start to feel an impact?"

The effects of cheaper Chinese competition are already apparent. Tier one companies, such as Cree have, for some time now, been dropping prices of lighting products in response to low-cost technologies from suppliers in China as well as South Korea and Taiwan.

Lighting has been the key application for these players, but over time other sectors will gain prominence. As Fox highlights: "I think the Chinese suppliers will first target lighting, but also signage and consumer applications, even just low-end applications such as toys and Christmas tree lights."

"Already these suppliers are not just competing directly by selling LEDs, they are vertically integrating and producing products such as LED lamp fixtures," he adds.

Market changes

Until now, LED package manufacturers such as MLS Electronics as well as the likes of Jufei, NationStar and Refond, have predominantly competed amongst themselves for a share of China's large domestic LED market.

The rise of China-based LED chip makers, such as San'an and Electech, government support and lighting market opportunities, have helped to deliver double digit growth amongst package suppliers, with, for example, Jufei and Refond recently posting around 35 percent year-on-year growth. But despite domestic growth, international sales have been few and far between.

MLS Electronics may have edged into the top ten of global packaged LED suppliers – up from 14th place in 2012 – but other suppliers do not even rank among the top 20. And as Fox highlights, while NationStar, for example, has entered the top 30, thousands of small manufacturers are dotted across the country making up a massive, but highly fragmented LED supply base.

Still, the analyst doesn't anticipate significant industry consolidation and expects the revenues of Chinese vendors to grow steadily as the nation's economy grows, enabling China-based suppliers to sell more internationally.

"For China suppliers, there are many issues around quality and performance but again, these issues depend on the application," he says. "China suppliers will find it easier to compete in low power and mid-power LED applications, but [segments] that demand higher power and longer lifetimes will be more challenging."

Quality issues aside, the intellectual property issues that have historically hampered LED-related exports will soon be resolved.

As the China-based LED market has developed, better regulation and provisioning of protection for IP is set to trigger more international sales.

And crucially, patents are now due to expire. "IP is becoming less of an issue, with some patents due to expire in 2015," concludes Fox. "Latest developments are just the beginning; expect more competition from China in the years ahead."

EPC:

Pursuing a broad GaN portfolio

Intent on flooding power device markets with GaN-on-silicon FETs, Alex Lidow, EPC, talks to Rebecca Pool about future market opportunities.

For a man that made his name from silicon, Alex Lidow, is now something of a GaN evangelist. On leaving International Rectifier and the world of silicon HEXFETs to launch GaN semiconductor business, EPC, in 2007, he set out to create high performance, cost-effective GaN power devices to replace incumbent silicon transistors.

Seven years on, the company has released some 25 devices – typically manufactured in Taiwan on standard CMOS lines – and industry can expect more.

"We've been delivering GaN transistors for nearly four and a half years and we've staked out this matrix of different products from 30 V all the way up to 200 V," says Lidow. "The costs of our smaller, [lower voltage] devices are actually lower than silicon MOSFETs, though we're not charging less as the performances are very high."

Indeed, Lidow reckons his latest raft of enhanced mode GaN-on-silicon FETs offers half the on-resistance and double the switching speed of previous devices.

"The performance gap between silicon and the last generation of GaN was very large, but we've now increased this gap further; we're very excited," he adds. "We've just delivered six new devices, and we're planning to do another forty soon."

Always-off

In the beginning, GaN-on-silicon transistors were depletion-mode types, operating as a normally on power switch and requiring a negative voltage to switch off. But despite high performance, industry pundits wanted a chip-to-chip replacement for silicon, with always off operation. And so EPC developed its so-called enhancement-mode GaN transistor with a GaN-on-silicon structure.

As Lidow puts it: "We needed to have enhancement-mode, rather than depletion-mode devices, and now we have this, I have no doubt that GaN will take over the power transistor business, over the next decade, for 600 V applications and less."

But this is where Lidow's take on the future of GaN in power devices gets interesting. While many manufacturers – including EPC – push 600 V GaN-on-silicon devices through qualification, Lidow reckons the real action still lies with lower-voltage devices.

According to the EPC chief executive, 600 V devices make up some 25 percent of the overall power transistor market, while devices rated at 200 V or less pull in a hefty 75 percent of the market.

"This lower voltage market is the most performance sensitive and really cares about the switching speed," says Lidow, adding: "Above 600 V, most applications are at 100 kHz and the market becomes focused on cost."

"So our strategy all along has been to aim at the low voltage performance market, and once we get our costs down, go after higher voltage applications," explains Lidow.

In the past, he has forecast that the basic cost of his company's GaN transistor should be less than a silicon MOSFET, with the same on-resistance and voltage, come 2016. But right now, he asserts his company's lower voltage devices have already hit this target, and all products will follow by mid-2015.

"We use standard silicon foundries and produce in volumes; all we have to do is buy the epireactor which is relatively inexpensive, and because our products are self-isolating, we don't have to package the devices," he says. "So GaN-on-silicon can be made cheaper than silicon due to the smaller die and not needing a package. So when you look at it all, the stress on the existing silicon infrastructure is zero."

But Lidow reckons EPC's price gains will dwindle beyond 600 V GaN-on-silicon FETs. He asserts that at much higher blocking voltages – 900 V and higher – transistors have typically taken a vertical, rather than lateral structure, in response to higher breakdown voltages and current collapse issues. As such, device

manufacturers have grown the device on bulk GaN or bulk SiC, rather than a cheap silicon substrate.

"GaN will only really compete with SiC at these higher voltages when the cost of GaN bulk crystals becomes competitive with SiC bulk crystals, but today GaN crystals are nowhere near that level," highlights Lidow.

And while M/A-COM, for example, has demonstrated high voltage, 1.5 kV GaN-on-silicon FETs, Lidow asserts: "I suspect that SiC will be the dominant growth engine in 900 V and above applications for the next decade or so, with GaN being dominant in 600 V and below."

So where next for EPC? According to Lidow, the company is still discovering applications for its 30 V to 200 V devices he couldn't have imagined a few years ago. The relatively new markets of envelope tracking in base stations, wireless power and LIDAR applications currently make up around half of his company's business and for him, this is just the beginning.

"The question I ask myself is where does the market go from here," he says. "Will GaN take over analogue ICs? Yes, I think there is a very high probability of that. Can you make digital CMOS with GaN? The answer here is probably yes."

"You'll soon see the very earliest forms of integrated circuit coming from us as well as higher frequency devices," he says, addding: "We intend to cover the entire $13 billion transistor market."

Red phosphor delivers intense LEDs

The latest red phosphor from Philips-Lumileds and LMU Munich researchers could usher in next generation white LEDs sooner rather than later, reports Rebecca Pool.

LATE THIS JUNE, researchers from Philips-Lumileds and the University of Munich unveiled a new phosphor material, that they reckon will lead to the next generation of high power white LEDs. Publishing results in *Nature Materials*, they detailed how their phosphor-coated LED prototypes produce a dazzling 14 percent increase in luminous efficacy relative to today's leading LED lights as well as an excellent colour rendition.

Former commercial phosphor-coated blue LEDs emit a cool white light and have a low colour rendering index due to low radiant power at red wavelengths. But as industry players have long known, boost the colour rendition of these illumination-grade and general lighting LEDs, and energy efficiency drops off.

So the hunt has been on to discover more efficient red-emitting phosphors that can take LEDs to higher luminescences than ever before. Wolfgang Schnick, University of Munich, believes he and colleagues have finally found the answer by adding a luminescent rare earth metal – europium – to a strong and sturdy strontium aluminium nitride host lattice.

In the beginning

As early as 2000, the LED industry was searching for new phosphor compounds to improve the luminescence properties of LEDs. As Schnick explains: "Researchers had realised that divalent europium ions would be very good for luminescence, but they needed to find an appropriate host lattice. Tens of thousands of host lattices had been tried, but none were suitable."

In short, the host lattice had to fulfil three criteria; it needed to take up the divalent europium without oxidising the ion to the lower luminescence trivalent state, be transparent to visible light and exhibit good chemical and physical stability. Not easy.

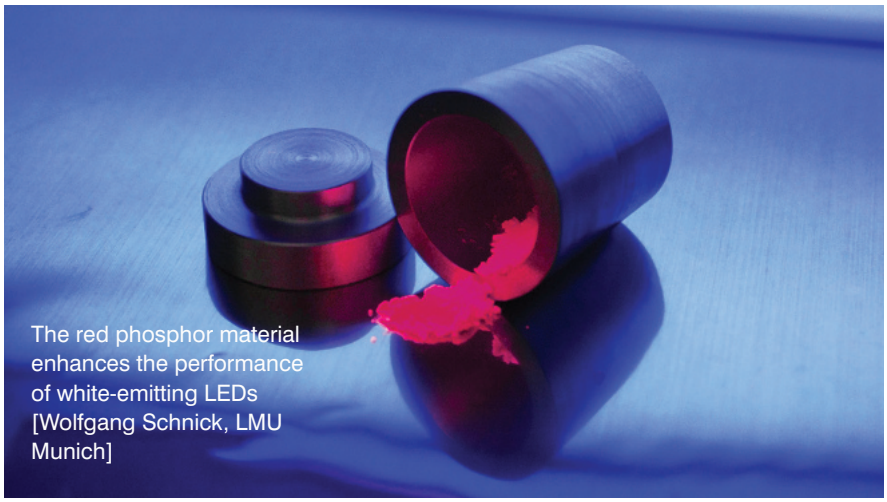
At around this time, Schnick and colleagues were experimenting with silicon nitride compounds. "I was deeply impressed by these nitrides. They were the structural ceramics of the 1980s and 1990s and were a highly stable material," he says. "So my dream was to use this binary compound as a parent compound, synthesise more complex structures and make a systematic study of these materials."

Which he did. Without any awareness of the needs of the lighting industry, Schnick and colleagues started adding europium, as well as strontium and barium to the basic compound, eventually forming $Sr_2Si_5N_8:Eu^{2+}$ now known as phosphor 258. In his words: "We found this beautiful, very strong and efficient luminescence."

Schnick published his results and within days had been contacted by Philips-Lumileds, where lead researcher, Peter Schmidt, had realised the potential of the new phosphor for LEDs. "He'd been screening literature for new host lattices, saw our spectroscopic results and immediately understood that this was exactly the material he had been looking for," adds Schnick.

Come 2007, phosphor-coated LEDs were in commercial production and today the devices can be found in: smartphones; automotive indicator lights; indoor, warm white lamps; and more. But still industry wasn't completely satisfied.

While the phosphor could be used with LEDs to create warm white light, it also emitted infrared radiation, or heat. Philips-Lumileds asked Schnick to look for a new LED phosphor that could produce white light from blue LEDs,



The red phosphor material enhances the performance of white-emitting LEDs [Wolfgang Schnick, LMU Munich]

minimizing the infrared; in other words, synthesise an efficient narrow-band, red-emitting phosphor. And so the search for new host lattices that could house europium and produce the necessary emission properties began.

Schnick moved away from silicon nitride compounds, and started looking at other nitride compounds. He had already synthesised narrow-band yellow-green emitting phosphors, and noted that the host lattices of these phosphors had highly symmetrical coordination around europium. So he and colleagues started synthesising compounds with similar lattice structures, replacing silicon with aluminium, lithium, magnesium and more. Their systematic studies eventually revealed a complex aluminium nitride as the most suitable binary compound, and in December 2012, the new phosphor – $Sr[LiAl_3N_4]:Eu^{2+}$ – was synthesised.

As Schnick explains, the building units within his final host lattice were highly cross-linked, yielding a highly stable, rigid structure, critical to narrow-band red emission.

"We always had this feeling, and there is also a lot of evidence, that if a network structure is open, and its chemical bonds are weak, the atoms within it will vibrate thermally and you just won't get narrow emission," he says. "But nitrides are highly cross-linked, stable and rigid. So when we doped this one with europium, the ions went straight to the strontium ion lattice sites giving a highly symmetric cuboid coordination within the rigid structure. And so we achieved narrow-band emission."

After more than a decade of collaboration Wolfgang Schnick and Peter Schmidt have delivered the the red phosphor that industry wants. [Deutscher zukunftspreis ansgar pudenz]

Crucially, the material system also lends itself to large-scale manufacture. According to Schnick, europium has been widely used as the red phosphor in television tubes so distribution chains are well developed. And while it is not the cheapest element in the world, and sourced from China, only micrograms will be used in each LED. "The price of europium will not influence the final entity," says Schnick.

Research has also demonstrated that altering the concentration of europium within the lattice does not significantly affect the emission peak wavelength, again, a bonus for mass manufacture. "When you synthesise the compound on an industrial scale, it is impossible to stir the material within a reactor so the concentration of europium is the same throughout," explains Schnick. "It is important that the emission properties only vary slightly with doping concentration; if these properties were to vary dramatically you could end up with different colour tones from LED to LED, and the lighting industry likes single LEDs to emit identically."

So given a research prototype has been demonstrated and manufacture supply chains are in place, when exactly will the world see the next generation of LEDs? Perhaps sooner than you might think. Researchers at the Lumileds Development Center, Aachen, are currently modifying the synthesis of the new red phosphor, ready for large-scale manufacture. Schnick is reluctant to provide details, but says: "We discovered that last [258] phosphor in 1997 and saw LEDs coated with this phosphor on the market in 2007."

"We then discovered this new phosphor in December 2012 and have quickly published the results," he adds. "I suspect that this will soon reach the market and will not take another five to ten years."

Keeping LEDs cool

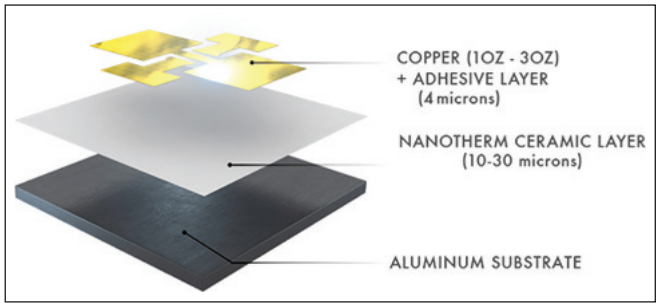
Claiming breakthrough performance with its metal-clad PCB substrates, Nanotherm, has already made inroads into LED markets, reports Rebecca Pool.

AS THE LED INDUSTRY SHIFTS to ever-higher brightness LEDs, the race is on to develop better thermal management strategies to dissipate heat. During LED operation a hefty 75 percent of applied electrical power is converted to waste heat, and be it by heatsink, heatpipe or cooling fan, how this heat is removed drastically affects LED performance and lifetime.

UK-based start-up, Nanotherm, claims to have the answer. Founded in 2010 by Pavel Shashkov and Segey Usov, former researchers at the Moscow State University, the company has developed a range of novel aluminium PCB substrates to act as heatsinks for electronics devices.

Currently targeting high performance LED markets, the substrates comprise an aluminium sheet, in which the surface – the top 10 to 30 microns – has been electrochemically converted to an alumina dielectric layer. A layer of copper is then epoxy-bonded or deposited to the dielectric layer, depending on customer budget, creating a circuit layer on the sheet, ready for PCB processing on industry-standard lines.

Shashkov and Usov claim their alumina dielectric layer provides excellent isolation with much improved thermal performance over the standard epoxies used as conventional dielectrics. The alumina layer is also up to ten times thinner than conventional epoxy layers and boasts a bulk thermal conductivity of 7 W m^{-1} K^{-1} whereas high thermal conductivity epoxies come in at some 3 W m^{-1} K^{-1}. And pleasingly for Nanotherm, its independent tests indicate the thermal resistance of the overall PCB substrates is 20 percent less than today's metal-backed PCBs, reducing LED operating temperatures by as much as 20 °C. As recently-appointed chief executive, Ralph Weir puts it: "I think this is a product that when engineers see it they say 'wow, I really love that'."



With a thin dielectric layer, Nanotherm materials have a short thermal path from the source – a semiconductor device soldered to the copper surface – to the heatsink. [Nanotherm]

Patented process

The key to success is the conversion of the metal surface to an extremely thin dielectric layer. This process has roots in so-called plasma electrolytic oxidation (PEO), an electrochemical process similar to anodising, and developed by Shashkov and Usov more than a decade ago, to harden metal alloys for engineering applications.

Like anodisation, metal alloys, such as magnesium and aluminium, are dipped into a liquid electrolyte with an electric potential than applied to form an oxide-based ceramic – magnesia and alumina – at the alloy surface. However, PEO employs higher potentials so voltage discharges occur with the resulting plasma modifying the structure of the oxide layer. For example, sequences of voltage pulses can alter the surface roughness and porosity of the coating to produce harder-wearing surfaces.

Shashkov and Usov spent the best part of the 1990s developing the hardness treatment, setting up Cambridge-based Keronite, in 2000, to exploit the technology. But while the treatment produces a hard-wearing, as well as thermally conductive and electrically insulating surface layer, porosity within this layer renders the treatment useless for electronic applications.

With this in mind, the pair went on to develop a new process that delivers an oxide ceramic surface layer comprising very densely-packed crystals with a lot less porosity, and launched Nanotherm in 2010. Details on how the surface layer is formed are scant although patent searches reveal a colloidal alkaline electrolyte is likely used, containing ceramic particles less than 100 nm in diameter.

Pavel Shashkov, CTO (left) and Ralph Weir, CEO: Nanotherm is now rolling out its heat dissipation materials high volumes to meet the growing needs of LED makers. [Nanotherm]

Meanwhile, the electrical treatment comprises a sequence of positive and negative voltage pulses to minimise micro-discharges during coat formation and better control porosity and surface roughness.

When asked about the process, Weir quips: "I wouldn't like to have to kill you", but confirms: "It is a heavily patented process, but the key is what's now in the electrolyte and the way the electrical power is applied; an enormous amount of control goes into this."

But while heavily under wraps, industry players have proven keen to trial the process. In response to supplier demand, the company recently set up its first production line in Cambridge, which according to Weir is 'ramping up nicely'. And plans are now underway to have two more lines up and running by mid-2015.

"We're already supplying to quite a number of people with a lot of our production going out to PCB processing companies that are then taking it out to the LED market," adds Weir.

For example, Nanotherm has forged a partnership with Scotland-based electronics packaging player, Optocap, already shipping orders to LED customers. And the company has also joined forces with PCB manufacturer, Spirit Circuits, UK, again to supply substrates to LED markets. Weir won't provide specifics on price, simply saying, 'we talk about being a Ferrari for the price of a Ford', but as he asserts: "Our partners say our substrates outperform any other aluminium boards by 25 to 35 percent."

"Also thermal PCB copper boards exist that are heavier and much more expensive than our substrates yet we can outperform these by 2 to 3 percent," he adds.

So where next for the UK-based start-up? According to Weir, while the company's next production line will service the LED industry, the company is also eyeing power electronics markets. "The reality is the lines can produce materials for either markets," he says.

What's more, the company is also developing substrates to rival high performance aluminium nitride ceramic tiles. As Weir explains, during fabrication of the company's 'entry-level' boards, a layer of copper is bonded to the dielectric layer using a 4 μm-thick layer of epoxy adhesive to create the circuit layer.

But the company is also using thin film deposition techniques to directly apply the copper circuit layer, producing a metal-backed PCB with performance to rival that of AlN tiles but at a lower cost.

"Partnerships with existing suppliers in the LED and power electronics packaging markets are key to us... and we will now scale the business up through such partnerships," he says. "We've got the production facilities to be a world player, so now it's all about that big scale up to reach the big volumes."

VCSELs:
Beyond Red

When it comes to VCSELs, GaAs is the leading light, but GaN and InP devices are now gaining market share, reports Rebecca Pool.

While high power vertical-cavity surface emitting lasers have been under development for more than fifteen years, only now is the technology truly set to rival alternative technologies in a range of applications.

GaAs VCSELs, emitting at 850 nm, have long-served as the workhorse of the data communications industry, providing optical data links for distances of a few hundred metres. But now the GaAs VCSEL as well as longer wavelength GaN and InP devices, are making in-roads into myriad applications with the global market set for double-digit growth.

A recent market forecast from BCC Research predicts VCSEL markets will be worth some $2.1 billion come 2018, representing a five-year compound annual growth rate of 33.1 percent.

Analogue broadband signal transmission and absorption spectroscopy market segments are predicted to each hit the highest CAGRs – just over 37 percent – while optical fibre data transmission is forecast to attain a 31.2 percent CAGR over the same five years.

For now the GaAs VCSEL is expected to remain dominant. BCC's 2012 figures reveal GaAs grabbed a little more than 80 percent of the VCSEL market, with InP taking 13 percent, GaN only 1 percent and other materials making up the remainder.

As BCC photonics analyst, Gaurav Bhushan, explains: "GaAs VCSELs are witnessing proliferating growth in advanced sensing applications that are anticipated to fuel the next wave of innovation in consumer products including tablets, cell phones and other handheld devices."

Gesture recognition with 3D sensing is a crucial and growing market for the technology. Earlier this year, IQE delivered the first 6-inch VCSEL epiwafers for high volume, low cost applications, citing gesture recognition for gaming and non-contact navigation in smartphones and tablets, as well as depth imaging for 3D vision in handsets as key markets.
In a gesture recognition system, light from an infrared source is passed through an optical element to spread the light into a light sheet, so sensors can capture depth information across, say, an entire room, by measuring light reflected from its objects.

Such a system demands high power and precision, which is where the VCSEL comes into its own. Distributed feedback lasers, for example, are relatively low power, so the gesture recognition system would require several of these edge emitters. Meanwhile the LED, while cheap, cannot be modulated quickly, limiting resolution and increasing power consumption.

In contrast GaAs VCSELs offer optical efficiency within a small footprint, and come at a low cost. "VCSELs have already replaced edge emitters and LEDs in lower power applications, thanks

to lower cost, beam quality and high reliability," says Gaurav.

Critically, all-vertical construction – VCSELs are top-side emitting – enables the use of existing semiconductor manufacturing infrastructure, keeping fabrication costs down. As Gaurav says: ""VCSELs are proposed to be ten times lower cost than edge emitters for these applications... due to chip-like manufacturing and simple packaging techniques."

Longer wavelengths

But it's no longer all about short-wavelength emission. According to Gaurav, blue and green VCSELs, based on InGaN, are beginning to fuel small photonics device markets, such as laser pico-projectors, and will find use in laser printers, high density and high speed optical discs as well as full colour displays.

"In the past, GaN-based LEDs and edge emitters have proved a great success," he says. "But with numerous advantages, such as lower manufacturing costs, single longitudinal mode emission, circular and low-divergence output beam, wafer-level testing, longer lifetime [and more], VCSELs have the edge."

Similarly InP-based VCSELs look set to, at long last, gain commercial recognition. While the first lasing operation of a VCSEL was demonstrated on InP-based materials as early as 1979, GaAs-based VCSELs soon reigned supreme.

Low gain, poor temperature performance and difficulties in fabricating a DBR to lattice match InP – to name but a few problems – stymied InP VCSEL development.

But while today's technologies still demand complex and expensive manufacturing processes, change is afoot with the development of so-called high contrast gratings; sub-wavelength gratings with a large refractive index contrast. These can be fabricated for a range of optical structures including broadband mirrors for InP VCSELs, making the technology viable as a tuneable light source in wavelength division multiplexing systems in fibre-to-the home and data centre applications.

"Due to very high manufacturing costs, the InP-based VCSEL has not impacted the market, and its market share is very low compared to GaAs-based VCSELs," he says.

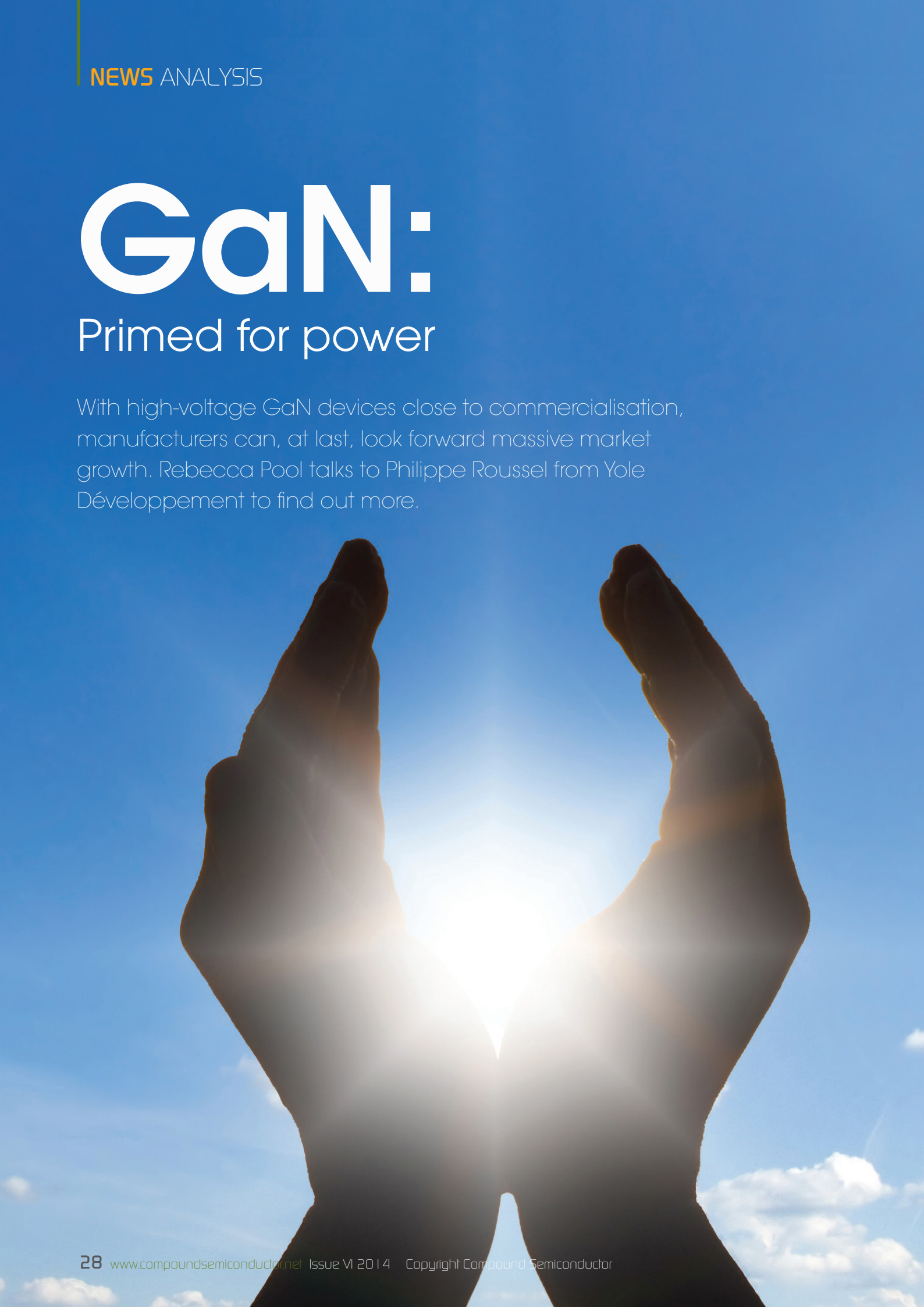
"But the introduction of high contrast gratings... means InP can now be used as an alternative and preferred material to GaAs."

Still, Gaurav is adamant GaAs will retain largest market share. "Designing a device structure that can be manufactured with as low cost as the 850 nm GaAs-based VCSELs is still a major challenge for the rest of the industry," he adds. "GaAs is expected to lead the market in the near future."

GaN:

Primed for power

With high-voltage GaN devices close to commercialisation, manufacturers can, at last, look forward massive market growth. Rebecca Pool talks to Philippe Roussel from Yole Développement to find out more.



After several false-starts, the GaN power electronics industry finally looks set to take-off. Latest reports from France-based semiconductor analysis business, Yole Développement, predict a hefty 80 percent CAGR for the market from 2016-2020.

As author, Philippe Roussel tells *Compound Semiconductor*: "We've lost two years. 600 V devices were supposed to be with us two years ago, but these were not ready. These devices do now exist, but most are under qualification for another year to a year-and-a-half."

In the meantime, 200 V GaN-on-silicon devices are seeing take-up in point of load applications, from servers and routers to switches and general-purpose point of load DC-DC converters. And as the likes of EPC and International Rectifier reap the first revenues from these devices, electric vehicle, motor drive and photovoltaic inverter manufacturers, to name but a few, are still holding out for the much-trumpeted 600 V GaN HEMT.

"There's been a lot of venture capital put into this technology, so maybe it had been a little over-promoted," says Roussel. "Today you cannot buy a 600 V GaN HEMT on Digi-Key or Mouser. You can get the devices if you are collaborating with the big manufacturers, but you and I cannot access them at the moment."

The analyst reckons the power supply and power factor correction sector will be the first major market for high voltage GaN devices, representing some 50 percent of device sales from 2015 to 2018. From here, electric vehicle makers are expected to start snapping up the devices, with manufacturers of PV inverters, wind turbines and rail traction systems close behind.

"Reverse costing simulations comparing silicon IGBT-based inverters with the same in GaN indicate come 2016, you can really make some savings with GaN at the system level," says Roussel. "Overall, 2020 could see an estimated device market size of almost $600 million, leading to approximately 580,000 six inch wafers to be processed."

Cost reductions come from the expected price erosion of GaN devices as market take-up increases, with savings on passive cooling, thanks to GaN's faster switching, also playing a key role. Factor in incremental improvements in conversion efficiency, and Roussel expects to see payback times of less than a year.

"So, from 2016, it seems all the necessary technical and economic parameters are in place," he adds.

Rival technologies

But 600 V GaN-on-silicon devices are not the only viable high performance technology for power electronics applications. The PV inverter sector has already adopted the SiC MOSFET with many products commercially available. According to Roussel, this qualified flavour of transistor, represents GaN-on-silicon's biggest threat.

"The main interest for the SiC MOSFET has been its chip to chip replacement. It's a normally-off device, like the silicon IGBT, so you just remove your IGBT, recompute your driver a little, and put in your SiC MOSFET," he says.

In contrast, the HEMT is traditionally a normally-on device that can be turned off by applying a negative gate bias voltage, but this is a challenge to apply in typical power electronic circuit topologies, demanding different drivers and a system re-design. So, to rival the manufacturers of normally-off SiC MOSFETs, GaN players have developed and are now promoting the enhancement-mode HEMT.

Here, the design of the GaN HEMT is altered to shift the gate threshold voltage from negative to positive, yielding a normally-off E-mode devices. These HEMTs are already available up to 200 V, and 600 V will follow.

"The price also needs to be lower to give the same overall [system] cost as SiC MOSFETs," says Roussel. "But to my knowledge, PV inverter manufacturers are technology-agnostic; if they can find the same cheaper, they will buy it."

The analyst reckons GaN device makers will also have to work on their supply chains. SiC devices are qualified and available from multiple sources of supply, while GaN supply is less established.

"We see a lot of announcements from International Rectifier, Transphorm and so on, claiming to have 600 V normally-off GaN, but will these manufacturers all be ready at the same time, supplying roughly the same product with the same specification so you can easily switch from one to the other?" he asks. "We don't know yet, it's too early to say."

But what isn't too early to predict, is the inevitable industry consolidation. Late last year, Japan-based Fujitsu – the world's third-largest IT services provider – scooped up GaN power device manufacturer, Transphorm, so together the companies could drive high-volume, high-performance GaN device production forward.

Roussel describes this as a 'smart approach' for both and expects more of the same. Highlighting start-ups such as China-based CorEnergy, ExaGaN, France, Dynax Semiconductor and Avogy, both in the US, he says: "These have totally different business models and are fabless or fab-lite. [Such companies] have to find a larger manufacturer."

"Licensing technologies is the natural evolution of this business," he adds. "There are tonnes of GaN HEMTs to be produced and this isn't compatible with the small start-up. I am not sure all these companies will remain in the next two or three years; the assumption is they will be absorbed."

Q&A

Hermann Waltl

EV Groups' Executive Sales and Customer Support Director offers insights into the evolving LED industry

Q Describe the state of the LED industry?

A The LED industry is still feeling the effects of overcapacity and this has led to increased industry consolidation. However, we expect to see growth driven by demand for LEDs in general lighting applications. The pressure is on to drive down manufacturing costs to a price point that will enable consumer adoption. New developments including larger-diameter substrates and more automated processes to increase manufacturing efficiency and yields, and new substrate technologies like silicon that can help reduce production costs.

Q You offer tools for wafer bonding and the creation of photonic structures. How much are these technologies appearing in today's LEDs?

A Our wafer bonding solutions enable vertical LED architectures and the integration of metallic mirror layers, while lithography products create photonic structures in the form of patterned sapphire substrates to increase light extraction. Some of these features appear in any high-brightness LED product, while other features will gain traction within a few product generations. Currently several EVG720 UV-Nanoimprint Lithography systems utilizing our next-generation SmartNIL process have been installed, evaluated and accepted at customer sites.

Q Inserting photonic structures boosts LED efficiency, but adds to fabrication costs. Is it worth it?

A LED technology is ideal for next-generation lighting due to its ability to reduce energy consumption but improvements in efficiency are needed for LEDs to be feasible. Adding photonic structures to LEDs by patterning the bare surface of sapphire substrates is one option. While this adds to the process, the outcome is greater LED lighting efficiency, which is getting harder to extract from improvements in the epitaxial growth process.

Q You produce tools based on optical and imprint technologies for the production of photonic structures. What are the pros and cons of both approaches?

A The LED industry uses our mask aligners for all generic patterning needs. For small features – below 3 μm – EVG offers projection (PHABLE) and imprint lithography (SmartNIL). The PHABLE technology, which has been licensed from Eulitha, is suited to low-cost high-volume manufacturing of growth substrates, such as patterned sapphire. SmartNIL provides design freedom for complex photonic features, which are attractive for enhancing light extraction and colour management in innovative LED architectures. SmartNIL enabled lithography systems support feature sizes down to 40 nm.

Q What new tools are you developing?

A We recently introduced our next generation nanoimprint solution, the EVG720, which supports EVG's SmartNIL process, and PHABLE exposure system—both of which can be used for manufacturing photonic components that help increase the efficiency of LEDs.

Q Setting aside the LED business, what do you see as the most exciting market for your tools?

A The industry is undergoing change as well as double-digit growth rates across key sectors. From new advances in silicon photonics to support higher data transfer rates in telecommunications, high-mobility transistors for mobile phones or satellite television broadcasting, high-performance/low-power logic devices for portable electronics, novel RF devices or high-power LEDs, heterogeneous integration is critical to achieving new breakthroughs in device performance. Wafer bonding is an essential process for enabling the integration of compound semiconductor and engineered materials with dissimilar properties.

Last year EV Group announced that we are developing equipment and process technology to enable electrically conductive, covalent bonds of compound semiconductors, other advanced engineered substrates and dissimilar, heterogeneous materials at low temperature for applications such as silicon photonics, power device manufacturing, MEMS and solar. At SEMICON Europa we are launching our first ComBond equipment platform for these applications.

Q Where will the most significant growth occur in the company?

A When one looks at the rise of companies built on the collection and analysis of information to provide value-added services, such as Google, Facebook, Amazon and Apple, as well as the billions of connected devices in the world and the drive for improvements in health care, energy efficiency, transportation and other areas, it's clear that we are in the era of Big Data and Internet of Things. Sensors are an essential element to gathering the vast volumes of data needed for emerging applications in these areas, while silicon photonics are expected to play a vital role in transmitting the huge amounts of data generated by the sensors at very high speeds and at low power.

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KEYNOTE	Presentation TBC **Jon Wierer** - Sandia National Laboratories
ANALYST	How will the solid-state lighting evolution unfold, and what will it mean for the LED chipmakers? **Stewart Shinkwin** - IHS Technology
SPEAKER	Commercialising the GaN-on-silicon LED and ramping its production **Keith Strickland** - Plessey Semi

FRONT-END MOBILES

KEYNOTE	How a CMOS front-end will wrestle share from the GaAs PA **Jim Cable** - Peregrine
ANALYST	Are we shooting ourselves in the foot with the multi – mode, multi – band PA? **Eric Higham** - Strategy Analytics
SPEAKER	Skyworks' system level integration and overall efficiency roadmap **Dr. Peter Gammel** - Skyworks Inc.
SPEAKER	LTE is driving complexity in smartphone design **TBC** - TriQuint

III-V CMOS

KEYNOTE	Heterogeneous integration of III-V's and CMOS **Daniel Green** - DARPA
ANALYST	When will III-Vs make an impact in the silicon foundries? And will it last for long? **Mike Corbett** - Linx Consulting
SPEAKER	III-V FETs for future logic applications **Jesus A del Alamo** - MIT
SPEAKER	Opportunities and challenges of III-Vs in Si-based nanoelectronics industry **Matthias Passlack** - Taiwan Semiconductor Manufacturing Company (TSMC)

POWER ELECTRONICS

KEYNOTE	Ditching the package to drive down GaN transistor costs **Alex Lidow** - Efficient Power Conversion (EPC)
ANALYST	When can WBG power electronics truly take off? Remaining technical and economic barriers to overcome **Philippe Roussel** - Yole Développement
SPEAKER	SiC Advances for Power Electronic Applications **Markus Behet** - Dow Corning Corporation
SPEAKER	High Performance GaN-on-Si Power Epiwafers Employing Rare Earth Oxide Buffer Layers **David Williams** - Translucent

OPTOELECTRONICS

KEYNOTE	Topic TBC **TBC** - SOITEC
ANALYST	Where the CPV industry is heading, and what it needs to do to increase its market share? **Karl Melkonyan** - IHS Technology
SPEAKER	Mid infrared light emitting diodes enable portable, battery powered gas sensing **Des Gibson** - Gas Sensing Solution

RF-ELECTRONICS

KEYNOTE	GaN for radar applications **Takahisa Kawai** - SEDI (Sumitomo Electric Device Innovations, Inc.)
ANALYST	The Future for GaN, SiC, InP and GaAs in Defense/Military Applications **Asif Anwar** - Strategy Analytics

The maturing MOSFET

Sales of SiC MOSFETs are rising on the back of falling prices, expanding product portfolios and the entrance of new chipmakers into the market

RICHARD STEVENSON REPORTS

DIODES AND TRANSISTORS are two of the key building blocks in many circuits. Diodes are used to control the direction of the current, while transistors act as switches, turning the flow of charge on and off.

Circuits incorporating diodes and transistors may be used to power motors, drive electrical equipment and convert the output from a solar cell into a form that can be fed into the grid. In all these cases, increases in circuit's operating efficiency are highly valued, because they trim carbon footprints.

To increase circuit efficiency, designers are replacing silicon components with those made from SiC. Switching to the wide bandgap alternatives slashes recovery times, which means that the devices cannot only turn on and off more efficiently – they can be deployed in circuits operating at far higher frequencies. Going up in frequency allows a trimming of the size of the capacitors and inductors, leading to savings at the system level, thanks to a reduction in the size and weight of the circuit. What's more, SiC devices have a far higher maximum operating temperature than their silicon equivalents, so cooling demands are far, far lower.

Since 2001, circuit designers have been inserting diodes made from SiC. But only more recently have they been able to use them alongside SiC transistors, and start to exploit all the benefits associated with this wide bandgap technology.

Waiting for the MOSFET

Designers had to wait until 2008 for the first SiC transistor to hit the market: a SiC JFET from the now defunct SemiSouth. But this class of transistor, along with several other forms of device, such as the BGT and BJT, has not been that successful. Why? Because they are not drop-in replacements for the silicon IGBT. Instead, they have to be paired with another device to be converted from a normally on to normally off transistor, and this transformation adds to cost and size while impairing efficiency.

One device that doesn't suffer the same fate is the SiC MOSFET. Due to this, market analyst Philippe Roussel from Yole Développement is tipping this particular transistor to lead the way. "To me it's logical and obvious that the MOSFET is the perfect solution," says Roussel.

The first to go to market with this form of SiC transistor was the US chipmakers Cree, which launched a 1200 V MOSFET in May 2011.

"We got lots and lots of interest and shipped a lot of parts," recollects John Palmer, co-founder of the company and chief technology officer for firm's Power and RF business units. "[The SiC MOSFETs] did everything that people thought they would," says Palmer, who points out that the only major downside was their price.

In the intervening years Cree has worked hard to address this weakness. Costs have fallen, partly through increases in yield, and also via a reduction in chip sizes while maintaining current ratings.

Succeeding on these fronts has helped Cree to maintain its pole position in the SiC MOSFET market. Competition initially came from Rohm of Japan, but in the last few years the likes of Microsemi and Mitsubishi have launched rival products.

Electric and hybrid electric vehicles are markets that could lead to surging sales of SiC MOSFETs.

A Cree fabrication engineer removes a 100 mm SiC wafer from a spin rinse dryer, which is a fabrication tool used to clean the SiC wafer as part of the fabrication process used to make SiC MOSFETs.

Expanding Cree's portfolio

One move that Cree has made to increase the competiveness of its MOSFETs is to broaden its portfolio, by offering different products with different current ratings. This approach, which is one that makers of silicon IGBTs and MOSFETs have taken for many years, means that customers don't have to buy a bigger, more expensive chip when a smaller one with a lower current rating will suffice.

"There is no point in making [customers] pay more – that only hurts both of us," argues Palmer. He points out that if prices are too high, customers will not buy these parts, and that is detrimental to the adoption of the company's SiC MOSFETs.

Expansion of the Cree portfolio has not included the launch of a 600 V SiC MOSFET to complement its 600 V SiC Schottky barrier diode. The reason is the competition from silicon: 600 V diodes are bipolar, so inherently slow, whereas 600 V transistors can be unipolar, super-junction MOSFETs. "They are quite fast," admits Palmer. "That does not mean that SiC could outperform it, because our capacitances would be far lower. But we choose to take on bipolar devices at higher voltages."

Going up in voltage makes a lot of sense. The recovery losses for SiC are one-fifth of those for silicon at 1200 V, but just one-tenth at 1.7 kV, and one-thirtieth at 3.3 kV. To allow customers to benefit from this superiority at higher voltages, Cree launched a 1.7 kV device in 2012.

Cutting costs

In 2013, Cree took a tremendous stride in increasing the affordability of its MOSFET line up by launching a range of second-generation devices that roughly halved the cost-per-amp. By reducing resistances, such as trimming the specific on-resistance from 8 mΩ cm^{-2} to about 5 mΩ cm^{-2}, engineers were able to maintain current ratings while shrinking die size. In turn, this led to an increase in yield, further trimming production costs.

Circuit designers are embracing the new products. "Gen II is now the majority of MOSFET sales," says Palmer. "We've had a very good adoption rate there."

One reason for this is that these second-generation devices can lead to costs savings. "Even though the component cost is higher than silicon, it saves money at the system level," says Palmer.

This is the case in solar inverters, a market where Cree is seeing a lot of activity. The company's 1200 V MOSFET is now being deployed in Delta Energy Systems' 11 kW PV inverter.

"Another area where we have had a lot of success is industrial high-frequency power supplies," says Palmer. These units, which are being deployed in semiconductor processing equipment, enable an increase in the power from a rack-mounted power supply. "You can double the amount of power they get out of the same sized box."

Expansion of the family of Cree's second-generation products continues. "We recently announced a 50 A packaged discrete: That's a lot of juice for a discrete package, and we've had a lot of interest in that," reveals Palmer.

Within the research and development group, efforts are focused on generation III products, which continue the die shrink approach applied during the move from generation I to generation II.

At a recent conference, Palmer presented results for generation III products that can operate at 900 V, 1200 V, 1700 V, 3.3 kV, 6.5 kV, 10 kV and 15 kV. "So we've done it across the board, and the question is what the first product will be," says Palmer. "We'll have to wait and see, but I would not expect it to be that long – I would expect that somewhere in 2015 we'd see a gen III product announced."

Although the number of suppliers of SiC MOSFETs is on the rise, Palmer still sees silicon as the main competitor for chip sales. "It's not all done in silicon. There is still room to improve, and it has a thirty year head-start on us."

Left: European power electronics giant ST Microelectronics is launching a 1200V SiC MOSFET this autumn.

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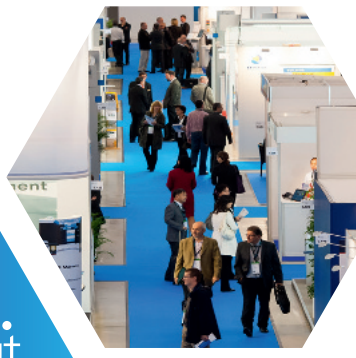

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Right now, the number of SiC MOSFET suppliers is set to increase, with one of the biggest manufacturers of power transistors, ST Microelectronics, launching a 1200 V, 45 A device.

"We are using all of the skills we've assembled – manufacturing, design, service, supply chain – to become a leader also in wide bandgap technologies," claims Michele Macauda, SiC and GaN Marketing Manager at STMicroelectronics.

According to him, many customers that buy SiC Schottky diodes from them have been asking the company for SiC MOSFETs. ST has taken some time to answer this call by ensuring that the new transistor delivers industry-leading reliability and quality. Guide price for the MOSFET, which is housed in a proprietary package optimised for high thermal performance, is $35 when shipped in quantities of 1000 or more.

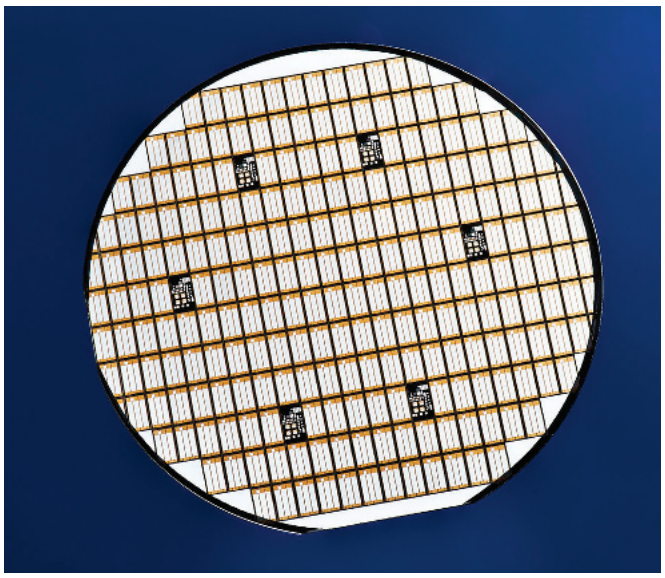
"We are working with our key customers and partners to ensure that we are competitive," says Macauda. "As is the history of the semiconductor industry, prices will likely come down in the coming years."

Plans for the company include expanding the MOSFET range by introducing devices with higher and lower current ratings, and higher blocking voltages. "We also plan to offer different package options," adds Macauda, who expects the majority of transistors to be initially deployed in solar invertors. Further ahead, makers of products for hybrid electric and electric vehicles should account for the lion's share of sales.

Competition in Japan

The pioneer of SiC MOSFETs in Japan is Rohm, but in the last few years Mitsubishi Electric has also launched products. In July 2012 Mitsubishi started shipping samples of SiC power modules, and in 2013 it followed this up with the launch of modules for home appliances, industrial equipment and rail traction systems, and this year it added modules for high-frequency switching applications.

Mitsubishi's recently launched traction inverter system, which features SiC diodes and transistors, has a switching loss approximately 55 percent less than its conventional inverter system incorporating IGBTs power modules.



A Cree wafer containing 50 A SiC MOSFET die.

"We have in-house customers in various applications fields, like traction, home electronics and industry," explained a spokesperson on behalf on Mitsubishi. "We believe that we can enhance competitive advantage by providing devices to in-house customers and getting detailed feedback from them."

To increase market share for SiC MOSFETs, those at Mitsubishi believe that SiC substrates must fall in price and their procurement must be more stable.

Meanwhile, Roussel argues that the increased number of suppliers could help all of these firms: "With the JFET there are only two sources, whereas with the MOSFET there are various sources. Multi-sourcing is something that is key for the system integrators."

The French analyst does not calculate a figure for the SiC MOSFET market, but he has determined a value for the SiC power electronics market, which is a mixture of die, discretes and modules – and he estimates that two-thirds of this is related to the MOSFET, with the remainder associated with Schottky barrier diodes.

"Today, the overall market [for SiC power devices] will be $115-120 million, and the market size will probably range from $500-600 million in 2020." When looking that far ahead, there are uncertainties, with market growth relying on the deployment of SiC devices in electric and hybrid electric vehicles. Recently, it appears that makers of these types of vehicles may be pushing out deployment of wide bandgap devices until the next decade.

That's not good news for the MOSFET, but even so, shipments of this device will still rise at a healthy rate over the coming years.

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ENVELOPE TRACKING and the future of the CMOS PA

With envelope tracking enhancing the efficiency of CMOS PAs to the levels of their GaAs cousins, is the incumbent technology under threat?

BY JEREMY HENDY FROM NUJIRA

RECENTLY, much has been made of the prospect of increased competition for traditional GaAs PAs from CMOS alternatives. Interest in this has been piqued by the release of products such as the Qualcomm RF360, which unites a universal PA, switch and antenna in a single front-end solution.

However, although launches of products such as this have helped CMOS to make significant inroads into the cost-sensitive GSM GPRS and 3G markets, GaAs continues to dominate the mobile marketplace – more than 90 percent of new smartphones are built with GaAs PAs.

Whether GaAs will continue to dominate is a hot topic of discussion. One view that is being widely expressed is that the evolving market offers an opportunity for CMOS PAs to 'kick GaAs', but the fact remains that the CMOS PA must overcome some technical challenges before it will undergo widespread deployment within the handset space.

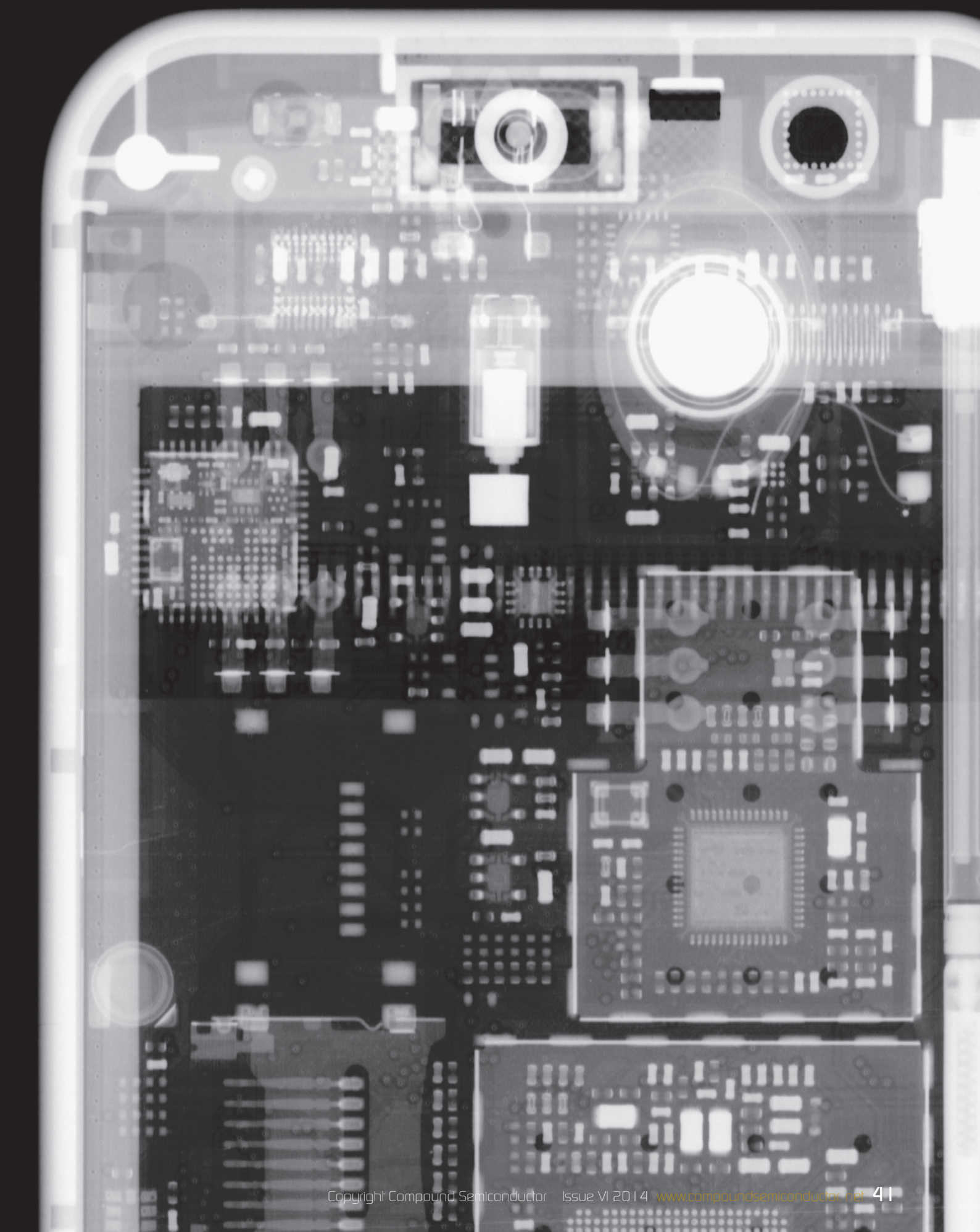
At the forefront of these is the fact that – despite success in the 2G market and some low-end 3G applications – significant performance drawbacks continue to limit deployment of CMOS PAs within high-end 3G and LTE applications.

Falling at the first hurdle

Drawbacks associated with the CMOS PA include an inferior device gain, lower breakdown voltage, and challenges with RF simulation models. On top of this, CMOS designs have tended to be larger – roughly three times the size of a comparable GaAs die – due to their heavy use of inductors and transmission lines. However, these concerns, although important, are overshadowed by the biggest flaw of the CMOS PA: Its poor inherent linearity.

One of the merits of the GaAs amplifier is its flat gain characteristic until relatively close to its point of saturation; here the gain response rapidly falls off in the space of 2 dB (see Figure 1). By contrast, for CMOS, the PA curve is non-linear over a wide range of output powers, with a 'soggy' compression characteristic stretching over the top 10 dB of the power range.

This lack of linearity is particularly problematic when a PA is used to provide coverage of 4G networks, which employ high Peak-to-Average Power Ratios (PAPR). Both classes of PA are capable of producing high enough peak powers to satisfy the requirement for high power constant envelope signals, such as GSM or simple 3G; but, for linear signals, such as



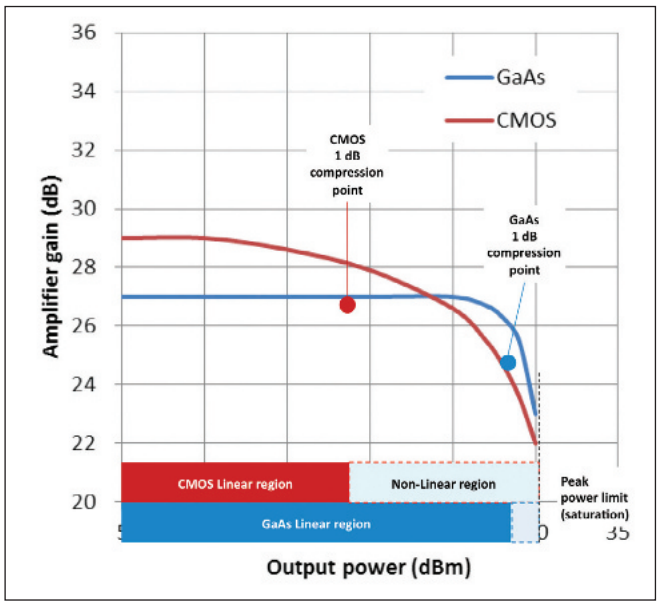


Figure 1. Power amplifiers built from GaAs deliver a linear gain over a wide range, while those based on silicon are significantly non-linear.

4G LTE, the CMOS device would need to be backed off to a low power, where the characteristic is relatively linear. This approach is highly undesirable, because it results in extremely poor efficiency.

Looking at the positives

Given these performance issues, why are CMOS PAs even under consideration for 4G handsets? Well, while GaAs is broadly synonymous with both RF design and HBTs, CMOS brings a number of attractive attributes to the PA marketplace.

One of the benefits of switching to silicon is lower production costs. While CMOS development costs can be higher at the product level, in large volume production the wafer costs for base CMOS are not just lower than GaAs – they are also undergoing a continual decline. What's more, working with CMOS technology opens the door to partnering with a wide choice of foundries that are capable of producing chips in far larger quantities; this, in turn, can help handset manufacturers regain control over their supply chains.

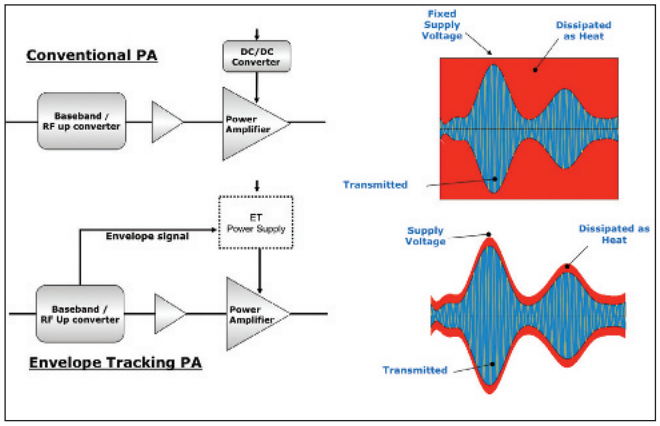


Figure 2. Envelope tracking leads to far more efficient operation of a PA, because the supply voltage is varied to give exactly what is needed at every moment in time.

From a design perspective, the most attractive attribute of turning to CMOS is that it unlocks additional levels of integration. As a result, non-PA components, such as controllers, antenna switches and tuners, can all be readily integrated within the PA. Similarly, CMOS also offers the integration of on-chip calibration, plus performance enhancing functionality, such as complex bias circuitry.

What's needed is a way to draw on these benefits, while not suffering from the consequences of the inherent non-linearity of CMOS, which makes it very challenging for this technology to play a role in the 4G marketplace.

Fortunately, this is possible by turning to external performance enhancement technologies that allow silicon CMOS PAs to compete with their GaAs cousins. At Nujira of Cambridge, UK, we have employed a technology that can do just that: Envelope Tracking (ET).

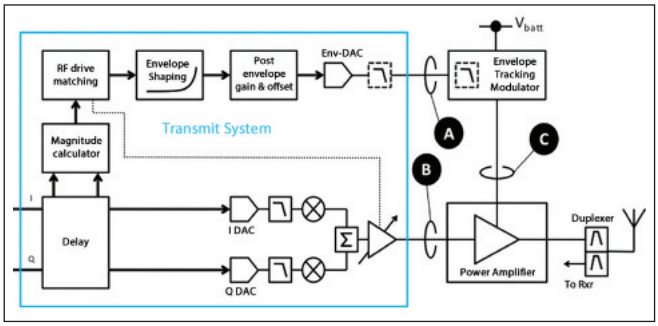


Figure 3.Envelope Tracking signal processing chain (courtesy of OpenET Alliance)

The primary benefit of ET is the hike it gives to the energy efficiency of a RF PA. This improvement results from the replacement of a traditional DC:DC converter with a highly agile, ET power supply modulator. Thanks to this modification, at any instant in time the PA is operating in a highly efficient compressed state, where the power supply voltage is just sufficient to enable the PA to transmit the instantaneous output power required (see Figure 2).

To do this, the ET power supply modulator has to dynamically modulate the power supply pin of the RF PA with a high bandwidth, low-noise waveform, synchronised to the instantaneous envelope (amplitude) of the signal being transmitted.

A key feature of ET systems is the digital control of the mapping of the instantaneous RF signal amplitude to the supply voltage using a programmable Shaping Table (see

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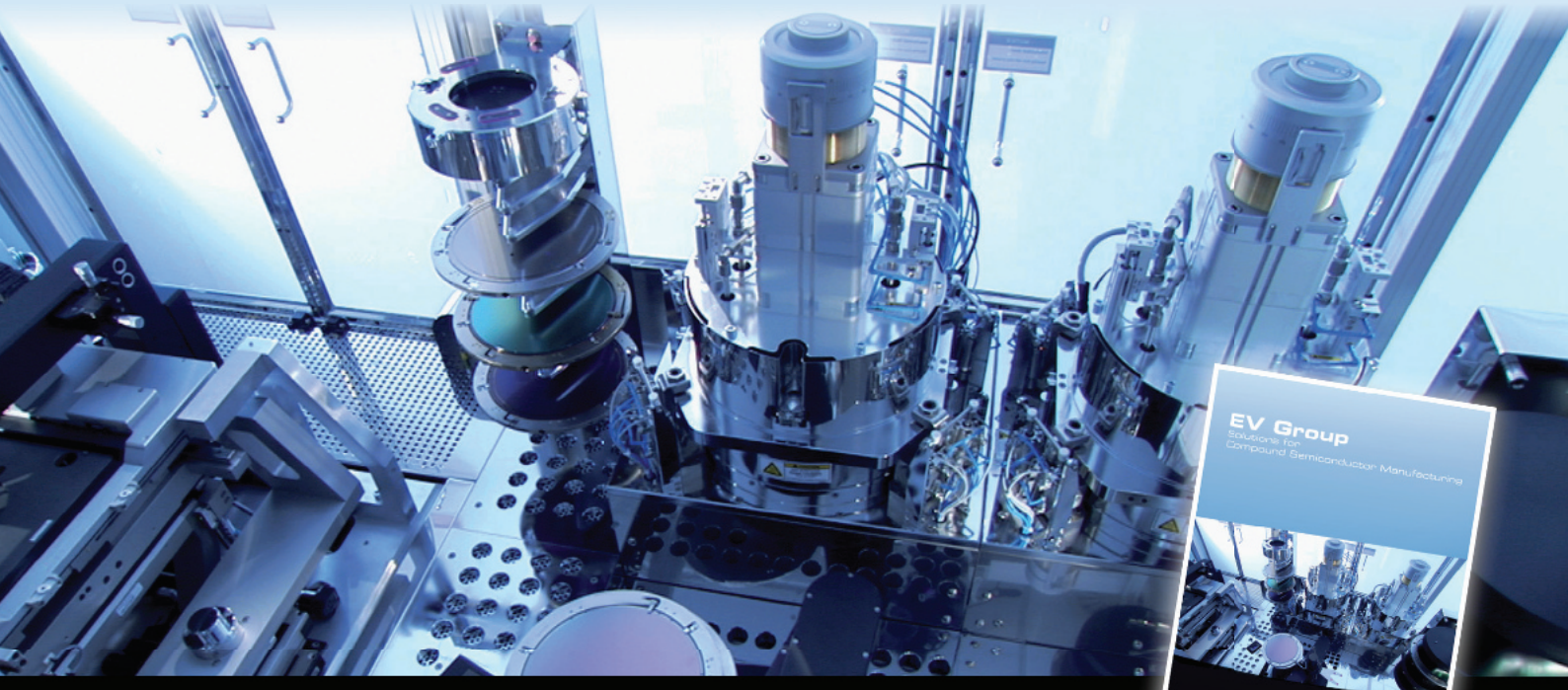

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> The very impressive performance gains resulting from the addition of ET will help to unlock an entirely new avenue for smartphone manufacturers and for future developments within the RF front-end. Now that CMOS PAs are demonstrating the capabilities to serve high-end 3G and 4G applications, the time has come when smartphone developers can start to explore the full benefits of an integrated CMOS system.

Figure 3). By defining amplifier behaviour with a digital look-up table, it is possible to optimise PA performance dynamically using software control. Thanks to this ET approach, non-linear devices are linearised with no computational overhead. When ET tracking, including the use of an IsoGain shaping table, is applied to a CMOS PA, this amplifier can be linearised to such an extent that it can meet both the stringent in-band performance requirements, such as error vector magnitude, and thetough out-of-band specifications, such as adjacent channel interference.

What is not clear, however, is whether the boost in linearity generated by ET is sufficient to enable CMOS to match – or exceed – the performance of traditional GaAs PAs. To answer that question, we have recently performed a series of measurements.

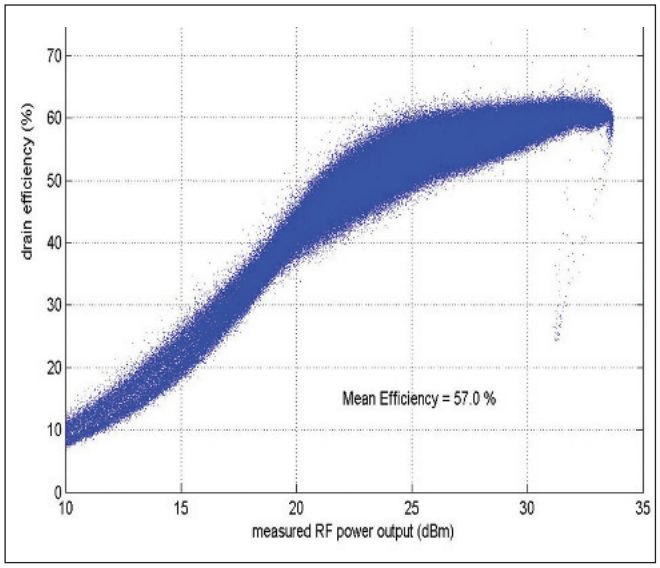


Figure 4. The measured efficiency plot of CMOS PA from dynamic supply measurements. Note that each point on this curve represents a measurement of instantaneous efficiency captured at around 100 MSPS under dynamic ET supply conditions using an LTE waveform.

Assessing performance

To test the viability of CMOS for 4G waveforms, our team of engineers connected a prototype CMOS PA operating in the 700 MHz band (Band 13) to our ET modulator. By characterising the PA with our ET Surface Explorer toolset, we generated an IsoGain shaping table.

Efficiency measurements involved using a high-performance current probe to sample the instantaneous PA supply voltage and current. Armed with this information, the instantaneous power being supplied from the high bandwidth ET supply can be calculated.

We also sampled the RF output power at high bandwidth, which enabled calculations of the collector efficiency (see Figure 4). These measurements revealed an average PA efficiency of 57 percent. This is a significant increase over a traditional GaAs PA without ET, where an efficiency of 30-35 percent would be expected for the same waveform.

To assess the maximum linear power that could be achieved using IsoGain ET, compared to a fixed 3.4 V DC supply voltage, we fed the amplifier with a variety of different waveforms (note that for both forms of power supply, conditions were ACLR compliant at -38 dBc).

These measurements revealed that the output power of the CMOS device quadrupled when driven with ET (see Figure 5). Meanwhile, when driven with a fixed supply voltage, the PA suffered significant nonlinearity with high PAPR waveforms such as LTE QAM.

Improvements in the linearity of a PA that is powered with a fixed voltage are possible by optimising the bias settings of the device (see Figure 6). However, even then the results are inferior to those produced with ET IsoGain, which delivers twice the output power.

Historically, ET has been viewed as an energy saving technology, and in our hands it can realise this. However, the main strengths of our patented IsoGain technology are the

enhancement of the performance of a CMOS PA so that it delivers the same output power, linearity and efficiency as any GaAs PA – even for LTE signals with high dynamic range.

The very impressive performance gains resulting from the addition of ET will help to unlock an entirely new avenue for smartphone manufacturers and for future developments within the RF front-end. Now that CMOS PAs are demonstrating the capabilities to serve high-end 3G and 4G applications, the time has come when smartphone developers can start to explore the full benefits of an integrated CMOS system.

These developers may seek to improve upon GaAs PA modules that already include multiple GaAs die and a separate CMOS controller die, because it is difficult to integrate the complex bias generation and digital control circuits onto a GaAs die.

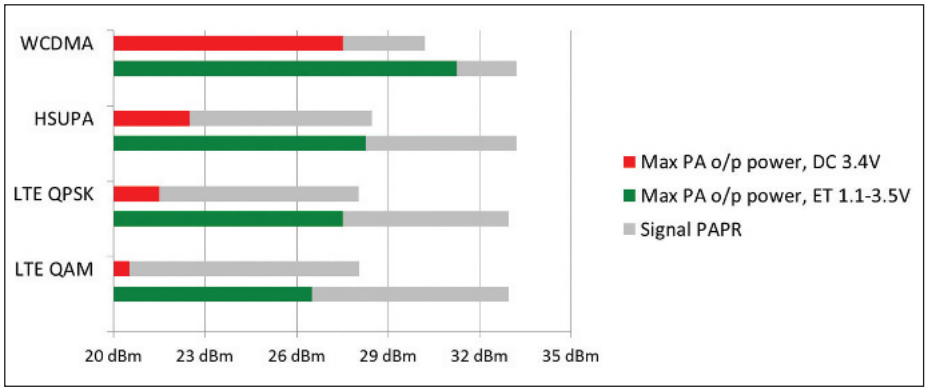


Figure 5. Values for maximum linear power at -38dB ACLR: initial bias settings. These measurements reveal that the output rises by 6 dB, or fourfold, with the introduction of ET.

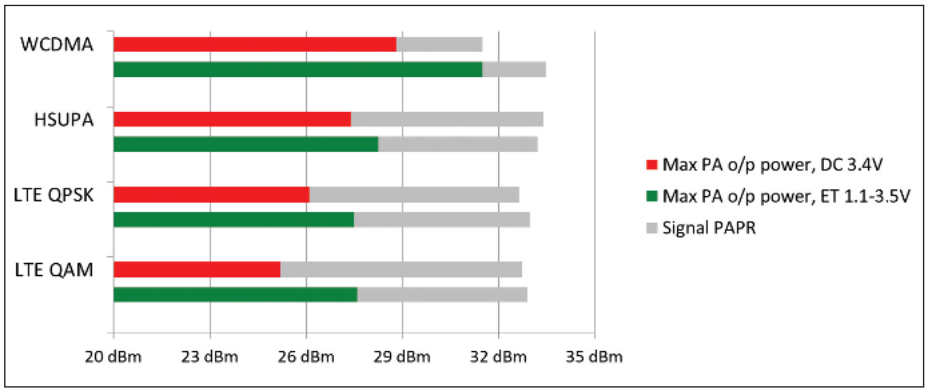


Figure 6. Maximum linear power at -38dB ACLR: optimised bias settings.

Turning to a CMOS PAs could integrate these functions into a single chip, while delivering two substantial benefits: the use of simpler, lower-cost packaging such as flip-chip onto FR4 substrates; and the elimination of the 'rats nest' of bond wires found within today's GaAs PA modules.

Integrating ET power supply modulators with CMOS PAs is relatively straightforward, because they have similar process requirements to those of a CMOS PA, and are today built on compatible CMOS process platforms. If further integration of ET power supplies with CMOS PAs takes place, mobile developers can benefit from reduced system cost and higher performance, opening up intriguing possibilities for the next-generation of smartphone products.

Making such a move should be an attractive option for the market leading suppliers of mobile phone modems and application processors, because they are all large, fabless CMOS vendors, with well-established foundry and supply chain relationships and significant buying power.

These firms may take the view that as the value of the RF front-end increases, the potential to absorb the PA into CMOS, and therefore make it an integral part of the smartphone chipset, offers some potential for significant revenue growth,improved multi-sourcing ability, and greater supply chain control.

A middle ground?

While it's easy to see ET and CMOS as a 'dream team' solution for the future of the RF front-end, the truth remains that GaAs continues to dominate 90 percent of the PA market. That's for good reason: GaAs is a well-established technology, and fundamental performance characteristics of PAs built with this material will continue to be advantageous in many applications.

However, ET is undoubtedly closing the 'performance gap' between the GaAs PA and its CMOS cousin. With new CMOS PAs coming to the market, such as Peregrine's Global1 device announced earlier this year, there is potential for even greater performance gains.

When provided with a more equal playing field, in the short term the choice between CMOS and GaAs PAs will probably come down to the individual purchaser. Regardless of where CMOS PAs eventually find their place though, it is clear that ET will play a lead role in getting there.

With almost all PA suppliers and handset OEMs investigating this performance-enhancing technology, the question is no longer if ET it will impact the PA market, but when.

Building better RF front-ends with UltraCMOS technology

When it comes to efficient delivery of power to the antenna, UltraCMOS technology is now outperforming GaAs

BY DUNCAN PILGRIM FROM PEREGRINE SEMICONDUCTOR

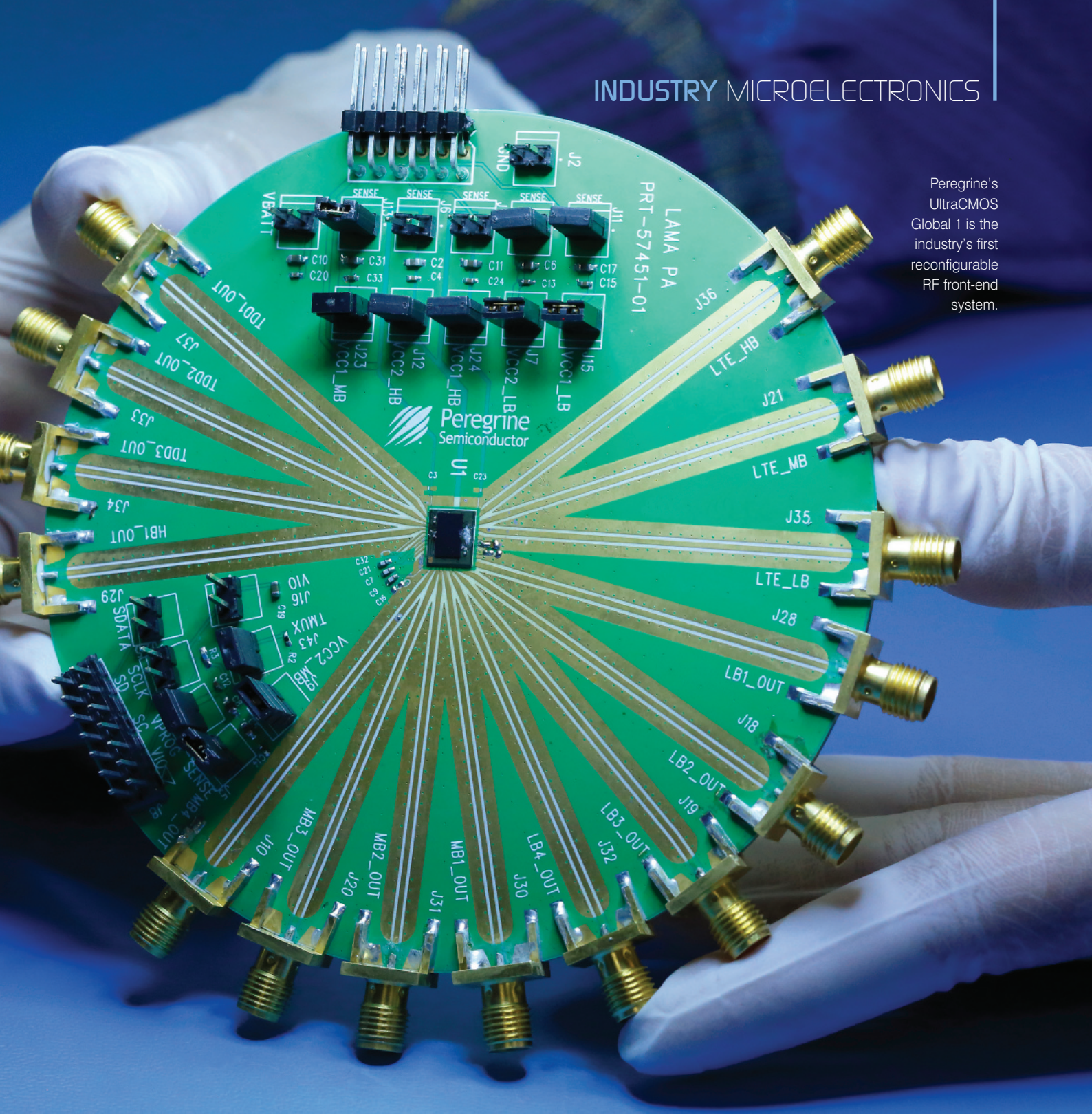
IN TODAY'S TYPICAL LTE-CAPABLE MOBILE HANDSET, the incredibly complex RF front-end is long overdue for rationalisation. To blame is the multi-die, multiple-technology approach that can be – and demonstrably, has been – made to work to an acceptable level of performance. What's needed is a new approach that can trim the costs associated with such a diverse bill-of-materials, and with the complexities of manufacturing and testing the air-interface.

The way to address this, as is invariably the case with semiconductor technology, is to move to further integration. Currently, a typical handset is packed with ICs from a range of different vendors, each sporting different technologies. One of the key elements – the stand-out item, it might be said – that lies in the way of fully integrating the RF front-end is the status-quo of the GaAs-based PA.

This amplifier has been refined as mobile wireless standards have evolved. There has been a rapid growth of spectrum allocations over time, and that has brought us to the present state-of-the-art loosely termed '4G'. Now there are over 40 distinct frequency bands throughout the world, and that is just one aspect of a multi-dimensional array of variables. There are also differences in modulation schemes, operating modes for the PA, antenna tuning settings, and accommodation of down-link carrier aggregation. The latter, like almost everything else in the mix, has been brought into play to serve the ever-increasing demand for data download capacity, while retaining backward capability with prior-generation air interfaces.

Multiplying all these factors together in a simple-arithmetic manner suggests that there has been a 5000-fold increase in possible operating states that the PA/RF front-end might occupy. Naturally, among those many states there will be groupings that will be quite similar; but equally, there is great diversity in operating conditions.

What is clear, therefore, is the need for a reconfigurable front-end. At Peregrine Semiconductor we are meeting this need with our UltraCMOS technology, which is a patented, advanced form of silicon-on-insulator (SOI).



Peregrine's UltraCMOS Global 1 is the industry's first reconfigurable RF front-end system.

The benefits of this technology have already been seen in the RF domain. In RF switches – to cite just one key function – CMOS was initially thought of as incompatible with RF signal paths. However, that's not the case now: devices fabricated in SOI have progressed rapidly from an initial demonstration to providing the required low losses, high linearity and high isolation, and this has made them the default choice of switch in a complex reconfigurable design. Switching – of passive component values – also underpins integration of functions such as antenna tuning.

Progress of silicon over the past decades is also evident from the continuing incursion of silicon CMOS into successive areas where it was initially thought of as fundamentally unsuitable. Looked at in this light, the objective of converting the power amplifier in a mobile terminal to CMOS, and then integrating it along with the other RF front-end functions on a monolithic device, can be viewed as obvious and attractive – although this move draws scepticism from analysts and handset makers.

CMOS credentials

Ignore, for a moment, the task of building the PA in CMOS. This leaves the challenge of integrating a reconfigurable RF front-end in a process such as our UltraCMOS 10 technology as the main challenge, and that is less formidable. After all, CMOS technology has already demonstrated its capability to build elements such as RF switches – in the complex multi-way, multi-throw configurations that 3G and 4G terminals require – and antenna tuners, which rely on the same switching technology. The capability of this switch is evident in the widely used figure-

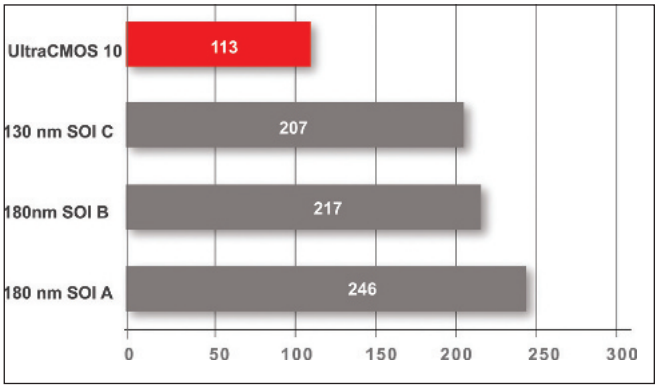


Figure 1. Peregrine's UltraCMOS 10 technology platform delivers significant performance enhancements, measured by the RonCoff figure of merit in fS.

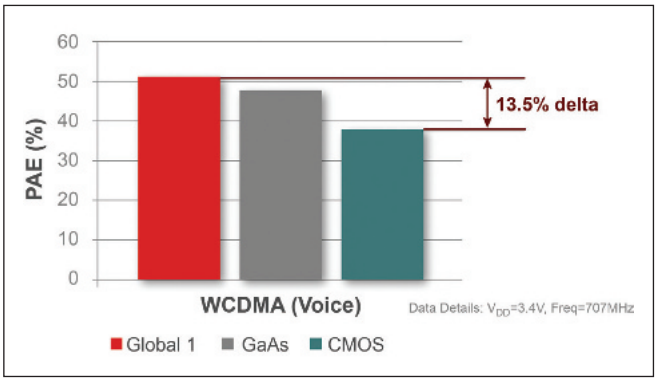


Figure 2. Peregrine's UltraCMOS Global 1 PA surpasses the leading GaAs PAs and exceeds the performance of other CMOS PAs by 13.5 percentage points. These figures are for the benchmark for PA performance of PAE (power-added efficiency) using a WCDMA (voice) waveform at an ACLR (adjacent channel leakage ratio) of -38 dBc.

of-merit for RF switches: The product of the on-resistance of the switch in its 'on' or conducting state, and the capacitance it presents in its 'off' state. The on-resistance determines the signal loss through the switched channel, so the smaller it is, the better. Meanwhile, the off-state capacitance sets the degree of isolation that the switch can provide; lower capacitance means lower signal leakage, so again smaller is better.

With our UltraCMOS 10 technology – the latest generation of a succession of technology steps that have employed diminishing feature sizes and constant refinements in performance – the key figure-of-merit formed from the product of on-resistance and capacitance in the off-state outperforms that of the closest competitive technologies by at least 30 percent (see Figure 1).

The objective of antenna tuning is to improve the impedance match between the PA output (or receiver input) and the antenna element itself. In smartphones, there are a variety of compact antenna forms, which are difficult to drive and often have to be used with a relatively high VSWR. These antenna also suffer from external loading effects.

One solution that can greatly improve the RF efficiency of the air interface and thereby, the battery life of the terminal, is to alter feed points (by switching) and impedances (by switching, for example, shunt capacitances, into or out of the feed). Our digitally tuneable capacitors can realise this by supplying the necessary degree of control, offering 5-bit resolution, and delivering tuning ratios of as much as 7:1 with capacitances in the range of several pF. These properties, coupled with the high linearity UltraCMOS technology, enable the progression to a complete, reconfigurable RF front-end. On a conventional silicon substrate, a variety of parasitic effects manifest themselves. Parasitic capacitances exist between various parts of the active (and passive) devices, and in addition are voltage-dependent – doping profiles cause them to act as variable-capacitance junctions. Such effects are highly undesirable because they are inherently detrimental to linearity.

Building on an insulating substrate removes many of these effects at a stroke. In addition, as demonstrated by the antenna-tuning components alluded to above, as the technology is CMOS, adding control logic on the same die as the RF path is straightforward. For example, the stand-alone antenna tuning parts in our range offer standard SPI and MIPI RF front-end control interfaces.

Many of the same properties of UltraCMOS technology lend themselves to further integration. With freedom from parasitic capacitances and from stray conduction paths via the substrate, it is possible to realise a high degree of isolation between functional blocks – linear RF signal paths, and control logic – and between those blocks and interconnection paths. The remaining critical question, therefore, is this: Can a CMOS power amplifier be designed into an RF front-end and surpass the performance obtainable with a GaAs device?

Trumping GaAs

With our development of the Global 1, that goal has been achieved. In terms of PA performance, no concessions have been made to a GaAs-based circuit. The incumbent technology, the GaAs-based PA, has dominated advanced handset air interfaces for some very good reasons: It can be designed to deliver the necessary power; it is broadband, with an individual

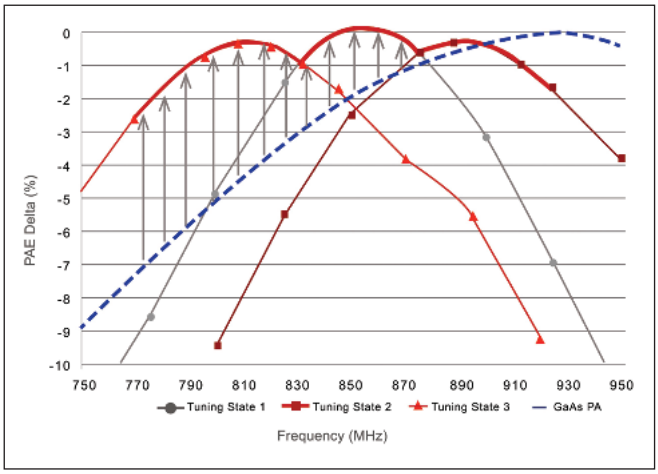


Figure 3. Peregrine's UltraCMOS Global 1 PA enables performance optimisation through tuneable matching networks; band-specific tuning provides additional rejection to other frequency bands, which helps mitigate some of the difficult interoperability cases.

power output stage serving a broad groupings of bands within the complete frequency range that the terminal covers; and it is relatively rugged. However, they cannot be optimised, relative to operating frequency, on a per-band basis.

Global 1 not only implements an all-CMOS RF front-end, it embodies a design approach that makes the optimal use of the characteristics of UltraCMOS technology. It takes advantage of the intelligence that can be integrated on a CMOS IC, to make use of the device characteristics possible in RF SOI. Once that intelligence is added, it becomes possible to not only recognise the need for the 5000-fold increase in possible operating states of the RF front-end, but to optimise operation for every one of them. Control is implemented, via the on-chip logic, through a MIPI interface, to deliver a performance that is markedly in advance of standard CMOS (see Figure 2). Handling a WCDMA signal, UltraCMOS Global 1 has better performance than GaAs technology, while bulk CMOS lags by an uncompetitive margin.

In an LTE-era smartphone, a typical PA stage will have three paths – in effect, three distinct power-amplifiers – that each cover part of the overall frequency range. They are selected for operation according to the band in use, and other operating conditions (see Figure 3). Operation of a GaAs-based PA can be optimised, at best, for each of those three frequency segments, and one set-up has to serve across the whole of each segment.

With the architecture of Global 1 it is a very different story. In this case, there is a much more focussed optimisation operating at the level of the actual band in use; this may only be 10 MHz for the narrowest bands as opposed to over 200 MHz for the entire path. For each operating state, it is possible to set up antenna tuning, filtering and stage-to-stage matching. To efficiently achieve high delivered-power levels from CMOS devices, it is necessary to use a stacked configuration of several FETs, connected in series – this overcomes the relatively low breakdown voltage of an individual FET. This structure functions as a single device that can handle the higher supply voltage needed to reproduce the LTE waveform profile, but presents challenges in setting the bias level of each transistor in the stack. However, this is not an issue with UltraCMOS technology, which can yield consistent devices that meet this requirement. This allows several devices to operate effectively as a single high-voltage FET.

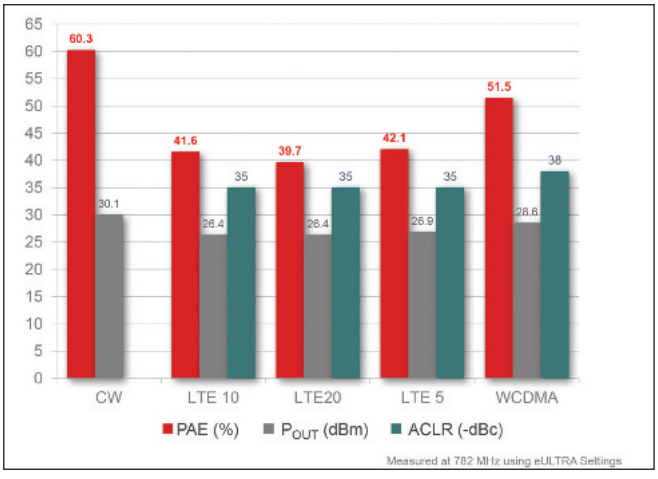
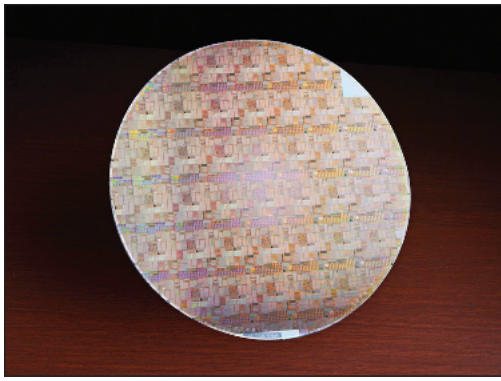


Figure 4. With W-CDMA, LTE5, LTE10 and LTE20 waveforms, Peregrine's UltraCMOS Global 1 PA shows little performance roll-off across the low band.

Above: Peregrine's state-of-the-art processes ensure uniformity and quality of high-end RF solutions.



Right: Peregrine's UltraCMOS 10 technology addresses the unique growth requirements for mobile applications and is the foundation of Peregrine's next-generation RF switches, tuners and power amplifiers, including UltraCMOS Global 1.

With Global 1, the PA is not limited to just competitive WCDMA performance in terms of efficiency, output power and linearity. Instead, GaAs-equivalent performance is maintained for LTE waveform allocations up to 100 Resource Blocks (RB) (see Figure 4). In mid and high bands of operation, similar competitive results have been demonstrated. The CW measurements show efficiency when the PA runs into saturation and is a good indication of the approximate efficiency that can be achieved with the addition of envelope tracking.

There is a clear precedent from many other semiconductor-device domains; as soon as CMOS with high-integration-levels can match the performance of a prior technology, then it quickly becomes the preferred solution. In this case, not only is the performance being matched, it is matched in a single device that is capable of being fabricated on a standard silicon CMOS line. Moreover, by covering all the operating states required for all worldwide frequency allocations and signal configurations, it will equip handset makers with what they have been wanting for years: a single stock-keeping unit that will allow them to build one PCB for all markets.

III-Vs prepare to replace silicon

Record mobilities, production processes on 300 mm silicon and impressive nanometre-scale performance indicate that III-V MOSFETs are getting closer to enter production

RICHARD STEVENSON REPORTS

FOR MANY YEARS, pundits have argued that the shrinking of silicon is about to come to an end. Often, though, thanks to unforeseeable innovations by the engineers in the labs and fabs, obstacles have been overcome and the march of Moore's Law has prevailed.

But now, arguably more than ever before, it seems that the days of silicon really are numbered. After all, why else would the silicon heavyweight IBM agree to pour $3 billion into the development of new technologies, including post-silicon materials for the 7 nm node and beyond?

The leaders of IBM view several materials as possible successors to silicon, including compound semiconductors. III-Vs sport high electron mobility, and if they could be used in the channel of post-silicon MOSFETs, they would enable devices to deliver a high current at a lower operating voltage. This would ultimately underpin a trimming of the power per transistor as size is reduced, one of the trends associated with Moore's Law that is now under threat.

Efforts at developing compound semiconductor MOSFETs were discussed at the most recent *VLSI Symposium*, which was held in Honolulu, Hawaii, from 9-13 June 2014. At this meeting a team headed by researchers at the Korea Advanced NanoFab Centre (KANC) claimed a new record for mobility in a III-V MOSFET; engineers from imec reported the development of foundry-compatible process for making compound semiconductor finFETs on 300 mm silicon; and a team led by researchers at the University of California, Santa Barbara (UCSB), claimed to have produced the first III-V MOSFETs that can match or exceed those of production silicon devices, while being constructed at dimensions relevant to the VLSI industry.

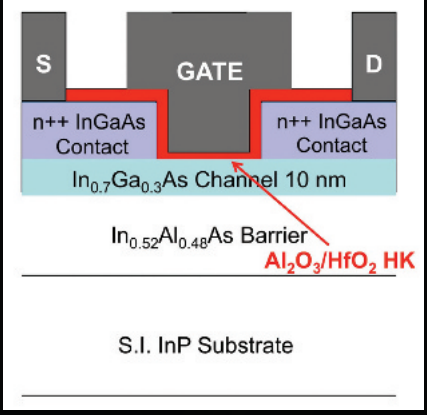


Figure 1. Researchers from KANC, working in partnership with those at Yonsei University, Sematech and GlobalFoundries, produced a MOSFET with a gate-last process that delivered an effective mobility of more than 5500 $cm^2 V^{-1} s^{-1}$.

Record mobilities

Researchers at KANC, working in partnership with those at Yonsei University, Sematech and GlobalFoundries, announced at the conference a claim for record effective mobility of more than 5500 $cm^2 V^{-1} s^{-1}$, using a III-V MOSFET incorporating an $In_{0.7}Ga_{0.3}As$ channel.

Chan-Soo Shin from KANC, speaking on behalf of the team, attributes the record to a combination of a high-indium-content InGaAs channel, MOCVD selective source and/or drain re-growth, and a gate-last integration scheme.

By employing a gate last process, the heart of the device is not subjected to high temperatures.

"Unlike silicon, the interface quality of an oxide-and-indium-gallium arsenide interface tends to be easily deteriorated when it experiences processes with temperatures above 500 °C," says Shin. Such temperatures are common in the conventional gate-first approach, with source and drain implantation-activation typically taking place at more than

800 °C, and raised source and drain re-growth processes occurring at 600 °C. But at these elevated temperatures, gallium atoms diffuse out of the InGaAs channel, impairing interface quality and carrier transport.

The team has optimised its composite gate stack, which has a thin, passivation layer of Al_2O_3 and a layer of HfO_2. According to Shin, this pairing produces good values for the equivalent oxide thickness, and can combine with InGaAs to produce a low density of interface states.

MOSFETs produced by the partnership were formed by first growing an $In_{0.52}Al_{0.48}As$ barrier and a 10 nm-thick $In_{0.7}Ga_{0.3}As$ channel on a semi-insulating InP substrate (see Figure 1). MOCVD re-growth formed heavily doped contacts for source and drain, prior to mesa isolation, the addition of ohmic contacts for the source and drain, and atomic layer deposition of 0.7 nm of Al_2O_3 and 3 nm of HfO_2 to form the gate stack (see Figure 2). Devices were constructed with gate lengths ranging from several microns to 22 nm.

Effective electron mobility for a device with a 5 μm gate exceeded 5500 $cm^2 V^{-1} s^{-1}$ at 300K (see Figure 3), and with a source-drain voltage of 0.5 V, this MOSFET had excellent electrostatic integrity, including a sub-threshold swing of 80 mV/decade and a drain-induced barrier lowering of 22 mV/V.

Shrinking device dimensions led to a deterioration in electrostatic integrity. At a gate length of 40 nm, sub-threshold swing and drain-induced barrier lowering climbed to 105 mV/decade and 150 mV/V, respectively, and at 22 nm they hit 250 mV/decade and 450 mV/V.

Shin blames the deterioration in performance at shorter gate lengths on short-channel effects, which could be addressed by switching to a three-dimensional channel architecture. "When and if InGaAs is introduced into silicon foundries, it will be somewhere around the 7 nm technology node or beyond. In those regimes, the transistor architecture should be non-planar, such as a three-dimensional channel or gate-all-around, to guarantee electrostatic integrity."

If the technology developed by the

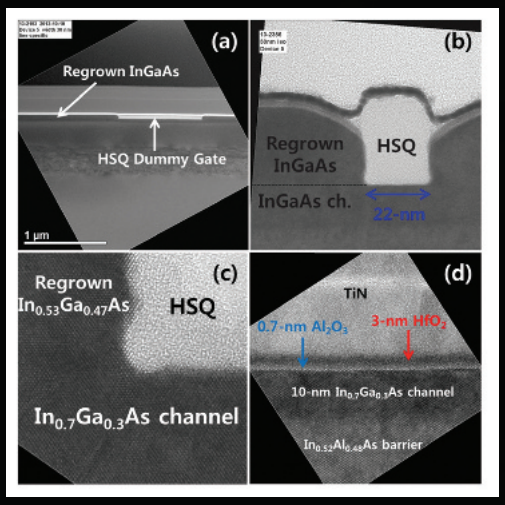
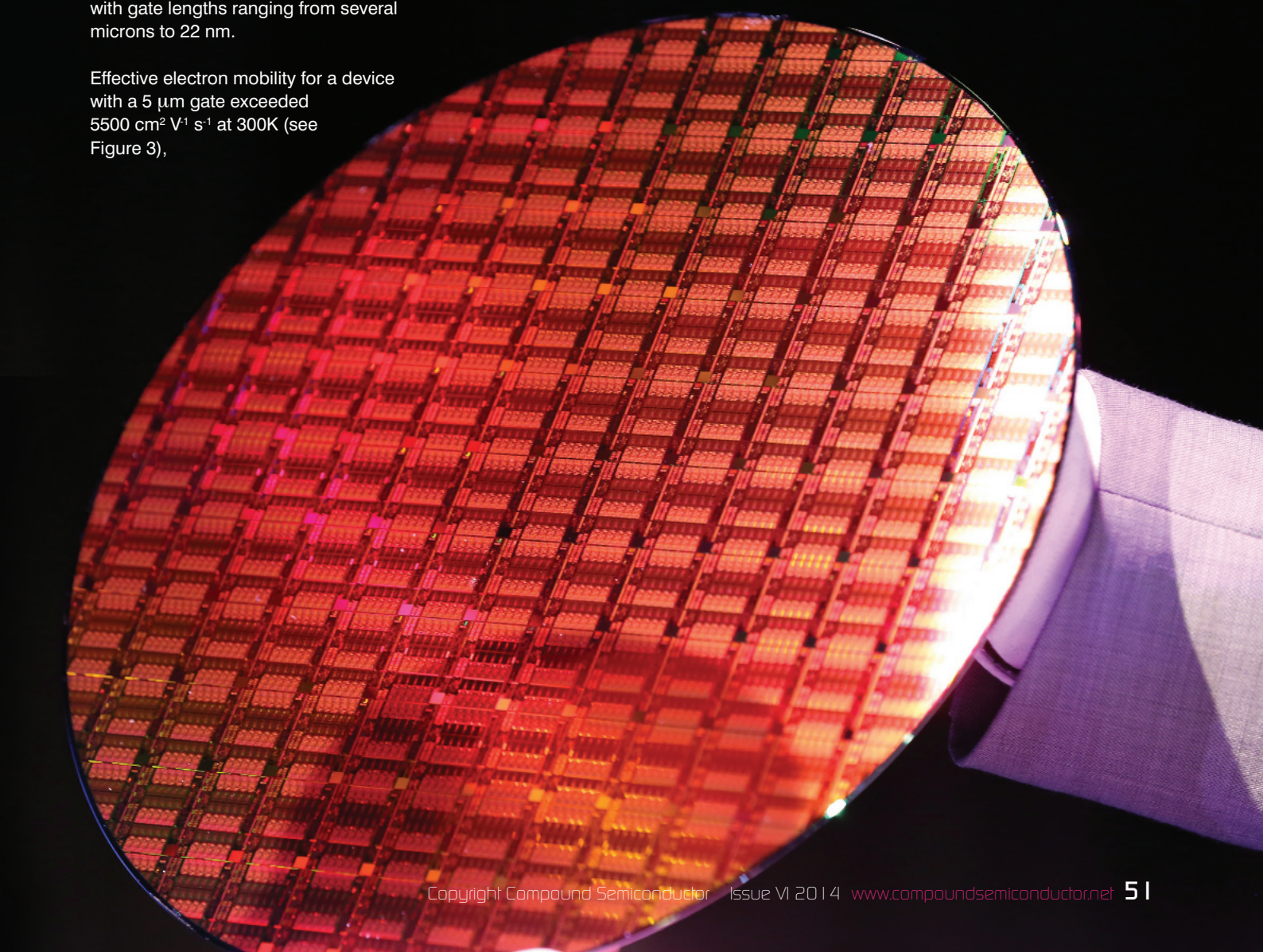


Figure 2. Cross-sectional transmission electron microscopy images of structures produced by the team led by researchers from KANC. These images show the photoresist, HSQ, and the dummy gate, for gate lengths of 1 μm (a) and 22 nm (b). High-resolution images offer insights into the quality of the interface between the $In_{0.3}Ga_{0.7}As$ channel and the regrown GaAs (c), and the Al_2O_3/HfO_2 gate stack on the InGaAs/InAlAs quantum well.



team is to make a commercial impact, production of the devices will have to be transferred to 300 mm silicon substrates.

"There are a couple of options, such as wafer-bonding, a blanket approach using a metamorphic buffer, and aspect-ratio trapping," says Shin, who reveals that the team's preferred approach is the latter one. "We really want to use a small area on silicon, where III-Vs are defined selectively, adjacent to other devices, such as silicon CMOS and/or germanium PMOS," says Lee. "Also, III-V materials grown by aspect-ratio trapping are known to be ideally defect-free on the top portion, enabling an overcoming of lattice mismatch issues."

III-Vs on 300 mm silicon

Leading development of aspect-ratio trapping processes for forming III-Vs on large silicon wafers is imec, a microelectronics research centre in Leuven, Belgium. At the VLSI Symposium, researchers from there unveiled the results of efforts to transfer their replacement fin process from 200 mm to 300 mm silicon.

"In the end it was a smooth transition as all the learning from the 200 mm tools for the other process steps was directly transferrable to 300 mm," says Niamh Waldron. "Likewise, there is no fundamental issue with transferring it to 450 mm silicon."

Fabrication of the team's InGaAs/InP quantum-well finFETs began by taking standard shallow-trench isolation templates, and etching out the silicon to form trenches (see Figure 4). Selective growth of III-Vs in the silicon-lined trenches followed. Although defects are generated due to lattice mismatch, these imperfections propagate towards the sidewalls and annihilate there, so there is relatively high material quality near the top of the trench.

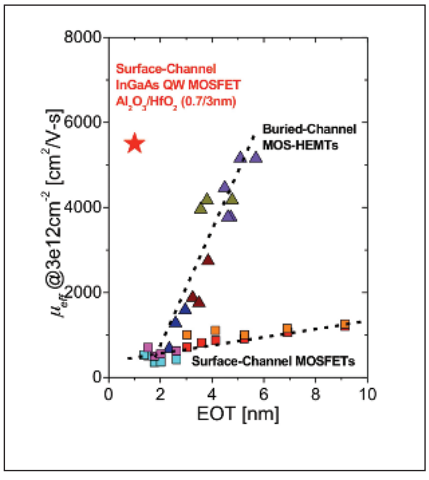


Figure 3. The surface-channel MOSFET produced by KANC produces very high mobility, while having a low equivalent oxide thickness.

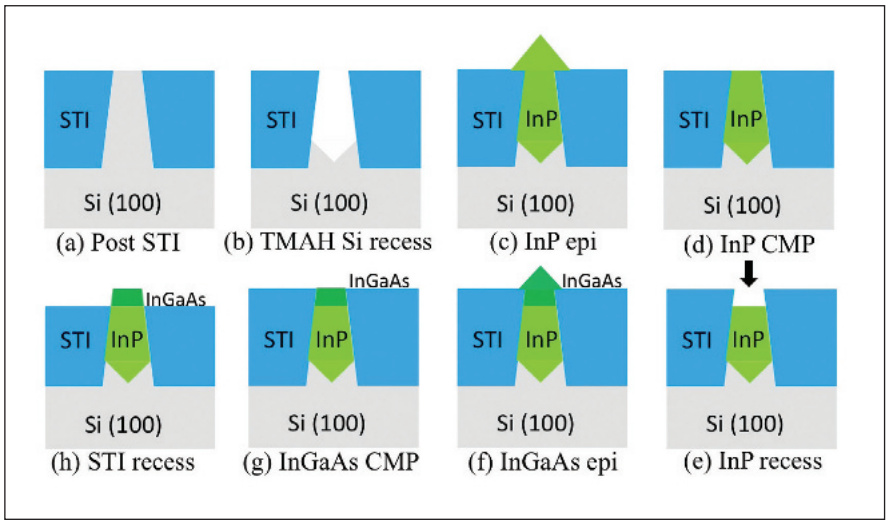


Figure 4. Researchers at imec employ aspect-ratio-trapping technology to create III-V MOSFETs on silicon with a high-quality InGaAs channel.

Formation of the finFET fabrication began by depositing InP in the trench, smoothing the surface with chemical mechanical polishing and etching away a little InP. InGaAs was then deposited in this recess, before the surface wass smoothed again with chemical mechanical polishing, and areas beside the trench were etched away with SiCoNi to produce a protruding fin (see Figure 5).

"Controlling the damage to the III-V during etch is not a fundamental issue, but does require optimisation," says Waldron. "We are currently working with our partners on both the replacement fin process – which does not require a fin etch – and also an etched fin approach."

Like the team involving researchers from KANC, Waldron and co-workers used a gate-last process to temper intermixing at the interface between the channel and the dielectric.

Another noteworthy aspect of imec's approach is the use of a magnesium dopant for both the InP buffer and the InGaAs channel. Metal organics used to form these layers are carbon rich, and when carbon is present in nominally undoped InP, it leads to excessively high source-drain leakage. By introducing magnesium, imec's engineers have formed *p*-type InP that not only slashes leakage currents, but also increases the conduction band offset with the channel layer, thereby increasing carrier confinement.

Engineers formed devices with an 30 nm-thick InGaAs channel and a 50 nm fin. For doped buffers, leakage is cut by increasing the doping in the channel – and improvements are more pronounced for lightly doped buffers. If the channel is undoped, leakage currents plummet with highly doped InP, thanks to up-diffusion of magnesium from the buffer to the channel during growth and processing. A doped channel is bad news, because carrier mobility declines. By applying conditions that offer the best compromise between leakage current and mobility,

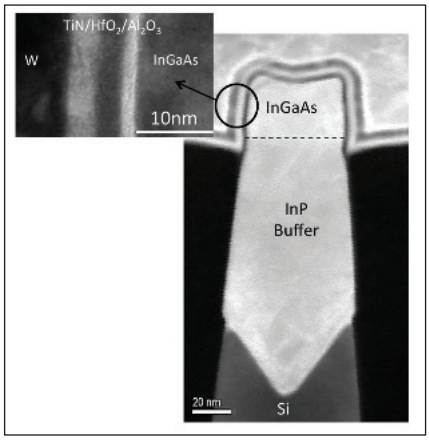


Figure 5. A dark-field, scanning tunnelling electron microscopy image of the InGaAs channel formed by imec's engineers. The inset is a transmission electron microscopy image of the gate stack.

devices can realise a saturated sub-threshold swing of 190 mV/decade.

"While magnesium doping is effective at reducing the off-state leakage, it does impact electron mobility and device performance, so we are pursuing device designs that need lower or no magnesium doping," comments Waldron. Efforts are also being directed at achieving a low defect density in the III-V layer when the process is scaled to 10 nm or 7 nm.

Superior scaling

Meanwhile, researchers at UCSB are claiming to have fabricated the first III-V MOSFETs that have on-current, off-current and operating voltages comparable to or exceeding production silicon devices – while being constructed at dimensions that are relevant to the VLSI industry.

Devices produced by the team, which is led by Mark Rodwell, Arthur Gossard and Susanne Stemmer, have a 25 nm gate length, can operate at 0.5 V, and produce an on-current of 0.5 mA and an off-current of 100 nA/μm.

To set a new benchmark for III-V MOSFET performance, modifications to the conventional device architecture included a trimming of the InAs channel thickness to just 2.5 nm. Sanghoon Lee from the team told *Compound Semiconductor* that the thinner channel aids the off-state current because it increases the quantised band gap of the InAs quantum well, leading to a reduction in band-to-band tunnelling, which is likely to happen near a high drain field region. Another benefit of a thinner channel is an increase in gate capacitance, which could help boost on-current.

"Meanwhile, researchers at UCSB are claiming to have fabricated the first III-V MOSFETs that have on-current, off-current and operating voltages comparable to or exceeding production silicon devices – while being constructed at dimensions that are relevant to the VLSI industry"

The high-performance of these MOSFETs has been aided by the development of a high-quality gate insulator, made from the pairing of Al_2O_3 and ZrO_2.

"We have used zirconium oxide instead of hafnium dioxide, because MOS capacitor analysis for zirconium oxide verses hafnium dioxide tells us that the permittivity of zirconium oxide, typically 23, is larger than that of hafnium dioxide, 19," explains Lee. However, the total gate capacitance would not increase by much if ZrO_2 was replaced by the more common HfO_2. According to Lee, that's because it is the semiconductor capacitance in the III-V MOSFET, rather than the oxide capacitance, that is the limiting factor for the total gate capacitance.

Due to this, Lee argues that the impressive performance of the MOSFET is essentially down to the insertion of a thin channel, plus the introduction of a vertical spacer that leads to a smoother distribution of the field within the device. By ironing out the spikes in the electric field profile, band-to-band tunnelling is prevented and leakage currents are reduced.

MOSFETs were formed from epistructures grown by MBE on semi-insulating InP. After depositing a 50 nm-thick unintentionally doped InAlAs buffer, engineers added: a 250 nm-thick, *p*-doped InAlAs barrier; an unintentionally doped 100 nm-thick InAlAs barrier; a 2 nm-thick InAlAs *n*-type, pulse-doped layer; a 5 nm-thick unintentionally doped InAlAs setback; a 3.5 nm-thick strained InAs channel; and a 2 nm-thick, unintentionally doped $In_{0.53}Ga_{0.47}As$ spacer (see Figure 6).

Dummy gates with lengths ranging from 12 nm to 1000 nm were formed by coating wafers with a 20 nm-thick film of the photoresist hydrogen silsesquioxane, and patterning the surface with electron-beam lithography. MOCVD added the

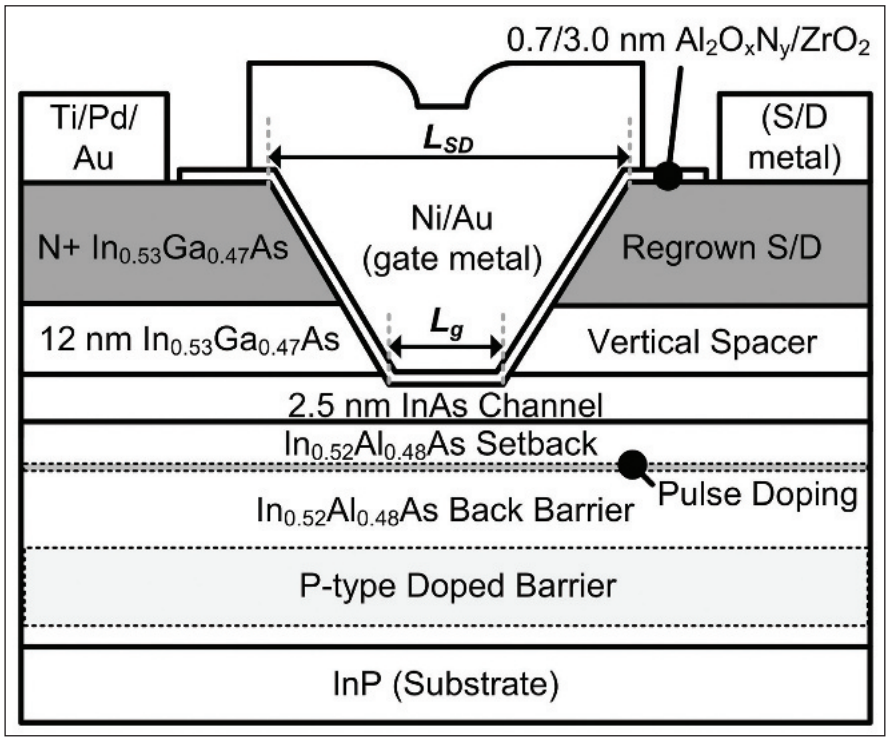


Figure 6. The vertical spacer and the thin InAs channel are claimed to hold the key to the high-performance of the UCSB MOSFET.

remainder of the 12 nm-thick spacer and heavily doped $In_{0.53}Ga_{0.47}As$ regions for the source and drain.

Using MBE processes for the creation of epiwafers for VLSI is not ideal, due to high costs and the challengers of growing uniform films over large wafers. "The reason why we are using MBE is that our MOCVD system has no aluminium source, so we cannot grow the indium aluminium arsenide barrier using MOCVD," explains Lee. "To my best knowledge, InP-related material can be grown using MOCVD that is as good as MBE, in terms of epi-quality."

To process the epiwafers into MOSFETs, device mesas were defined with a wet etch, before dummy gates were stripped in buffered hydrofluoric acid. A two-cycle isotopic digital etch then removed about 2 nm of the $In_{0.53}Ga_{0.47}As$ cap and about 1 nm of the InAs to leave a 2.5 nm-thick channel. These wafers were immediately loaded into an ALD tool.

After *in-situ* nitrogen plasma/tri-methyl-aluminium treatment led to the formation of a 0.7 nm thick layer of $Al_2O_xN_y$, a 3 nm-thick ZrO_2 gate dielectric was deposited. MOSFETs were ready for testing after subsequent annealing at 400 °C, plus the creation of a Ni/Au gate and source and drain contacts formed from a Ti/Pd/Au stack. Transistors with a 25 nm gate length produced a peak transconductance of 2.38 mS/μm at a drain-source voltage of 0.5 V. Operating at a voltage of 0.5 V for the drain (V_{DD}), the device produced an on current of 0.5 mA/μm (see Figure 7) and an off-current of 100 nA/μm. Sub-threshold swing was just 72 mV/decade at a drain-source voltage of 0.1 V, rising to 77 mV/decade at 0.5 V.

Lee believes that even though the silicon industry has recently moved to three-dimensional, finFET structures, when III-Vs are introduced into the channel, there could be a move back to planar devices, such as their MOSFET. "III-V materials are vulnerable to dry-etch damages," argues Lee, "so it might be very difficult to get fins using current dry etch techniques. In addition, planar processes could be more cost-effective."

Devices produced by the team were designed for high-performance applications, which require an off-state leakage current below 100 nA/μm. Even lower values of 1 nA/μm and 30 pA/μm must be met for standard and low-power performance, and Lee and co-workers are aiming to address these requiremnets by modifying the channel and vertical spacer.

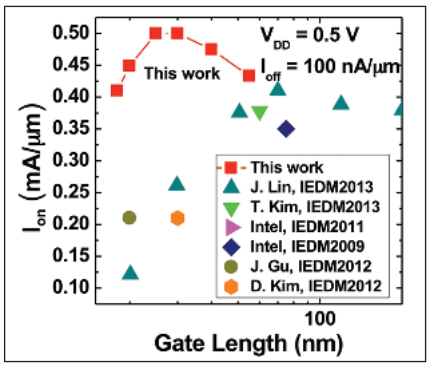
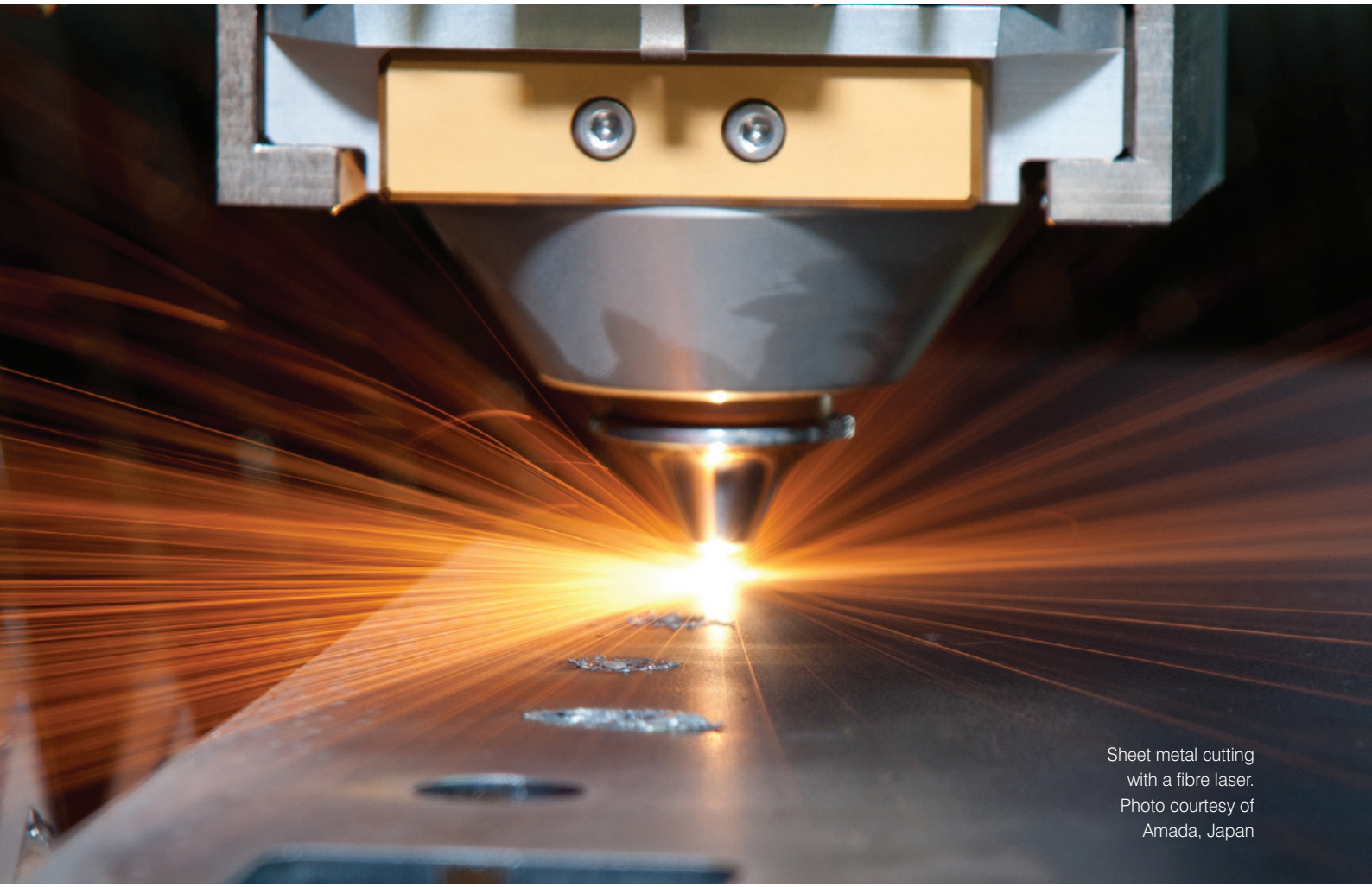


Figure 7. The MOSFET from UCSB sets a new benchmark for on-current at short gate lengths.

Efforts by this team, plus those at imec and KANC, are clearly closing the gap between the state-of-the-art of the III-V MOSFET and the characteristics it requires to make an impact in the foundries. As time goes on, this gap should continue to shrink – but will it be at sufficient speed to allow compound semiconductors to make an impact at the 7 nm node?



Sheet metal cutting with a fibre laser. Photo courtesy of Amada, Japan

Pumping up high-performance **fibre lasers**

Breakthroughs in laser diode and fibre-coupling technologies are enabling low-cost, high-reliability sources with remarkable sheet metal cutting capabilities

BY ERIK ZUCKER FROM JDSU

CHANGE IS AFOOT in the sector of the laser market covering high-power sources for metal processing. This 'macro' material market has traditionally been dominated by CO_2 lasers, but lasers based on the optical pumping of a doped fibre are now winning significant market share, thanks to their combination of low cost of ownership and excellent cut quality on a wide variety of metals. According to Industrial Laser Solutions, which has been working with analyst Strategies Unlimited, the macro fibre laser market is growing at 24 percent per year, and should hit $536 million in 2014. In comparison, sales of CO_2 lasers in this sector are falling by 7 percent per year, and will be worth $647 million this year.

If the current trend in the macro fibre laser market continues it will not be long before the dominant source is a semiconductor-pumped fibre laser – a laser in which GaAs-based laser diodes are used to pump ten metres or more of fibre, which has a Bragg grating at either end to form a resonant,

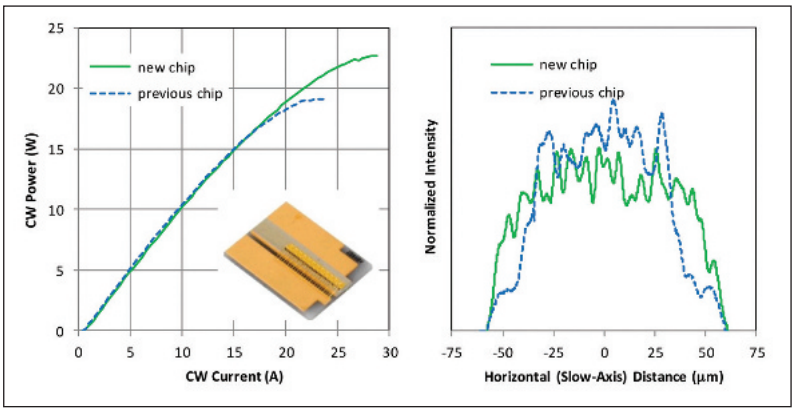


Figure 1. Left side: CW power versus drive-current at 25 °C for the latest laser diode and its predecessor. Both chips have 4.1 mm cavity length. Right side: near-field images of the intensity at the front facet at 12 W, 25°C. The new chip has better uniformity and lower peaks, which should lead to better facet reliability.

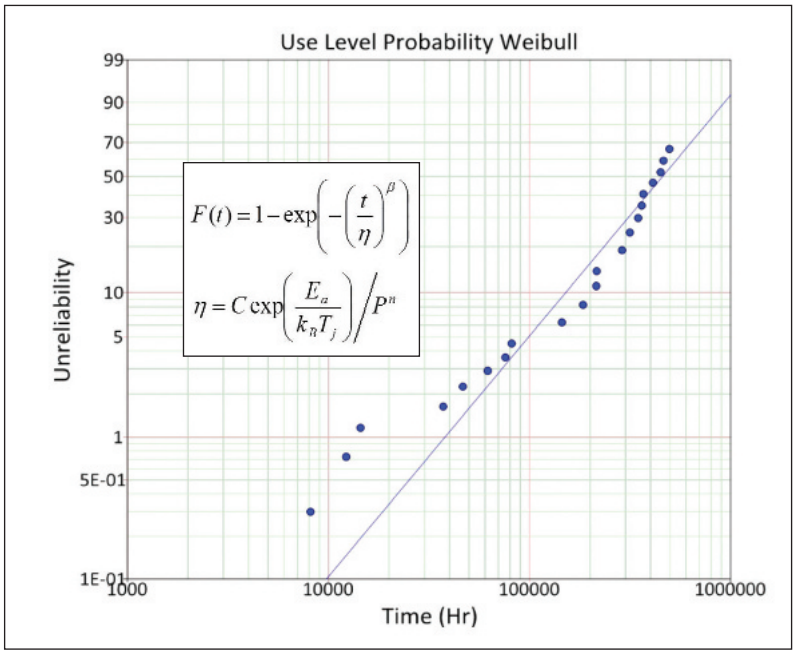


Figure 2. Reliability analysis employed the maximum likelihood method to fit a Weibull model with acceleration factors based on diode junction temperature and optical power. Activation energy, E_a, was fixed to 0.45 eV as in prior models, and laser diode junction temperature, T_j, is calculated from thermal resistance and dissipated power. The extracted shape parameter β is 1.7, and the power acceleration factor n is 6.5. The resulting scale parameter at 12 W, 25 °C is η = 570,000 hours, and cumulative failures from the model at 20,000 hours is 0.3 percent. Three early failures fell outside of the model and were removed. These can be treated as infants and eliminated with a longer burn-in.

high-power, laser cavity. In this form of laser system, gain is generated in the fibre by active ions, such as ytterbium or erbium, that are doped into the fibre core. The light that is coupled into this fibre from the GaAs diodes pump the active ions, generating light at a longer wavelength, which is guided within the fibre waveguide. The longer-wavelength light resonates between the two gratings, while being amplified with every pass through the cavity. Making one of the gratings partially transparent allows some light to pass through and impinge upon any material that needs to be processed.

Constructing a fibre laser in this manner allows the production of high-power fibre lasers with a single resonator that can deliver an output of over 2 kW. That may not sound like much, since it is only equivalent to the power drawn by a hand-held hair dryer. But the key difference is that the output from the fibre laser can be focused to a spot the size of a few diameters of human hair – several hundred microns.

At such a high power density, the laser light can rapidly cut through mild and stainless steels, aluminium, brass, and copper, as well as weld, mark, or braze a wide variety of materials. It is possible to cut mild steel up to 25 mm-thick with a 2 kW fibre laser, while a cousin with double that power can cut 1 mm-thick aluminium at 75 m per minute.

The most costly component within the fibre laser is the set of fibre-coupled pumps, which can account for more than half of the bill of materials. This makes the macro fibre laser market a considerably significant one for manufacturers of high-power GaAs-based lasers, which can pump at wavelengths of 910 nm to 980 nm to enable lasing further in the infrared – doping a fibre with ytterbium, for example, leads to lasing around 1060-1080 nm.

To succeed in this market, laser diode manufacturers have to focus on supplying adequate pump brightness – that is, the power divided by the optical aperture in physical and angular space – at the lowest dollars-per-watt. There are also other criteria to consider: the laser must be reliable, because how long it lasts governs the lifetime of the system; and the packaging of the laser and the coupling into the fibre must preserve the hard-fought-for brightness from the chip, while ensuring that the product is competitively priced.

Serving the market

At JDSU of Milpitas, CA, we are meeting all of these requirements with our latest generation

of GaAs-based, high-power lasers. Fabrication begins by using MOCVD growth technology to form epitaxial structures on 3-inch GaAs substrates. Processing creates broad-area multi-mode chips featuring separate confinement InGaAs/AlGaAs quantum wells, a lateral output aperture of 100 μm and a 4.1 mm cavity length. By varying the composition of indium in the well, the lasing wavelength can be tuned from 910 nm to 980 nm.

The length of the chip cavity is identical to that of its forerunner, but the near-field and far-field emission patterns have been improved through optimization of the lateral index-guiding step, lateral gain profile, and transverse (epitaxial direction) mode design. These refinements result in a more uniform near-field pattern with fewer high-intensity spikes – this means better long-term facet reliability.

For burn-in and test, the chip is bonded to an expansion-matched ceramic submount with AuSn solder and clamped to a copper carrier. Comparison at the chip-on-submount level shows that this latest chip has less thermal rollover than its predecessor, and can deliver a CW output in excess of 20 W at 25 °C (see Figure 1). Peak power conversion efficiency is greater than 60 percent.

We have carried out extensive reliability testing of our latest chip design. Only 10 percent of the tested population failed across seven highly-accelerated life test cell conditions, making it challenging to employ a reliability model. However, we have performed reliability analysis with a Weibull model, which uses acceleration factors based on diode junction temperature and optical power (see Figure 2). This study suggests that if our lasers were operated continuously for ten years, the expected failure rate would be below 4 percent.

Multiple emitters

To increase the output power of a source, laser chips can be combined to form a multi-emitter package (see Figure 3). We have done this, stacking chips in the vertical direction with a staircase-like layout, in two rows, polarization combined, and focusing their output into the fibre.

The result is a source that can deliver a continuous-wave output of 140 W from a 106 μm/0.22 NA fibre – and 95 percent of this power is contained within 0.15 NA. Note that power conversion efficiency, the portion of terminal electrical power that is converted to useful light, is almost 50 percent at 140 W.

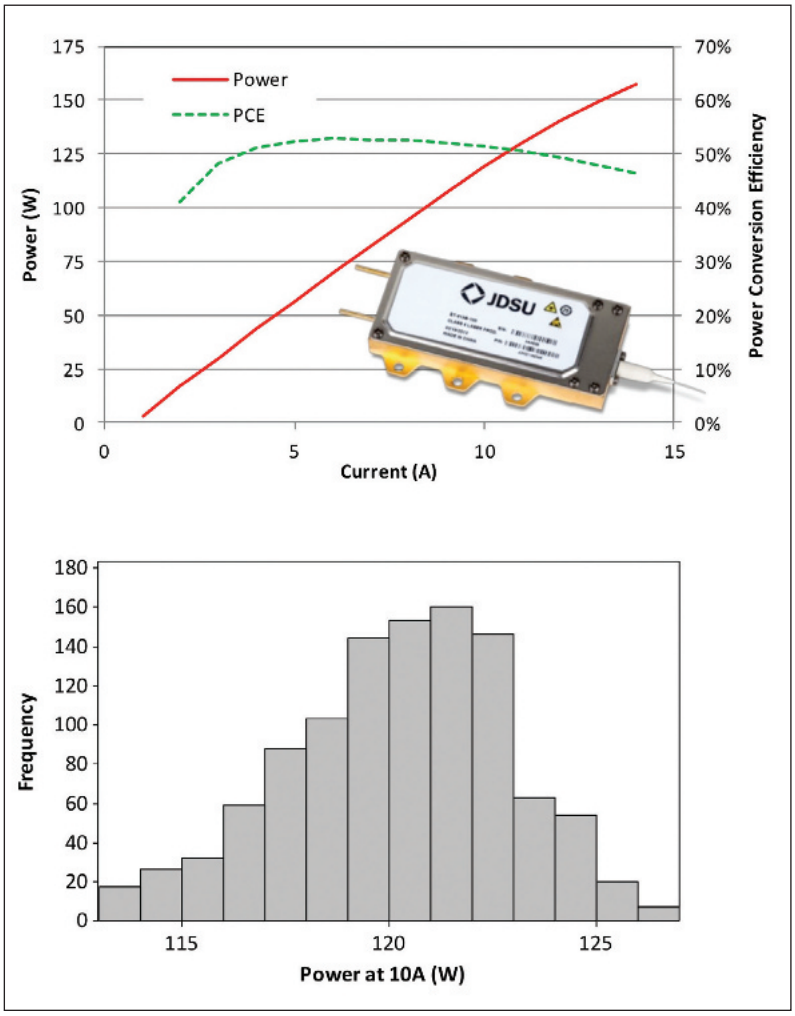


Figure 3. (a) Optical power versus drive current at 35 °C case temperature for the multi-emitter, fibre-coupled package. The laser is rated at 140 W and achieves nearly 50 percent power conversion efficiency at the rated power. (b) Optical power reading at 10 A from 1,000 units assembled. Typical optical power is about 120 W

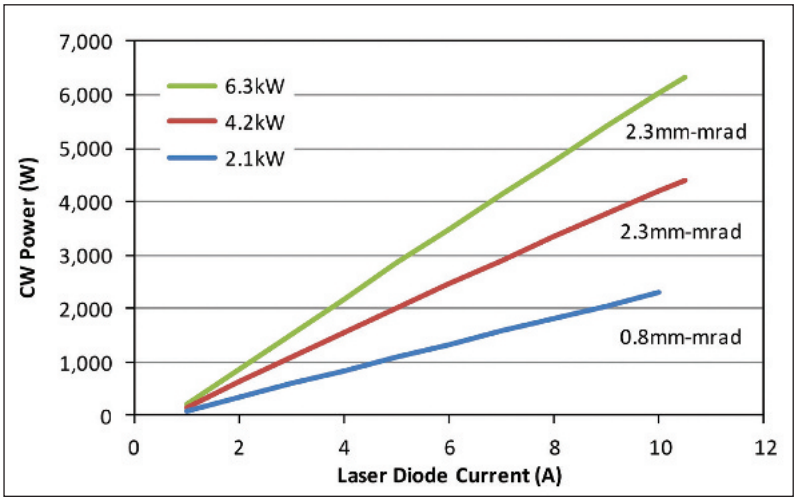


Figure 4. Fibre laser power versus pump diode current for 1-, 2-, and 3-module combined engines

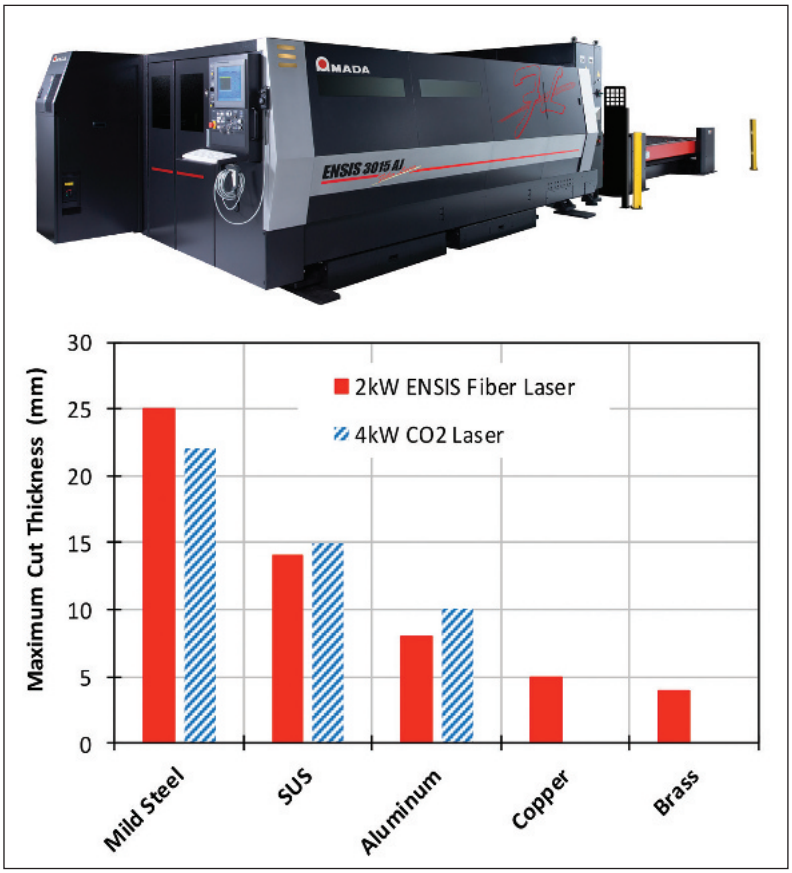


Figure 5. Maximum cut thicknesses for a variety of materials for the Amada fibre laser cutting system, ENSIS 3015 AJ, with integrated 2 kW fibre laser compared to a 4 kW CO_2 laser. Image coutersy of Amada

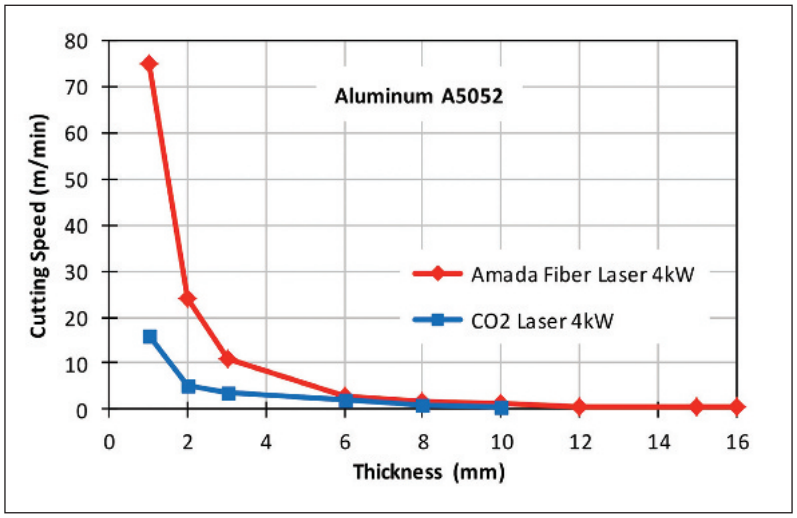


Figure 6. Cutting speed comparison for aluminium between the 4 kW Amada fibre laser and a 4kW CO_2 laser

Historically, this platform has shown excellent process stability in ongoing production. Differences in ex-facet chip power/efficiency, polarization-combination and optical coupling efficiency can lead to variations in power output, but these are very small as monitored at a driving current of 10 A and a typical output power of 120 W.

We have partnered with Amada, Japan, integrating the high-brightness, multi-emitter pump described above into a more powerful fibre laser. Pump output fibres are fusion combined and spliced to end-pump a 2.1 kW fibre laser module with dimensions of 433 mm x 153 mm x 650 mm. This source has a typical electrical-to-optical efficiency of 35 percent, rise and fall times of 16 μs, and a beam parameter product (BPP) from the feeding fibre of 0.8 mm-mrad.

This 2.1 kW module may be used as a standalone source or combined with additional modules for higher power. Using a 3:1 signal combiner can create 4.2 kW or 6.3 kW fibre laser engines with a BPP of 2.3 mm-mrad (see Figure 4 for plots of fibre laser power versus laser diode pump current for one, two, and three module fibre laser engines).

Superior cutting

Amada has developed a cutting system, ENSIS 3015 AJ, that incorporates the 2 kW module (see Figure 5). It delivers an exceptional cutting performance that is comparable to that of a 4 kW CO_2 laser. To our knowledge, this is the first 2 kW fibre laser with a maximum cut thicknesses of 25 mm for mild steel and 14 mm for stainless steel.

Using this class of laser, it is possible to cut a variety of metals at high speeds (see Figure 6). A 2 kW source can cut 1 mm-thick aluminium at up to 40 m per minute, while a 4 kW version can hit 75 m per minute.

Due to such exceptional cutting performance, the adoption of fibre lasers as a superior alternative to conventional CO_2 lasers is well underway. To accelerate this trend, manufacturers are focused on further reducing total cost of ownership of these systems – through lower initial selling price, faster cutting speed, higher cut quality, and higher efficiency.

One way that we will meet these needs is through continuous reduction of pump dollar-per-watt cost, and higher brightness and power per pump package. This will be enabled by yet higher powered and more reliable laser diode chips.

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Speeding up silicon with infrared lasers

Growth of laser structures on silicon chips promises to overcome a looming bottleneck in data transfer

BY HIMANSHU KATARIA AND SEBASTIAN LOURDUDOSS FROM KTH-ROYAL INSTITUTE OF TECHNOLOGY

THE WAYS THAT WE SPEND OUR FREE TIME have changed. While many of us still watch TV, read books and listening to the radio, over the last decade or so we have also started to surf the web, watch films over internet and stream our music.

This relatively new opportunity for so much choice at the click of a button is great, but it comes at a price: Ever-growing levels of data transfer are putting increasing strain on the internet backbone, and the CMOS-based electronics that is used to upload, download and transfer this data is running out of steam.

What is the cause of this impending bottleneck? Well, it is not due to the processing speed of the microprocessor. Instead, it is associated with the speed of data transfer between the chips. This is limited by the copper wires that connect them.

A hike in data transfer rates is possible by replacing the wire with tracks in silicon that can route light from one chip to another, and direct it around the chip. However, this silicon-photonics approach is hampered by the lack of an efficient silicon laser, so one made from III-Vs has to be employed – and

the integration of this is challenging.

One way to unite a laser with a silicon chip is to bond the two together. This is quite easy to do, but it does not guarantee great performance, due to the silicon-on-insulator wafers used in the process. The insulating layer sandwiched between the silicon is a low-thermal-conductivity dielectric that hampers the dissipation of heat generated by the laser, leading to device heating and reduced performance. What's more, bonding chips together can compromise yield. To bring the laser onto the silicon chip, either III-V dies or a wafer must be selectively bonded to a larger silicon substrate. This can lead to unacceptable variations in the thickness of the intermediate bonding layer across the silicon. Although chip-to-chip bonding can address this, it is expensive, and stringent alignment requirements can impact yield.

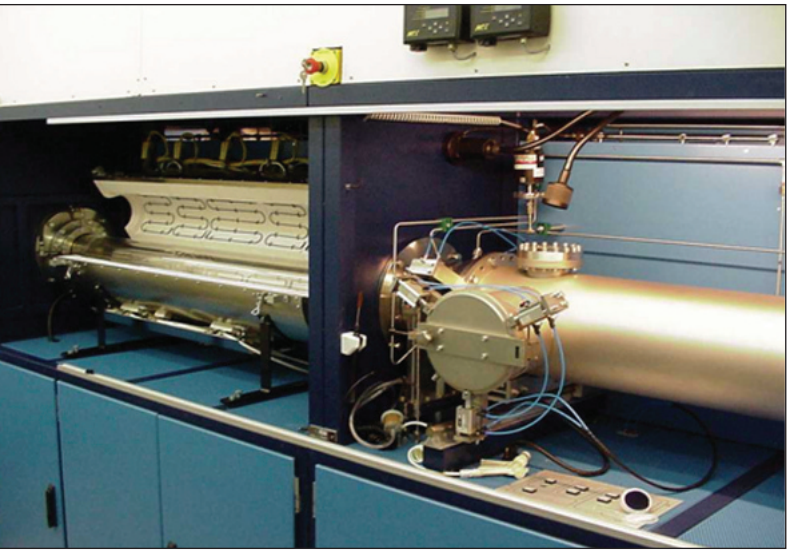
Monolithic integration

A far better way to unite a microprocessor chip with a III-V laser is via monolithic integration. This is the approach that has been adopted by several groups across the world, including ours at KTH in Sweden, where we have developed a novel approach for creating defect-free layers of InP.

The biggest challenge with all epitaxial approaches to integration is to combat the large differences in lattice and thermal expansion coefficient. This can lead to III-V materials that are riddled with defects, which can act as charge trapping sites that reduce carrier lifetimes and ultimately kill the device. To prevent this from happening, we employ a method known as epitaxial lateral overgrowth (ELOG), which involves selective growth of a defect-free layer of InP in openings defined in a thin film of dielectric deposited on silicon (see Figure 1).

With this approach, defects generated at the interface between the III-V and silicon are filtered by the dielectric film, enabling the deposition of a defect-free InP layer that can act as a virtual substrate for selective growth of InGaAsP-based multi-quantum wells. Armed with this technology, the door has been opened to the creation of truly monolithic integrated photonic circuits on silicon, which up until now have only been possible with bonding approaches.

Creation of the high-quality InP that is essential for adding a laser is based on selective-area growth via HVPE, employing near-equilibrium conditions. The first step involves deposition of a thin InP layer on silicon to create a seeded substrate. After this, a film of the dielectric SiO_2 is deposited and subsequently patterned using lithographic techniques to create a series of SiO_2 stripes across the wafer. This leaves us with a region of exposed InP that is riddled with defects. On further growth



The HVPE reactor at KTH has been used to form InP layers on silicon substrates with SiO_2 stripes.

of InP these defects can climb, but what is interesting – and critically important – is that they follow a specific angle associated with a crystal plane. What this means is that if the ratio of the thickness of the opening to the height of this trench is chosen carefully, defects can annihilate at the walls, and therefore block defects not only beneath the mask, but also within the opening.

By carrying out a series of experiments, we have optimised the growth of coalesced ELOG InP in ten openings that are 300 nm across and spaced 1 μm apart. This has led to the formation of templates with a smooth ELOG InP layer that has an overall width of around 15 μm.

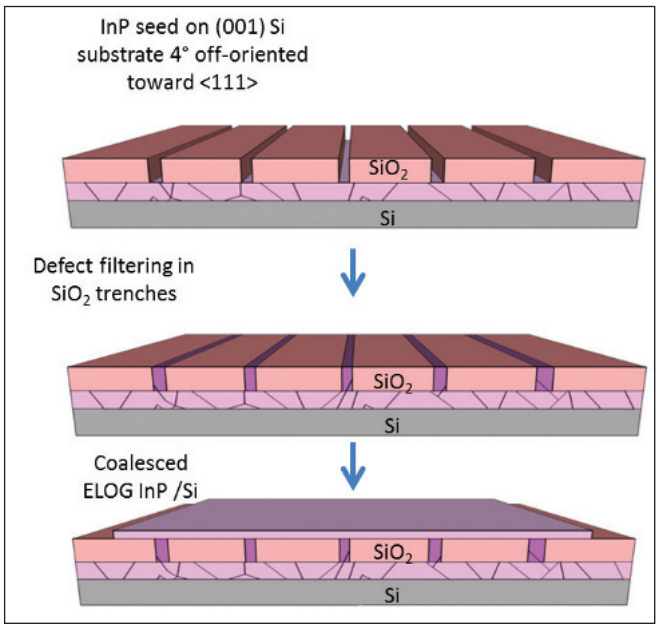


Figure 1. Epitaxial layer overgrowth holds the key to forming defect-free InP on silicon.

We have used these templates as a foundation for the MOCVD growth of InGaAsP-based multi-quantum well structures emitting at 1.55 μm. Forming such structures has not been easy, due to loading effects – selective growth can result in thicknesses and composition of the wells and barriers being far different from those on a planar substrate. However, after conducting many experiments, we have refined the dielectric mask pattern so that the loading effect is reduced during MOCVD growth.

Atomic force microscopy reveals the smooth epitaxial surface after multi-quantum-well growth (see Figure 2). However, this active region is by no means perfect, and there is inhomogeneity in the thicknesses of the multi-quantum wells, according to images provided by transmission electron microscopy (see Figure 3). It is possible that this is caused by the tremendous loading effect during selective growth of multi-quantum wells on a very small area. However, it might also result from unevenness caused by the coalescence of parallel growth fronts during ELOG.

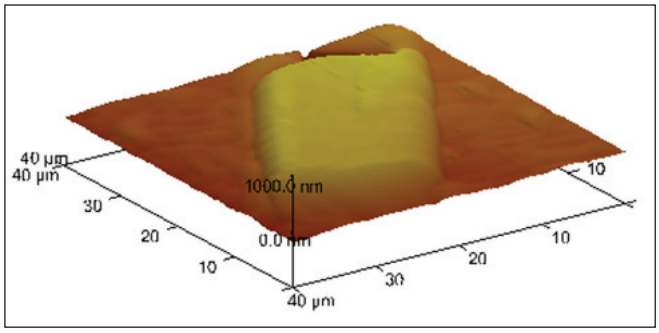


Figure 2. Atomic force microscopy reveals the high degree of flatness of coalesced ELOG InP on silicon.

Growth of a polar material onto a non-polar layer – such as the growth of InP on silicon – can create anti-phase domains, which are formed when bonds between identical atoms occur along particular directions. These domains can be eradicated by turning to growth on off-orientated substrates, but even this step may not prevent new defects arising. That's because imperfections can also appear at the coalescent junction between two parallel growth fronts, and form due to the interaction of an epitaxial layer with the dielectric thin film. So, in order to achieve a defect-free epitaxial layer all over the dielectric mask, it is essential to avoid coalescence of parallel growth fronts and obtain a dielectric film with a smooth surface and sidewalls.

Thanks to these insights, we have formulated our experiments in such a way that we have been able to grow almost-defect-free, isolated large areas of ELOG InP on silicon (see Figure 4). These un-coalesced stripes of InP were formed via growth in 1 μm-wide openings separated by 20 μm. The openings were defined by conventional optical lithography –

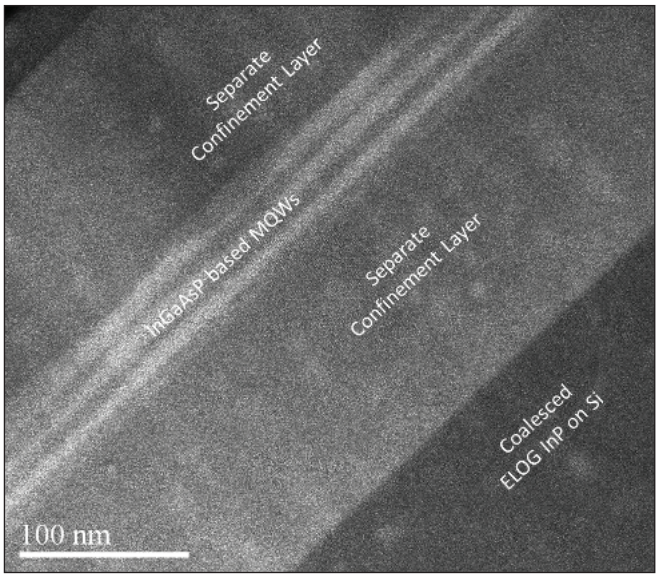


Figure 3. Cross-sectional transmission electron microscopy reveals the variations in thickness in individual layers within the InGaAsP multi-quantum wells that are formed on coalesced ELOG InP on silicon.

a common workhorse in the present day photonic industries – and covered a square area with sides of 12.5 mm. Note, however, that there is no reason why this process cannot be scaled to enable the growth of InP regions over large wafers.

Although the stripes of SiO_2 are far more isolated than before, an ELOG approach can still be applied. This is what we have done, fine-tuning our process to avoid the coalescence of parallel growth fronts. Defect blocking still takes place, despite such a wide opening, according to cross-sectional transmission electron microscopy of a lamella taken from a sample (see Figure 5).

We have used these templates as virtual substrates for MOCVD growth of InGaAsP multi-quantum wells emitting at 1.55 μm. Our previous efforts provided us with the approaches to reduce loading effects during the growth, and this has ultimately enabled us to form a high-quality, highly uniform active region with clean interfaces across the whole layer (see Figure 6). We believe that this high level of uniformity in the quantum wells is

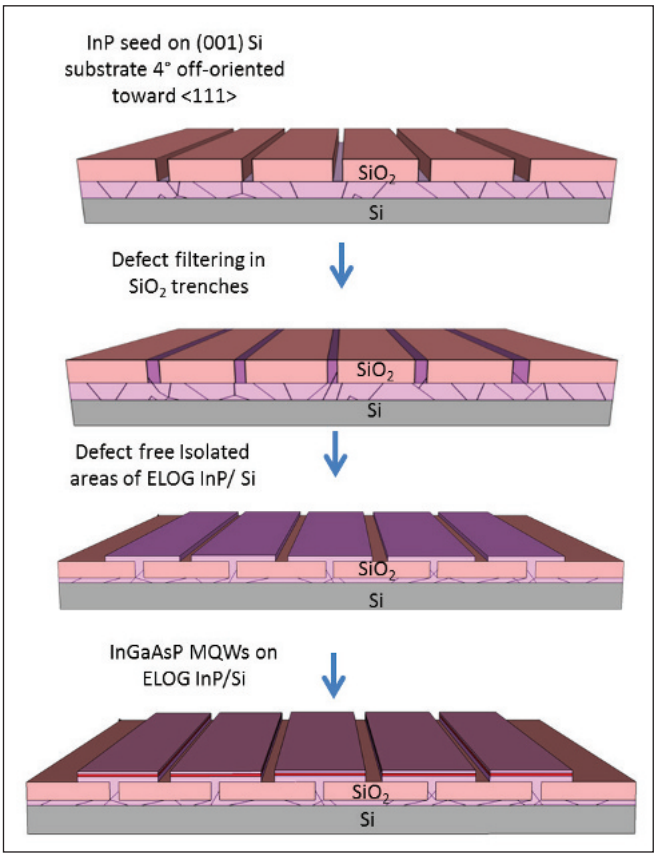


Figure 5. Turning to a new ELOG process led to the formation of un-coalesced large areas of InP on silicon.

also due to the relatively large area of InP available, which is sufficient for broad area laser fabrication. Encouragingly, the photoluminescence produced by these samples is comparable to that emitted by a control sample, which was grown at the same time on planar InP.

Keeping cool

By having InP beneath the laser, rather than an intermediate bonding layer, the surrounding region is far better at sucking heat out of the device and preventing it from over-heating. Interestingly, simulations by our team have shown that the

> “We are still to fabricate final devices using our ELOG technology. However, we don’t anticipate any major obstacles to realising this, given the excellent material quality of the isolated large areas of InP, and the subsequent growth of uniform InGaAsP multiple-quantum wells”

wider the opening in SiO_2, the better the thermal conductivity, so we have tried to use this in our templates. This has led us to optimise the deposition process for structures with 1 μm-wide openings in SiO_2 that are etched to a depth of 2 μm. By optimising our growth process, we can realise complete defect filtering with these processed wafers, while maintaining a smooth SiO_2 surface and sidewalls to avoid generation of any new defects.

Getting the light in

Integration of III-Vs and silicon requires coupling of the generated optical mode in the active region to the underlying silicon. To do this, there must be evanescent coupling of the optical mode with the silicon waveguide, which is buried in the dielectric mask in such a way that the whole structure works not only as a defect filter but also as a platform for evanescent coupling of the optical mode.

Simulations by us, and also by the group of Pallab Bhattacharya from the University of Michigan, show that evanescent coupling can occur between InGaAs/GaAs based quantum dot lasers and a lab-grown silicon-SiO_2 waveguide-cladding structure with similar dimensions. We are still to fabricate final devices using our ELOG technology. However, we don't anticipate any major obstacles to realising this, given the excellent material quality of the isolated large areas of InP, and the subsequent growth of uniform InGaAsP multiple-quantum wells.

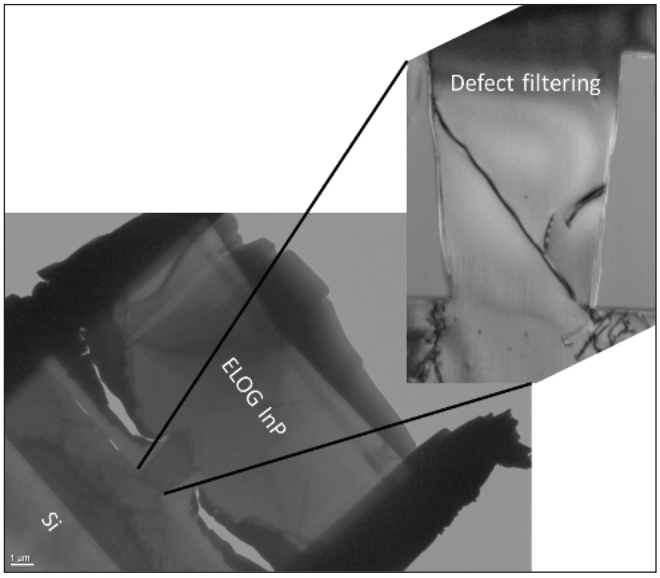


Figure 5. Cross-sectional transmission electron microscopy reveals the defect-filtering mechanism in wide openings.

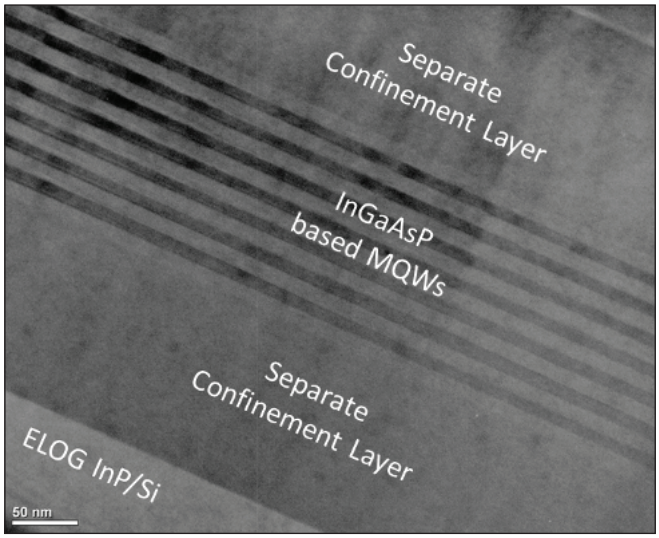


Figure 6. Transmission electron microscopy shows the high quality of the InGaAsP multi-quantum wells grown on uncoalesced ELOG InP on silicon.

One of the challenges that still lies ahead is that the photonic industries continues to live in the micro world, and substantial scaling is therefore required, given that the electronics industry has reached the smallest possible nano-dimensions.

Other groups have started to try and close this gap by either developing tiny plasmonic-based devices or ultra-small cavity lasers based on GaAs nanowires and InP polytypic nanorods – the latter feature ultra-low thresholds.

Our integration scheme may help in all these efforts, because it promises to deliver an affordable, monolithically integrated platform for III-Vs and silicon that can form the foundation for the highly complex photonic integrated circuits needed in the near future.

Several co-workers in our laboratory contributed to this work. This work was partially supported by URO of Intel Inc., US, in which we enjoyed the fruitful collaboration with John Bowers from UCSB.

Further reading

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SiC extends the temperature range for op-amps

Bipolar 4H-SiC technology allows the construction of analogue circuits operating at 500 °C

RESEARCHERS at KTH Royal Institute of Technology have turned to SiC bipolar technology to set a new benchmark for the operating range of a fully integrated op-amp. The team's monolithic amplifier, built using 4H-SiC bipolar technology, can operate at up to 500 °C, and should open the door to other analogue integrated circuits constructed from SiC operating at this temperature extreme.

Carl-Mikael Zetterling from KTH says that the performance of the op-amp is good enough to be used for Venus exploration, and also in aviation, automotive, and oil and gas drilling industries.

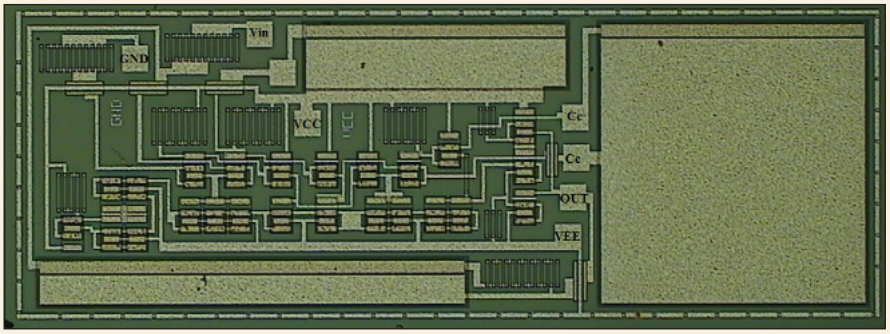
"If higher open loop amplification is needed, more stages can be added," adds Zetterling, who points out that it is relatively straightforward to design any analogue circuit block using SiC technology, since it is bipolar.

Thanks to previous efforts by Zetterling and his co-workers that were reported last year, digital circuits built from SiC can also operate at very high temperatures.

Another material system capable of producing devices working at very high temperatures is GaN.

"But this work explores integrated circuits at high temperatures," explains Zetterling. "So far I have only seen simple GaN ICs like MMICs – on transistor circuits – where as our work opens [the door] for making any integrated circuit at high temperatures."

Zetterling says that bipolar transistors or MOSFETs for CMOS are the preferred technologies for making integrated circuits. He points out that it is only SiC BJTs and JFETs that have demonstrated operation at 500 °C or more, while SiC MOS technology is limited to 400 °C, due to the gate oxide, and silicon-on-insulator technology is only capable of temperatures up to 300 °C.



Monolithic op-amps made with 4H-SiC bipolar technology are capable of operating at 500 °C

The building block for the team's monolithic two-stage op-amp is an npn transistor with a resistive load. This device is formed on a 4-inch SiC wafer accommodating six epilayers with a total thickness of 4.3 μm. Measurements on a transistor reveal a current gain of 38 at 25 °C, falling to 15 at 500 °C.

Op-amp characteristics were determined from on-wafer measurements using a high-temperature probe station. Reliability evaluations were not included, but no degradation in performance was observed during two hours of testing at 500 °C.

At 25 °C and operating in a closed-loop configuration with a 500 Ω resistor connected to the output, the op-amp produced a DC gain of 39.86 dB and a gain bandwidth of 5.92 MHz. At 500 °C, DC gain declined marginally to 39.46 dB, and the gain bandwidth fell to 4.36 MHz. In an open-loop configuration, op-amp gain fell from 76.3 dB at room temperature to 64 dB at 500 °C. According to the team, this decline is small enough to preserve a relatively constant closed-loop gain over a wide temperature range.

Zetterling and co-workers are trying to improve their devices. "We are presently working on the metallisation for high temperature packaged devices, and are doing on-wafer characterisation in air on a hot stage using needle probes."

Another goal for the team is to make new circuits. In addition to the *npn* process, the team has one for making *pnp* transistors, and this pairing of devices will allow the construction of higher-performance amplifiers that can accommodate active loads. "We also have a sigma delta modulator that we plan to publish," says Zetterling.

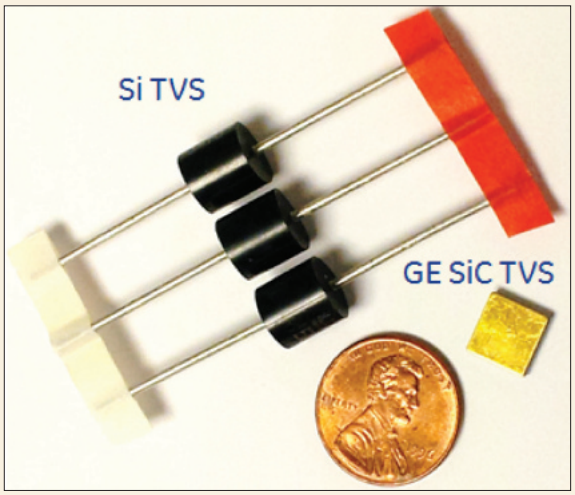
R. Hedayati *et. al.* IEEE Electron Device Lett. **35** 693 (2014)

We are presently working on the metallisation for high temperature packaged devices, and are doing on-wafer characterisation in air on a hot stage using needle probes, was observed during two hours of testing at 500 °C

GE researchers develop 250°C+ SiC Transient Voltage Suppressor

Compact chip can replace multiple silicon TVS devices.

TRANSIENT VOLTAGE SUPPRESSORS (TVS) are critical components for protecting sensitive electronics from lightning, EMI and other temporary over-voltage events that may occur within the system. However, COTS silicon TVS devices are limited in operation to temperatures of about 150°C. At higher temperatures, leakage currents become excessive and the surge current is highly de-rated.



To address this lack of performance at high temperatures, a team led by Avinash Kashyap at the General Electric Global Research Center at Niskayuna, NY has developed a punch-through physics SiC-based TVS device. This could serve aviation, down-hole applications and high performance power electronics.

Currently, the prevailing design technique for reaching the intended protection specifications using silicon TVS devices (when optimal combinations of breakdown voltage and power ratings may not be available) is to connect several parts in series and/or parallel. This takes up valuable board area in space-limited applications, while drastically reducing reliability due to a combination of: increased number of components; and non-ideal current sharing between the devices under short pulse durations, leading to premature failure.

Multiple devices also increase the cost, not only because of the obvious reasons of using more than one part, but also due to increased component up-screening requirements - as the devices have to be closely matched to one another, leading to lower yields.

The punch-through physics based SiC TVS developed by Avinash Kashyap and his team, can replace multiple Si TVS devices with a single, smaller SiC device (shown in a hermetic package above) in certain applications.

The SiC device is capable of operating at 250°C and beyond, with minimal de-rating in the surge capability. Surge testing also demonstrated the device conducting current at over 10 kA/cm^2, at elevated temperatures (225°C). The high current density capability allows the SiC devices to be several times smaller than their silicon counterparts, lending themselves towards miniaturisation. Even at these high current densities, the resistance of the device is low, leading to low clamping voltages (about twice the breakdown voltage at 10 kA/cm^2). Therefore, it is possible to afford a higher level of protection to downstream electronics because their de-rating can then be decreased, allowing for the maximum utilisation of the transistors.

Pictured above: Comparison of leakage currents of Si (blue) and SiC (red) TVS at 225°C. Note the several orders of magnitude lower leakage for the GE SiC device.

According to Kashyap, these new SiC TVS parts can also pass all the DO-160 surge requirements (up to waveform 5, level 5) for aviation electronics and can hence be used in composite aircrafts requiring enhanced lightning surge protection. Since a single device can be used for passing any DO-160 level, it eliminates the need to parallel several parts, and thereby increases the reliability of the overall system. The smaller size has another unintended benefit - lower capacitance compared to equivalent silicon devices, thereby not loading communication buses or in some cases, obviating the need to connect pn-diodes in series.

The ruggedness of the SiC TVS devices were demonstrated thorough multiple DO-160 hits, back-to-back in one minute intervals with no apparent degradation in the electrical characteristics. Some of the devices were tested up to 50 consecutive hits with no failures.

The die temperature increases to high values during surge events, but the unique material properties of SiC (~1.5 times the thermal conductivity of silicon and 17 times lower intrinsic carrier concentration) allows the device to operate without causing thermal runaway even under extreme ambient conditions (>200°C), which would simply not be possible in silicon.

A validation of these facts are the results from long term HTRB tests that have shown no degradation in the leakage current or breakdown voltage at 225°C after over 8000 hours of stress.

This is the first known wide bandgap transient suppressor device that has successfully undergone surge testing not just in terms of high current densities (which can be achieved through small devices), but also high absolute values of current (~3kA with an 8μs/20μs surge waveform), clearly establishing that the GE design can be scaled to large area die with no apparent current sharing shortcomings.

This work will be presented at the IEEE Workshop on Wide Bandgap Power Devices and Applications to be held at Knoxville, TN in Oct. 2014.

Laser fulfils optical interconnect requirements

Quaternary laser combines a small footprint with sufficient power and a low threshold current

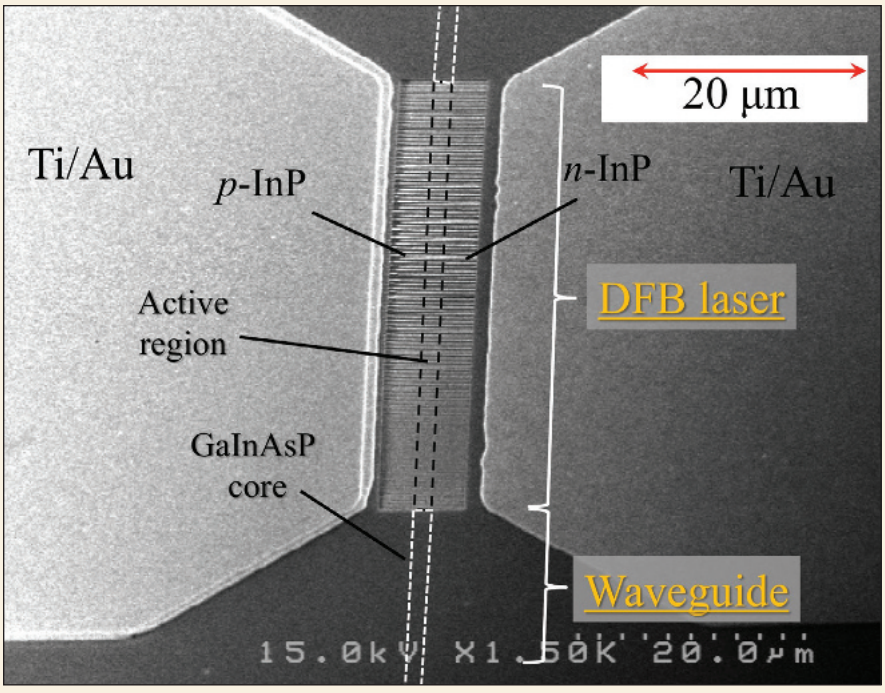
DATA TRANSFER RATES from one silicon chip to another are held back by the copper wires that link them. To unlock this bottleneck, engineers in many different groups have been striving hard to try and develop the III-V lasers that are suitable for deployment in optical interconnects.

Now, Daisuke Inoue from Tokyo Institute of Technology, is claiming that he and his co-workers have broken new ground, fabricating the first lasers satisfying the requirements for on-chip optical interconnection. "Previously reported devices satisfying all of these requirements – such as in-plane integrability, small footprint, sufficient output power and low threshold current – cannot be found."

Inoue and his colleagues from Tokyo Institute of Technology have fabricated GaAsInP-based lasers with a lateral-current-injection architecture and attached them to a silicon wafer using the polymer benzocyclobutene (BCB). Use of BCB has been claimed to compromise performance, by preventing efficient heat extraction from the laser.

Inoue accepts that BCB has a low thermal conductivity, but argues that this does not necessarily have to hamper laser performance: "According to [our thermal] analysis, if ultra-low power consumption operation is achieved, the poor thermal dissipation characteristic will have a small effect on the lasing characteristics."

Lasers were formed by first depositing etch stop layers – 300 nm-thick GaInAs and 100 nm-thick InP – on an InP substrate, and then adding a stack of epitaxial layers, which included a highly doped *p*-type GaInAs contact layer, a strain-balanced active region with five $Ga_{0.22}In_{0.78}As_{0.81}P_{0.19}$ quantum wells, and an un-doped, 50 nm-thick InP cap. The membrane core layer of this MBE-grown structure has a total thickness of 220 nm.



Scanning electron microscopy image of GaInAsP/InP membrane, distributed-feedback lasers integrated with waveguides and detectors.

Engineers then performed a two-step MOCVD regrowth to create a lateral *p-n* junction. This involved forming 7 μm-wide, 50 nm-thick stripes on the epitaxial structure, carrying out a reactive ion etch, and filling trenches with *n*-type InP. Etching away this InP region from one side of every laser structure, and filling it with *p*-type InP, created devices with lateral current injection.

To unite lasers to the silicon substrates, the team deposited a 1 μm-thick film of SiO_2 onto the epiwafer by plasma CVD, and bonded this to the silicon host substrate, which was topped with a spin-coated, 2 μm-thick film of BCB that had been pre-cured at 210 °C in a nitrogen atmosphere. Wafer bonding involved applying a pressure of 25 kPa to the wafers while they were held at 130 °C, followed by hard-curing at 250 °C for one hour in a nitrogen atmosphere.

Polishing and selective wet chemical etching removed the InP substrate, the etch stop layers, and then the contact layer in all areas apart from the *p*-electrode region. After removing the *p*-type InP cap on the *n*-electrode region, Ti/Au electrodes were added on the heavily doped *p*-type GaInAs contact and the *n*-type InP.

It took an hour to remove the 600 μm-thick InP substrate by chemical polishing and wet etching. "We are considering to re-use the InP substrate by applying a smart-cut technique," says Inoue.

Cleaving the wafer formed Fabry-Perot lasers with a 350 μm-long cavity and a 0.7 μm stripe-width had a 2.5 mA threshold current, a front facet external differential quantum efficiency of 22 percent, and a 1.1 mW output at a 10 mA injection current. Since near-facet and far-facet light output were identical, the differential quantum efficiency of the device was 44 percent. Inoue says that the introduction of a distributed feedback structure will drive down the threshold current to below 100 μA, leading to a high efficiency for optical interconnects.

"Our target on the performance of the lasers will soon be realised," explains Inoue, who reveals that the team's next plan is to implement the semiconductor membrane optical interconnection on CMOS large-scale-integration chips.

D. Inoue *et. al.*
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Nitride LEDs emit in the red

Aluminium-rich interlayer boosts efficiency at longer wavelengths

RESEARCHERS from Toshiba are claiming to have produced the first red-emitting LED with an output power exceeding 1 mW at 20 mA.

Under that drive current, a 629 nm LED delivered 1.1 mW at an external quantum efficiency of 2.9 percent.

Producing efficient emitters in the green, yellow, orange and shorter-wavelength red is challenging, but this success should help the development of white light sources that combine a very high colour-rendering index with an absence of energy-sapping, colour-converting phosphors.

Efforts by Toshiba's engineers could help to lead to the commercialization of red, nitride-based LEDs.

Reaching shorter wavelengths with today's commercial, AlGaInP-based red-emitting LEDs is not possible, due to a transition from a direct to an indirect bandgap. So what is needed is to stretch the emission of nitride LEDs, which can deliver external quantum efficiencies in excess of 80 percent in the blue, to longer wavelengths. Efficiency of the nitride LED declines at longer wavelengths due to the quantum-confined Stark effect (QCSE): an internal electric field pulls apart electrons and holes, hampering radiative recombination.

Turning to semi-polar or non-polar substrates can reduce or eliminate these fields, but a higher indium content is then be needed, because the QCSE leads to a red-shift in emission. Increasing the indium content in the InGaN quantum well is far from trivial, because significant lattice mismatch between InGaN and GaN can cause the well to be riddled with light-sapping defects.

Toshiba's engineers have been able to overcome this by introducing an AlGaN interlayer into the active region.

Production of these devices involved atmospheric MOCVD growth on *c*-plane sapphire. Construction of the LEDs began with a 2 μm-thick undoped GaN layer and a 3 μm-thick silicon-doped GaN layer, which had an estimated threading dislocation density of 4×10^8 cm^{-2}. The four-period multi-quantum well active region that followed consisted of a 3 nm-thick InGaN quantum well layer, a 1 nm-thick AlGaN interlayer, and a 10 nm-thick InGaN barrier. Well and interlayer were grown at 755 °C, while the barrier was grown at 100 °C higher. Addition of a magnesium-doped *p*-type GaN layer and heavily-doped cap completed the growth.

In these devices, the indium content in the well is estimated to be 35 percent, while in the barrier it is below 1 percent. Meanwhile, the aluminium content in the AlGaN layer is varied: in one type of device it is around 30 percent, but in another type it is about 90 percent.

To test device performance, simple device structures were formed with a transparent indium-tin-oxide *p*-type contact and an *n*-type electrode formed from a Ti/Pt/Au stack. Ray tracing calculations indicate that the light extraction efficiency from these chips should exceed 60 percent. Dark spots and dotted emission are seen in fluorescence images of the LED with the $Al_{0.3}Ga_{0.7}N$ layer. These imperfections are present, but far less pronounced, in the device with an $Al_{0.9}Ga_{0.1}N$ layer.

To understand why this is, the team evaluated surface morphology of the quantum well, interlayer and barrier with atomic force microscopy (AFM), scrutinising samples with growth stopped on top of each of the layers. This approach uncovered an atomic-step-and-terrace structure in the quantum well layer, which featured V-shaped defects with a density of 5×10^8 cm^{-2} – this is comparable to the threading dislocation density.

Further revelations from the AFM study included a smoothing of the surface with the addition of the $Al_{0.3}Ga_{0.7}N$ layer, which did not occur for the $Al_{0.9}Ga_{0.1}N$ layer that had a three-dimensional structure. Differences in lattice mismatch are thought to be behind this.

Depositing the barrier improved the surface morphology of the structure with the $Al_{0.9}Ga_{0.1}N$ layer, while V-shaped defects with a larger diameter than seen before appeared after a barrier covered the $Al_{0.3}Ga_{0.7}N$ layer. The density of these defects was 1.5×10^9 cm^{-2}, compared with 7×10^8 cm^{-2} for the structure with an $Al_{0.9}Ga_{0.1}N$ layer.

The team speculates that the density of V-shaped defects exceeds that of threading dislocations due to the generation of misfit dislocations. It is possible that the misfit dislocations are suppressed with the $Al_{0.9}Ga_{0.1}N$ layer, thanks to strain compensation.

Based on these observations of surface morphology, the team constructed LEDs with an $Al_{0.9}Ga_{0.1}N$ layer. Driven at 20 mA, devices produced 1.1 mW at 629 nm, while cranking the current up to 250 mA increased the output to 7.8 mW, and blue-shifted the emission to 607 nm.

J-Il. Hwang *et. al.*
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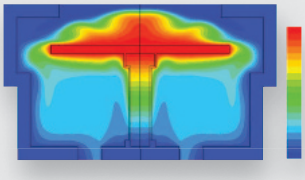

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News Digest Contents

LEDs

Seoul Semiconductor Launches Smart Lighting Acrich LED Light Engine

Device features efficiencies of up to 100 lumens per watt.

Seoul Semiconductor has released a new LED light engine with Acrich 3 technology. The device combines as LED module with Acrich MJT 5050 series LED, Acrich3 IC technology, and an innovative heat sink and secondary optics.

Acrich is claimed to be the first semiconductor light source that operates directly from both AC and DC power supplies. 'Acrich MJT - Multi-Junction Technology' is a proprietary family of high-voltage LEDs.The Acrich light engine does not require a complex AC/DC converter and can be operated directly from the AC mains which simplifies designs, reduces component count and improves on the reliability of the luminaire.

The new 30W Acrich engine delivers a typical luminous flux of 3000 lumens at 120VAC operation at 5000K corresponding to a typical efficiency of 100 lumens per watt. When operated in a power compensation mode the Acrich3 technology can adapt to variations in the line-voltage as great as 20 percent and still deliver power-level regulation within 5 percent to ensure uniformity of the light output.

Furthermore, the new Acrich3 solution enables smart lighting control systems the Acrich3 technology can interface through a wide variety of wireless networks such as IEEE 802.15.4, WiFi, and Bluetooth to control dimming, and further optimize on energy savings. This IP67 light engine is available in various color temperatures and beam patterns.

Seoul Semiconductor executive vice president of lighting sales division, Jay Kim said: "The payback period for streetlights can be significantly reduced with this new Acrich light engine. By eliminating AC/DC converters in streetlights, maintenance costs can be lowered and reliability can be improved without compromising on price, quality and energy savings to dramatically improve the lighting experience for customers. This product will enable the market to come up with the next generation of high quality, energy efficient and competitively priced LED lamps."

Seoul Semiconductor Seoul Semiconductor is a Global LED Manufacturer and was ranked as the fourth largest manufacturer of LED packages in 2013 according to IHS Technology market research firm.

Cree Introduces Replacement for Halogen MR16 Lamps

TrueWhite LED lamps use 83 percent less energy

Cree has introduced the MR16 Series LED lamps with TrueWhite Technology, that delivers the soft, diffused light of a traditional 50W halogen MR16 lamp. According to the company, the lamps consume up to 83 percent less energy and are designed to meet ENERGY STAR qualification.

"Cree's latest innovation is poised to replace the billions of MR16 lamps currently installed around the world by delivering an unprecedented combination of energy savings, colour quality and compatibility. The Cree MR16 Series TrueWhite LED lamp is setting a new standard for the category," said Norbert Hiller, Cree executive vice president, lighting.

Featuring a design that delivers greater than 580 lumens in conjunction with a proprietary lens, Cree MR16 Series TrueWhite LED lamps eliminate the glare commonly associated with 50W halogen MR16 lamps to deliver a soft, diffused light with category-leading colour rendering index of 92.

Cree and Lextar Electronics Announce LED Cooperation

Cree to own nearly 13 percent of Lextar as part of deal

Cree, a market leader in LED lighting, and Lextar Electronics, a subsidiary of AU Optronics specialising in high-brightness LED epitaxial, chips and packages have entered into a supply agreement for sapphire-based LED chips.

As part of the agreement, Cree will invest approximately $83 million to purchase 83 million Lextar shares at a price of NT$30 per share. Lextar and Cree will also enter into a long-term LED chip supply agreement, as well as a royalty-bearing license agreement for certain Cree LED chip and component intellectual property. Upon closing of the investment, Cree will own approximately 13 percent of Lextar.

“We are excited to be strengthening our relationship with Lextar to enable growth in LEDs and Lighting,” stated Chuck Swoboda, Cree chairman and CEO. “Working with Lextar to supply high quality mid-power LED chips enables Cree to focus its resources on the high performance, high-power LED chips that differentiate Cree LEDs in the market. This approach provides the operational and financial flexibility to help Cree achieve the best return on our people and invested capital.”

“Lextar has established a strong technology position and customer base in the mid-power backlighting LED segment, while Cree has had outstanding performance in the high-power LED component and lighting markets,” said David Su, chairman and CEO of Lextar.

He added: “We are very excited about this new cooperation with Cree. We strongly believe this new collaboration will increase the competitiveness of our products and technology, enabling both companies continued growth in the LED lighting market. Furthermore, the cross license of LED chip and component intellectual property will afford both Cree and Lextar the benefits from our product and technology development, thereby strengthening our mutual competitiveness in the global LED industry.”

The agreement has been approved by the boards of directors of both companies, and is targeted to close in Cree’s second quarter of fiscal year 2015, subject to the approval of Lextar’s shareholders and the Taiwan Investment Committee, and other customary closing conditions.

SemiLEDs introduces new Chip Scale LED Series

Combines flip chip and ReadyWhite technologies for white-chip solution

SemiLEDs Corporation has announced sampling and mass production of its newest line of white chip scale packages, the ReadyMount Enhanced CSP, or EC series.

Combining SemiLEDs’ Enhanced Flip chip (EF) approach with the company’s ReadyWhite phosphor technology, the EC is said to offer flexibility, reliability and manufacturability in a single 1.4 x 1.4mm with a low profile device of 0.4mm.

In addition to the manufacturing benefits of the chip scale package, the elimination of the wire bonds is claimed to improve the optical integration characteristics by taking advantage of the unobstructed and nearly edge-to-edge emitting chip surface which enables the die to be mounted very close together.

This simplifies the optics by eliminating the need for complex mixing lenses which are used to control ghosting and shadows in narrow beam applications. The glass top surface is also mechanically robust, and is not prone to the handling damage or stresses faced by wire-bond or flip chips with a

silicone covering. The typical 145 degree field of view also demonstrates good colour-over-angle characteristics as a result of the ReadyWhite technology.

Mark Tuttle, general manager for SemiLEDs Optoelectronics, said: “Our unique Chip Scale Package brings all the benefits of SemiLEDs’ rugged EF Series FlipChip architecture to an extremely compact emitter, which is simple to integrate using standard tape and reel surface mount manufacturing. This innovation reduces final component cost up to 50 percent, with a packaging cost reduction of up to 80 percent over conventional packaging. EC Series products, such as the EC-W1414, enable system-integrators and luminaire manufacturers a direct path to a highly cost effective solution on a per-lumen basis now, with additional viewing angles and die sizes under development.”

The EC is rated for input power of up to 3W and is a fully packaged white emitter SMD component, ready for surface mounting on any board level module or COB application. The compact chip scale package can produce outputs of up to 300 lumens at 1A. The SemiLEDs EC series is available in standard ReadyWhite correlated colour temperatures ranging from 2700K to 10,000K with colour rendering indices up to 90 minimum.

While useful for creating compact multi-die white packaged LEDs, the ReadyMount products will provide particular benefit to light-engine and luminaire manufacturers who have previously had to rely exclusively upon packaged die solutions, says the company.

Space Station crew can do bio experiments thanks to SETi’s UV LEDS

High power LEDs decontaminate surfaces, liquids and air inside experiment ‘glovebox’

Conducting science experiments in space aboard the International Space Station, presents many challenges from working in a microgravity. But thanks to the Microgravity Science Glovebox (MSG), those aboard the space station have been able to safely conduct their experiments since 2004.

Over the past ten years, the MSG has been put to good use on a wide range of research programs but now, thanks to the activation of a new decontamination system inside the MSG, crew members can safely perform biological research.

Developed and built by Teledyne Brown Engineering (TBE) the decontamination system makes use of high-power Uvclean ultraviolet LEDs developed by Sensor Electronic Technology Inc (SETi) in part through the DARPA Compact Mid-Ultraviolet Technology (CMUVT) program.

Above: NASA astronaut Rick Mastracchio, Expedition 38 flight engineer, prepares to test the ultraviolet light decontamination hardware. ***Image Credit: NASA***

The UV LEDs have the power to sanitise the surfaces, liquids and air inside the MSG in a matter of minutes and are used before and after the experiments are conducted for the safety of the crew.

The upgraded MSG with TBE›s decontamination system and SETi›s UV LEDs will allow for a much wider range of microgravity experiments and will be available to all biological payloads that operate in the MSG with a concern about contamination.

«Our products passed space flight qualification in the past», commented Remis Gaska, president and CEO of SETi, «However, this is the first space launch, installation and successful testing of our devices in the orbit. This demonstrates the level of maturity of Deep UV LED technology».

SemiLEDs Launches FlipChip LED Series

Enhanced flip chip method maximises lumen density and simplifies integration

SemiLEDs Corporation has announced sampling and volume availability of the first in its new Enhanced FlipChip, or EF, LED series. The series launches with the EF-B40, a blue 40-mil flip chip that the company says simplifies packaging and integration by eliminating wire-bonding.

SemiLeds adds that the series offers improved lumen-density while enabling packagers to use standard surface mount assembly techniques.

Mark Tuttle, general manager for SemiLEDs Optoelectronics explained, "SemiLEDs'unique flip chip approach combines a sapphire front surface and proprietary back side architecture that provides the electrical contacts exclusively on the bottom of the chip, making it fully compatible with chip-on-board (COB) surface mount processes. Eliminating wire-bonds also lowers the profile of the chips, and allows them to be placed more closely together, which results in higher lumen-density and reduces the complexity of the optics. The EF series is an ideal platform for COB assemblies, or really for any approach that calls for either secondary optic design or high-density mounting."

Flip chip construction presents what was originally the bottom sapphire layer in a horizontal LED structure as the top surface of the chip. By flipping the chip, the electrical pads become part of the bottom of the device rather than running bonding wires from the top surface of the chip down to the package or board. The delicate areas of the chip are therefore protected by the clear sapphire layer and by eliminating wire bonds, both reliability and overall design flexibility of the packaged device are increased. In addition, individual chips may be more closely mounted. The nearly continuous light emitting surface, unbroken by gaps, bonding wires, or top electrodes, can simplify the mounting and mixing requirements of the optics, producing smooth lighting effects. In addition, in a flip chip structure, the heat-generating junction is positioned adjacent to the substrate, increasing thermal conductivity and allowing improved device performance at high currents.

The EF-B40 is available in wavelengths from 445 to 460nm, with outputs of up to 300 lumens at 1A as a packaged emitter. The SAC compatible chips are offered with standard Au bonding pads, or are available with an AuSn option to further reduce thermal resistance and add to system reliability. A 140-degree viewing angle makes the EF ideal for general and commercial lighting, while the lowered profile addresses the application needs of LED backlight, smartphone flash or LED projector.

Chip on Board LED to reach over £9000m by 2020

According to a new report by Grand View Research, the global chip-on-board LED market is expected to reach $9179.7m by 2020. Increasing urbanisation and infrastructure spending are expected to be the key drivers of growth over the forecast period.

Key findings of the report '*Chip on Board (COB) Light Emitting Diode (LED) Market Analysis By Application (Automotive, Backlighting, Illumination) And Segment Forecasts To 2020*' are that the illumination segment, which dominates the market, will be the largest and fastest-growing application over the next six years.

This segment accounted for over 45 percent of the market in 2013, mainly because of COB LEDs' wide area light-emitting property. The backlighting application segment is expected to grow substantially due to the rise in the number of applications in handheld devices, monitors and LED televisions.

Asia Pacific accounted for over 50 percent of global market revenue in 2013, and is expected to

dominate demand over the forecast period. Further, it is expected to exhibit the fastest growth from 2014 to 2020, due to government initiatives favoring COB LED adoption and a large number of market participants.

Key firms operating in the market include Philips LumiLEDs Lighting Company, Cree Inc, Samsung Electronics Co Ltd, Citizen Electronics Co Ltd, Osram Opto Semiconductors GmbH, Everlight Electronics Co Ltd., Seoul Semiconductor Co Ltd, Nichia Corp, Lumens Co Ltd, and LG Innotek Co Ltd.

The market is consolidated in nature, and the development of efficient and cost-effective products is expected to serve as a key growth strategy over the forecast period.

Hong Kong team integrates on-chip light source with III-nitride electronics

Approach holds promise for synchronous RF/optical comms and more...

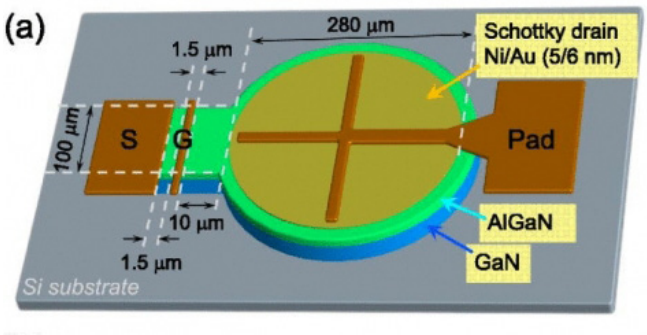
Integrating III-nitride-based light-emitting and electronic control devices would help make more compact optoelectronics systems such as on-chip lighting control, synchronous RF/optical communications, and opto-couplers for power conversion. But attempts to grow LED and HEMT structures on the same substrate have been hampered by the incompatibility of their optimised growth temperatures and by the complexity of integrated devices with different active layers.

Now a team from Hong Kong University of Science and Technology has reported producing GaN band-edge ultraviolet emission at 3.4eV at room temperature, at a small forward bias larger than -2V, from a simple metal-AlGaN/GaN Schottky diode. Their findings were published in Applied Physics Letters **105** (2014).

Schottky-drain electrode in an AlGaN/GaN HEMT

The researchers' goal was to produce electroluminescence (EL) at room temperature from metal-AlGaN/GaN Schottky diodes on a conventional doping-free III-nitride heterostructure suitable for HEMTs. (EL was first discovered in a metal-SiC structure in 1907. EL emissions from Schottky diodes on Si, II-VI, and III-V semiconductor have also been reported by research groups over the last 30 years).

By employing a semi-transparent Schottky-drain electrode in an AlGaN/GaN HEMT, the team succeeded in building a UV high electron mobility light-emitting transistor (HEM-LET) in a relatively straightforward manner. Figure **a)** below presents the schematic device structure of the device demonstrated in this work.



The team used an AlGaN/GaN heterostructure consisting of a 21nm Al 0.25Ga 0.75 N barrier and 3.8μm GaN buffer, grown by MOCVD on a 4inch p-type S (111) substrate. The heterostructure contained a 2DEG channel of density $10^{13}/cm^{-2}$ and mobility $2080 cm^2/V^{-1}s^{-1}$ at room temperature.

They defined the ohmic contacts using photolithography and formed them with Ti/Al/Ni/Au metallisation annealed at 850degC for 30s in N 2 ambience. Remote plasma pretreatment in an atomic-layer-deposition (ALD) machine was used to remove the residual native oxide and nitridise the surface. The passivation and surface protection layer was an AlN/SiN x (4/50nm) stack.

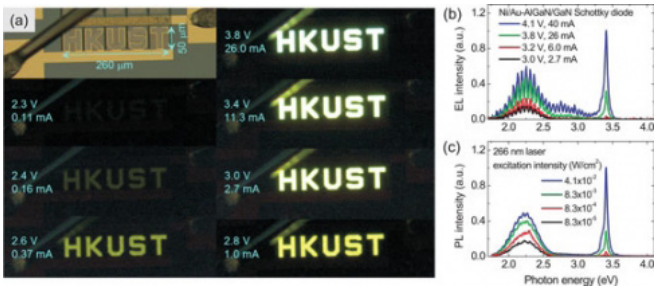
After the Schottky area was defined with photolithography, the SiN x was dry etched by a low-power plasma process and the AlN thin film removed by dilute alkaline solution. Then the semitransparent Schottky metal Ni/Au (5/6 nm)

was deposited using an e-beam evaporator. A high electron mobility light-emitting transistor (HEM-LET) with ohmic source and semitransparent Schottky drain was made simultaneously.

Ni/Au (20/200 nm) was used as the gate metal and a SiN x/AlO (15/8 nm) stack insulator used as the gate dielectric for the HEM-LET, in order to single out the Schottky drain. Finally, the device was annealed at 400degC for 10 minutes in N2 ambience.

EL emission at room temperature

The team measured the current- voltage characteristics, and the EL and photoluminescence (PL) spectra. (A 266nm laser was used to excite the AlGaN/GaN heterostructure for the PL measurement).



With semi-transparent Ni/Au (5/6 nm) Schottky metal, the team reported clearly seeing EL emission from the Ni/Au-Al 0.25Ga 0.75 N/GaN Schottky diode at room temperature when the forward bias is higher than 2.2V. The EL intensity becomes stronger at a higher bias.

They found that the EL spectra consisted of not only yellow and blue luminescence but also a narrow GaN band-edge UV component at 3.4eV, similar to the PL spectra of the AlGaN/GaN heterostructure as shown in graph c) above.

Both the EL and PL spectra are from the GaN layer; no emission from the thin AlGaN barrier layer was detected. The yellow/blue is due to radiative transition of electronics from conduction band of a shallow donor to a deep acceptor in the GaN layer. Its relative intensity, compared with GaN band-edge UV emissions decreased with increasing bias/ current or laser excitation intensity in both the LE and PL spectra

The team also experimented with another Schottky metal, Pt/Au and found similar results concluding this is a general property of metal-AlGaN/GaN Schottky diodes.

From these results, the researchers think it would be possible to realise synchronous radio-frequency/ optical communications using an AlGaN/GaN HEM-LET, and an all-on-chip opto-coupler for III-nitride power electronics.

They also suggest that the metal-AlGaN/GaN light-emitting Schottky diode provides an alternative for micro-display with unique advantages. The back electrode is served by a high-mobility 2DEG channel, and the pixel is defined by the top Schottky contact, eliminating th mesa etching process and current spreading design and allowing for a higher resolution and smaller pixel size.

Plessey expands its distribution network for GaN-on-Si LEDs

Solid State Supplies appointed for the UK and Ireland

Plessey announced that it has entered into a distribution agreement with Solid State Supplies Ltd, an electronics distributor headquartered in Redditch, UK, to expand its European network with coverage in the UK and Ireland market for its GaN-on-Si LED products.

John Macmichael, managing director of Solid State Supplies said: “Plessey’s GaN-on-Si technology looks set to cause major disruption in the LED lighting market. Our in-house lighting division is already geared up to support lighting and luminaire designers with these new LEDs. We look forward to a very bright future in partnership with Plessey.”

David Owen, Plessey’s regional sales director, added: “Plessey is very pleased to join forces with a distributor that has a focused lighting division already up and running, helping the significant number of lighting and luminaire makers in the UK. Solid State Supplies has a strong portfolio of products to support the lighting eco system which is

now enhanced by the addition of the Plessey GaN-on-Si LED product range. This will accelerate the time to market for Plessey LEDs in this region."

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

ProPhotonix releases 3D Pro Laser Green Series

New range of laser diode modules provides compact solutions for machine vision

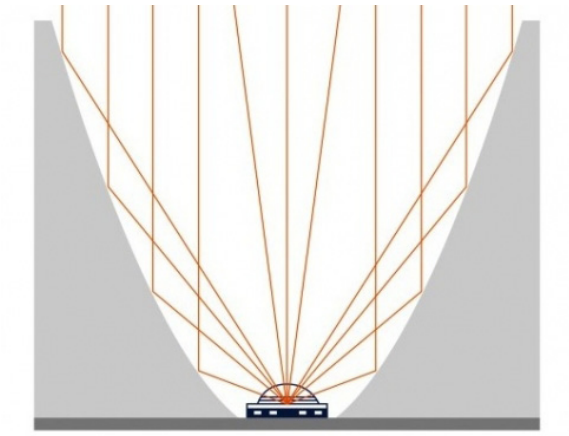
ProPhotonix Limited, a designer and manufacturer of LED illumination systems and laser diode modules with operations in Ireland and the UK, has announced the release of the 3D PRO Laser Green Series, an extension of the structured light laser product portfolio.

The 3D PRO Laser Green series includes the 3D PRO Green, the Adjustable Focus 3D PRO Laser Green and the 3D PRO Laser Mini Green, all available in either 19mm or 10mm diameters. These direct emission green structured light lasers deliver excellent uniformity making them an ideal solution for a wide range of 3D imaging applications.

The 3D PRO Laser Green Series of 520nm structured light lasers are available in a range of output powers and with uniform line and diffractive options.

Osram introduces 940nm IR LED with 150degree beam angle

Better beam shaping, with more compact optics

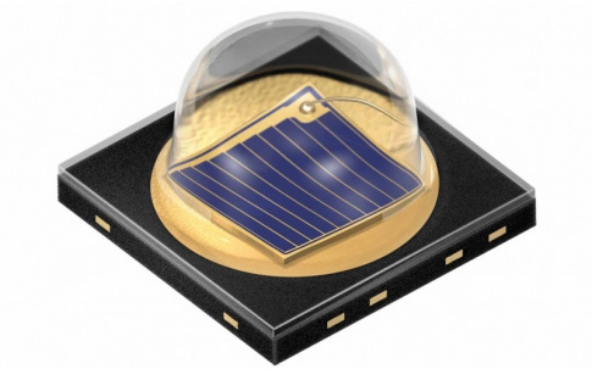


Osram Opto Semiconductors is launching the SFH 4726S, a high-power member of its IR Oslon Black product family with a wide beam angle of 150degrees.

When integrated in reflector-based optics, the infrared LED (IRED) pre-shapes the light beam, concentrates it and can then focus it efficiently via other optics. As a result, smaller optics can be used, permitting generally more compact lighting solution designs. This system will replace the current conventional approach, which requires optics with a much larger optical aperture. Customers also stand to benefit, for the smaller dimensions offer much greater design freedom for lighting solutions. Another advantage of the new IRED is its high optical performance of 990mW at a current of 1A.

Like its sister IRED product, the SFH 4725S, the new Oslon Black has a wavelength of 940nm. This long-wave radiation at the red end of the spectrum is barely visible to the human eye. Even the slight red glow which can be perceived at a wavelength of 850nm rarely occurs with this version. Infrared LEDs are hence suited for discreet surveillance applications; for instance in the main hall of a bank or at border crossings.

The launch of the SFH 4726S now provides customers with another Osram product for discreet security surveillance. Other fields of application for the IR Oslon Black family include optical vehicle security systems or gesture detection for computer games.

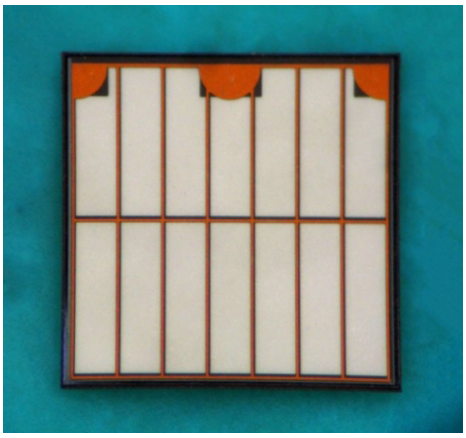


Earlier, the company also announced the 850nm Oslon Black SFH 4715A (pictured above), which boasts a typical electro-optical efficiency of 48 percent.

Commenting on the the SFH 4715A, Jörg Heerlein, senior manager for product marketing at Osram Opto Semiconductors said: “We are not aware of any other opto-electronic component with an optical efficiency to rival this one. Thanks to a boost in output to 800mW (previously 630mW) the new Osram IRED can illuminate objects over 100m away depending on the application and type of external optics. What’s more, this higher output generates more light, improving the image in the process.”

SemiLEDs Releases Complete line of 80mm rugged LED chips

Includes ReadyWhite kilolumen devices, blue and UV



Taiwan-SemiLEDs Corporation has announced sampling and volume availability of a complete line of 80x80mm rugged metal LED chips, including white, blue, and UV variations.

The EV-80mil family allows packagers and integrators a wider variety of high-efficiency/high-output choices to address the growing number of applications in both the commercial lighting and industrial spaces.

With the new family, a single 80x80mil device will typically replace four 40x40mil LED chips, which simplifies packaging and optical designs, while minimising color fringing and shadow effects common to multi-chip implementations. SemiLEDs EV family, which combines vertical LED architectures with rugged copper-alloy substrates, has proven to be especially well-suited for handling the increased thermal and electrical demands of large-chip implementations.

Tuttle, general manager for SemiLEDs Optoelectronics Co, commented: “Applications in commercial and residential lighting, along with UV industrial applications, share the common challenge of achieving high output in compact form-factors, in the most cost-effective manner. SemiLEDs’ unique vertical-metal architectures allow these devices to be driven hard, without compromising either their stability or reliability, allowing packagers and integrators to deliver maximum optical power from extremely small package or chip-on-board footprints.”

Tuttle continued: “The EV-80mil line is also able to deliver substantial versatility, including die-level white options that incorporate SemiLEDs’ proprietary ReadyWhite(tm) phosphor coating technology, which minimises blue-leakage and delivers impressive levels of color uniformity with tight binning options for low-profile and multi-colour white packaged LEDs.”

The new EV-80mil ReadyWhite chips incorporate SemiLEDs’ proprietary phosphor technology, and when packaged in a typical 5x5mm ceramic package, can be expected to deliver up to 1200 lumens at 3A. They are available in correlated colour temperatures (CCTs) ranging from 2600 to 10,000K with colour rendering indices from a minimum 65 to a minimum of 90, after packaging.

Combined with their vertical LED chip architecture, SemiLEDs’ ReadyWhite solutions deliver a

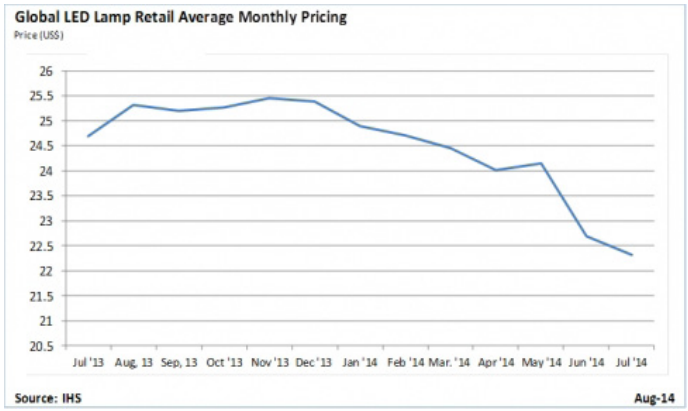
package-ready white chip to COB, single-die or multi-die packaging applications, eliminating requirements for sophisticated and costly phosphor manufacturing technology. When driven with currents below 1.0A, with the 80mil ReadyWhite chips deliver up to 145 cool white lumens per watt in typical package configurations, and are suited for such applications as outdoor street or area lighting, or heavy duty flashlights/torches.

The 80mil blue chips are available in standard wavelengths from 445 to 460nm, with options up to 470nm additionally available upon request, and deliver up to 4000mW of optical power at 450nm in typical ceramic packaging. As single-chip implementations, the ReadyWhite and blue chips are ideally suited to narrow beam pattern kilolumen applications that benefit from simplified optics and compact emitter sizes, including projectors, MR/GU/PAR spotlights, and automotive front lighting. The reduced chip count from the larger devices also simplifies system architectures for high-bay and other multi-die kilolumen applications.

LED Lamp Price down nearly 10 Percent on July 2013

Lumens-per-dollar ratio up by 17.6 percent

The July 2014 release of the IHS Technology LED lamp Retail Price Tracker has found that the global average retail price of LED lamps was $22.31, indicating a fall of 1.6 percent in July 2014 from the prior month, and down 9.6 percent compared to the same time a year earlier in July 2013.



Over the past 12 months, the lumens-per-dollar ratio of LED lamps has increased by 17.6 percent to 34.3 lumens per dollar.

IHS has been tracking LED lamp retail pricing trends for more than two and half years. Each month IHS analysts sample of 2,600 individual LED lamps sold in retailers across 15 countries globally.

Oclaro Japan sells LED business to Ushio

Deal includes LED, red, violet and some infrared laser diodes

Ushio Inc has announced that its subsidiary Ushio Opto Semiconductors, headquartered in Tokyo, has signed an agreement to acquire the LED, red, violet and part of the infrared laser diode business from Oclaro Japan.

By this transfer, Ushio aims to expand of its solid-state light sources business. Ushio will receive transfer of the business related to the development, manufacture, and sales of semiconductor lasers and LEDs (other than Oclaro Japan's optical communication business) from Oclaro Japan.

"Today, optical processes and applications have become more and more diversified and important in the industry. We at Ushio will provide a variety of light sources, including high-brightness and high-quality LEDs and LDs, as well as our existing lamp products to meet the diversified needs of our customers," commented Shiro Sugata, president and CEO of Ushio Inc.

"We are pleased to sign this agreement with Ushio, it was critical for Oclaro Japan to find a respected partner that would provide new opportunities to our Komoro employees and continued support and innovation to our customers," commented Tadayuki Kanno, president of Oclaro Japan.

The closing of the transaction is expected to occur

during the fourth calendar quarter of 2014.

Ushio Opto Semiconductors was established in July 2014 as a wholly owned subsidiary of Ushio Inc. Established in 1964, Ushio Inc manufactures light sources in a broad range from ultraviolet to visible to infrared wavelengths, as well as of optical equipment and cinema-related products that use these light sources. It also makes semiconductors, flat panel displays and electronic component.

Oclaro Inc makes optical components, modules and subsystems for the core optical, enterprise and data centre markets, based on more than three decades of laser technology innovation, photonics integration, and subsystem design.

Novati gets 'trusted foundry' stamp for US defence applications

One of only nine fabs to win DoD accreditation

Novati Technologies, a developer of photonics, MEMS, 2.5D/3D, III-V-on-silicon and nanotechnology products, has announced that its wafer fab in Austin, Texas has been accredited by the US Department of Defense (DoD) as a Category 1A Trusted Foundry.

The DoD accreditation distinguishes Novati as a trusted manufacturer of integrated circuits for US aerospace and defence applications. Category 1A has been granted to only nine CMOS fabs that exhibit the highest levels of process integrity and protection.

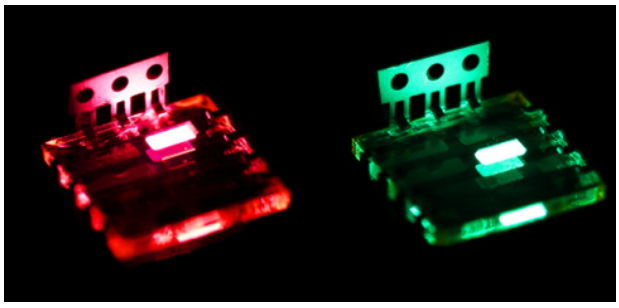
Novati builds MEMS, sensors, actuators, photonic and electro-optic devices, Infrared (IR) detectors, wide bandgap electronics, non-volatile memory, power semiconductors, RF devices and a range of 2.5D/3D devices for aerospace and defence customers.

"Today's security applications for DoD demand suppliers who can meet the most rigorous requirements for utilising non-traditional elements and support low-volume manufacturing," said David Anderson, president and CEO for Novati. "We've proven that customers with really tough problems that require innovative materials, combinations of heterogeneous devices and high-risk processing techniques come to Novati. We regularly help develop products from concepts that have never been built before. The Trusted Foundry accreditation reflects our focus and strong commitment to supporting aerospace and defense contractors."

The Trusted Foundry program, administred by the Defense Microelectronics Activity (DMEA) organisation on behalf of the DoD, ensures that the US government has guaranteed access to specialised, high-performance components.

Perovskite semiconductor shows promise for low cost LEDs

Material can be easily tuned to emit light in a variety of colours, say researchers



A hybrid form of perovskite - the same type of material which has recently been found to make highly efficient solar cells - has been used to make low-cost, easily manufactured LEDs, potentially opening up a wide range of applications such as flexible colour displays.

This class of semiconducting perovskites have generated excitement in the solar cell field over

the past several years, after Henry Snaith's group at Oxford University found them to be remarkably efficient at converting light to electricity. In two years, perovskite-based solar cells have reached efficiencies of nearly 20 percent, a level which took conventional silicon-based solar cells 20 years to reach.

Now, researchers from the University of Cambridge, University of Oxford and the Ludwig-Maximilians-Universität in Munich have demonstrated a new application for perovskite materials, using them to make high-brightness LEDs. The results are published in the journal *Nature Nanotechnology*.

Perovskite is a general term used to describe a group of materials that have a distinctive crystal structure of cuboid and diamond shapes. They have long been of interest for their superconducting and ferroelectric properties. But in the past several years, their efficiency at converting light into electrical energy has opened up a wide range of potential applications.

The perovskites that were used to make the LEDs are known as organometal halide perovskites, and contain a mixture of lead, carbon-based ions and halogen ions known as halides. These materials dissolve well in common solvents, and assemble to form perovskite crystals when dried, making them cheap and simple to make.

"These organometal halide perovskites are remarkable semiconductors," said Zhi-Kuang Tan, a PhD student at the University of Cambridge's Cavendish Laboratory and the paper's lead author. "We have designed the diode structure to confine electrical charges into a very thin layer of the perovskite, which sets up conditions for the electron-hole capture process to produce light emission."

Spin-coating

The perovskite LEDs are made using a simple and scalable process in which a perovskite solution is prepared and spin-coated onto the substrate. This process does not require high temperature heating steps or a high vacuum, and is therefore cheap to manufacture in a large scale. In contrast, conventional methods for manufacturing LEDs make the cost prohibitive for many large-area display applications.

"The big surprise to the semiconductor community is to find that such simple process methods still produce very clean semiconductor properties, without the need for the complex purification procedures required for traditional semiconductors such as silicon," said Richard Friend of the Cavendish Laboratory, who has led this programme in Cambridge.

"It's remarkable that this material can be easily tuned to emit light in a variety of colours, which makes it extremely useful for colour displays, lighting and optical communication applications," said Tan. "This technology could provide a lot of value to the ever growing flat-panel display industry."

The team is now looking to increase the efficiency of the LEDs and to use them for diode lasers, which are used in a range of scientific, medical and industrial applications, such as materials processing and medical equipment. The first commercially-available LED based on perovskite could be available within five years.

Soraa re-asserts the virtue of high colour quality in LEDs

Other manufacturers are beginning to see the 'white'

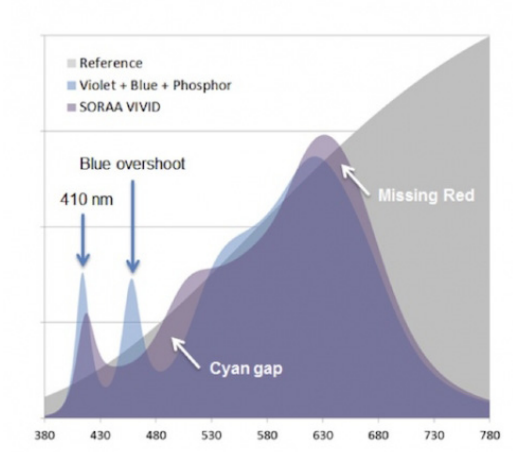
More than a year after Soraa demonstrated the importance of whiteness rendering in LED lamps, the topic is being noticed by the larger lighting manufacturers, according to a recent blog by Soraa's chief technology officer Mike Krames.

Philips is a notable new arrival: it is mixing violet-emitting with blue-emitting LEDs to provide a level of Optical Brightening Agent (OBA) excitation, which is necessary for whiteness rendering.

Inferior light quality holds back sales of many LED-based replacements for halogen lamps in casinos, hotels, high-end retailers and cruise ships. Soraa, a start-up based in Goleta, California, has targeted this area with a novel chip that features in its solid-state replacement for 50-75W halogen lamps.

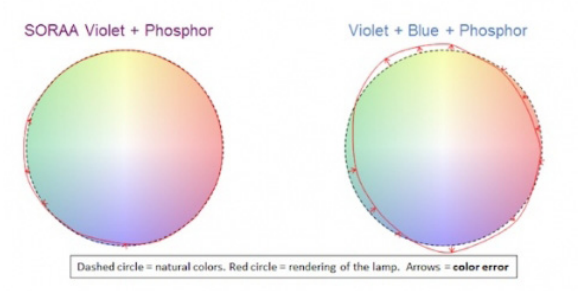
Soraa's lamps produce a full-colour spectrum by pumping red, blue and green phosphors with a violet-emitting chip. In contrast, most white-light sources employ a blue LED to excite a yellow

phosphor, which is sometimes combined with a red variant. According to Soraa, when you excite with a blue LED, it is not possible with a phosphor to tune the light down to violet, so typical competitor products are missing the violet all together. This omission makes a big difference to the appearance of anything containing whiteners, which are excited by violet light.



Philips, by mixing in some violet-emitting with blue-emitting LEDs, does not completely address the colour rendering problems associated with blue-based LED sources, says Krames. These problems include "blue overshoot and a lack of cyan and red content." The resulting spectrum is shown above, in comparison to Soraa VIVID and to a reference (blackbody) illuminant.

Newer colour rendering metrics, such as NIST's Color Quality Scale (CQS), as shown in the colour charts below, reveal the colour quality in the mixed violet/blue approach better, says Krames, including the hue distortions. Krames adds that the Philips LED targets an off-Planckian white point to mimic the pinkish light characteristic of ceramic-metal-halide discharge lamps (CMH or CMD), while the Soraa VIVID spectrum is exactly on the blackbody curve and designed to give accurate and natural colour rendering.

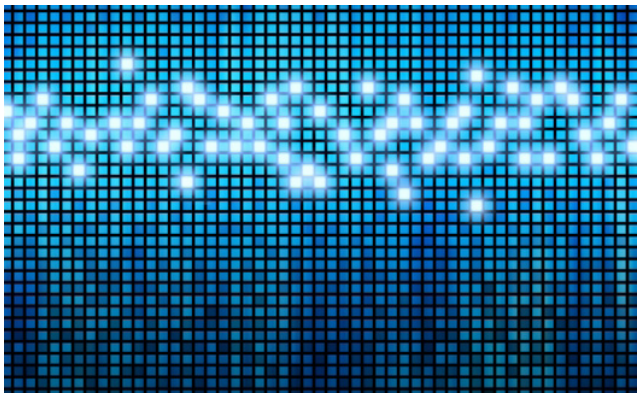


Krames concludes: "For the consumer it is a good thing that quality of light (for rendering whites as well as colours) is catching on. With the big guys taking notice, hopefully it will be easier for standards to be set that ensure natural, high quality lighting is available for our future."

Founded in 2008, Soraa has pioneered lamps using LEDs built from pure gallium nitride substrates (GaN on GaN).

Global LED Market up 9 percent in 2014

Slower growth in 2015 and a new round of price wars predicted



In 2014, the LED market is forecast to be up 9 percent from 2013, with the market size reaching $16.562 billion, according to a new report by Research In China called '*Global and China LED Industry Report, 2013-2014'*. However, it says the market is expected to slow down in 2015 because of oversupply and the risk of a new round of price wars .

The report divides the global LED industry into four clusters. First, Europe and America underline general lighting with an emphasis on high reliability and high brightness. Second, Japan embodies the most comprehensive technology, performing outstandingly in both of general lighting and backlight display. Besides, it also targets general lighting, automobiles, mobile phones and TV. Third, South Korea and Taiwan targets laptop display backlight, LED-TV backlight and mobile phone backlight with large shipment, low unit price and low margin. Last, mainland China centres on AlInGaP, outdoor display, advertising screen and signal

lights, which require low technology and reliability; and in these fields, customers are scattered and the unit price is low.

The report says since 2013, the development of the LED industry has been mainly reflected in the packaging field. In the future, the LED cost reduction depends on packaging instead of epitaxy. Packaging costs over 50 percent of the LED chip spending. Prior to 2014, LED cost cutting concentrated in the epitaxy field, so that epitaxy vendors witnessed a sharp decline in profits, even many of them left the industry due to losses. After 2014, packaging factories will suffer the cost-cutting pressure, so some of them with poor technical capabilities may see descending profits.

37 companies are profiled in the report which is available from Chinamarketresearchreports.com/

Seoul Semiconductor introduces LED module for retrofit lighting

Combines LED, driver, optics and thermal management

LED maker Seoul Semiconductor has released a new module for omnidirectional lamps, comprising the Acrich MJT 2525 series LED along with an Acrich3 driver chip and a reflector optic.

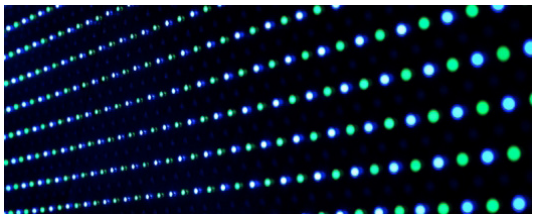
“The new Acrich A19 module is optimised for the performance and cost requirements of the retrofit lamp market,” said Jay Kim Seoul Semiconductor’s executive vice president of lighting sales. “This new module combines the light source, driver, optics and primary thermal management in a single, compact system, simplifying designs and lowering costs for lighting manufacturers”.

The Acrich MJT 2525 series LED with dimensions of 2.5 x 2.5mm and a wide beam angle has a lumen density of 15 lm/mm^2. It incorporates Seoul Semiconductor’s proprietary Acrich Multi-Junction chip technology to create the high voltage LED package. The Acrich3 IC is the latest generation driver chip that can work directly from AC mains. It enables lower cost driver solutions and is designed to work with existing TRIAC or phase-controlled dimmers without sacrificing on power quality or efficiency.

All LEDs and the driver chip are on one board, 38mm diameter, making the light engine easy to use in an A19 form factor.An optional heat bridge could also be used to improve thermal dissipation of the light engine, says the company.

Changelight chooses Veeco MOCVD for GaN LEDs

Purchase marks Changelight’s move into GaN-based lighting market



Veeco Instruments has announced that Xiamen Changelight has chosen it as the primary equipment provider for making GaN based blue/green high brightness LEDs for display and general lighting applications.

During the second quarter of 2014, Changelight ordered multiple TurboDisc MaxBright M GaN MOCVD Systems. In addition, Changelight purchased a TurboDisc K475 MOCVD system to expand its production of red, orange and yellow LEDs.

“In the past we have used competitive MOCVD equipment for the majority of our production of red, orange and yellow LEDs,” said Wang Xiangwu, general manager of Changelight. “As we make this important move into the GaN-based lighting market, we decided to switch to Veeco’s MaxBright M MOCVD system, which we believe will offer the best throughput and cost of ownership to help enable our success and growth in the general illumination market.”

The MaxBright M offers a modular, compact design with a number of layout configuration options to fit various fab spacing requirements, including sub-floor storage, enabling more wafer starts per square foot, which translates into a lower cost of ownership.

"We have seen Changelight dominate the red, orange and yellow market in China for some time and believe that, with our technology and its knowledge of the industry, Changelight is well positioned to successfully expand into the backlighting and general illumination market," said Jim Jenson, senior vice president and general manager of Veeco MOCVD.

Xiamen Changelight was established in February 2006. It specialises in quaternary alloy AlGaInP of red, orange, yellow LED wafers, chips and high-performance GaAs solar cells.

Cars playing increasing role in Optoelectronics sector

17 percent of headlamps to use LEDs in 2019

With car ownership increasing in less economically developed regions and vehicles becoming more advanced, the automotive sector is playing an increasingly important role across all the major opotoelectronic component product types, according to a research note by Stewart Shinkwin at IHS Inc.

Following a new European Union Directive 2008/89/EC, which required after 2011 all new models of car to be fitted with daylight running lamps, adoption of LEDs in automotive exteriors has significantly increased. Due to the long lifetime and energy efficient nature of LEDs, penetration in this area of the market was high and has helped drive adoption of LEDs.

Use of LEDs specifically in headlamp units is still relatively low, with only 2 percent of car headlamps using LEDs in 2013 according to figures from IHS Automotive. As their popularity, performance and efficiency grow, this is set to increase to 17 percent in 2019. This will bring significant growth to the LED market, with packaged LEDs for automotive exterior lighting set to grow at a CAGR of over 8 percent.

Technological advancement in the automotive industry has increased the adoption of infrared components, with a wide range of automotive applications including auto headlamps, automatic windscreen wipers, gesture control, and night vision displays. Infrared revenues in this sector are forecast to increase from $118 million in 2013 to $207 million in 2019. It is unlikely, says IHS, that these technologies will become standard features in lower cost models; however, their penetration in mid-tier models is constantly increasing.

The increase in sales of hybrid electric vehicles (HEV) and full electric vehicles (EV) is also promoting growth in the optocoupler market. Optocouplers are used in HEVs to isolate the onboard chargers and other high-voltage systems. With HEV shipments growing at a CAGR of 18 percent through to 2019 and little price erosion due to the significant barriers to entry, this market is a lucrative one for those manufacturers that can operate here. IHS forecasts that this market will nearly double from $74 million in 2013 to $146 million 2019.

Toshiba lab develops InGaN-based red LED

First nitride-based red LED with the light output exceeding 1mW at 20 mA

Scientists at Toshiba's Research and Development Centre, Kawasaki, Japan have demonstrated the first nitride-based red LED with light output power exceeding 1mW at 20mA. Their findings were reported in the journal *Applied Physics Express*.

The InGaN-based red LED was grown on a c-plane sapphire substrate. Blue emission due to phase separation was successfully reduced in the red LED using an active layer consisting of 4-period InGaN multiple quantum wells embedding an AlGaN interlayer. Al content was 90percent on each quantum well.

The light output power and external quantum efficiency at a dc current of 20mA were 1.1 mW

and 2.9 percent with the wavelength of 629nm, respectively.

VI Systems gets US patent for 40G VCSEL technology

Patent also applies to visible and infrared LEDs

VI Systems GmbH, a developer and producer of optical devices for data transmission, has received a US patent covering the material composition of optoelectronic devices including VI Systems' 40 Gbit/s vertical cavity surface emitting laser (VCSEL).

The patent *'Optoelectronic Device with a Wide Bandgap and Method of Making Same'*, protects the company's proprietary concept of ultra high-speed vertical VCSELs. The invention relates to semiconductor light emitting devices for visible and infra-red spectral ranges, and can therefore also be applied to LEDs targeting the bright red, orange, yellow, or green spectral ranges.

VI Systems' offers engineering samples of its 40 Gbit/s VCSEL at 850nm wavelength as bare die chips or as fibre coupled test modules.

Philips accelerates lighting business changes

Intensified focus on LED systems

Philips is accelerating the drive to LEDs, the group said today in its second quarter and semi-annual results 2014. The move follows the company's announcement a few weeks ago to combine its LED and automotive lighting businesses in a stand-alone company.

The firm's LED-based sales grew 43 percent in Q2 and now represent 36 percent of total Lighting sales, compared to 25 percent in Q2 2013. There was a 13 percent decline in conventional lighting sales in the quarter.

Along with the increased focus on LED, Philips will pull forward plans to scale down production and cut costs in the conventional lighting sector over the coming years in an effort to retain profitability. To this end, it will be raising charges in the second half of 2014 from EUR 100 million to approximately EUR 170 million.

"In Lighting, we are intensifying our focus on connected LED lighting systems and services, LED luminaires, and LED lamps for the professional and consumer markets," said Frans van Houten, CEO. "Our decision to combine the Lumileds and Automotive lighting businesses into a stand-alone company within Philips will allow it to extend its leading portfolio of digital lighting components and achieve robust growth, serving even more customers in the industry, as well as Philips Lighting."

Nichia to commercialise laser diodes for Automotive Head-Up Displays

New blue and green laser diodes to replace LEDs

Nichia Corporation, headquartered in Tokushima, in Japan, plans to commercialise blue and green semiconductor laser diode models specifically designed for automotive Head-Up Display (HUD) systems.

LEDs are currently the most common light sources for automotive HUD systems. By replacing LEDs with semiconductor laser diodes, Nichia says it will be possible to achieve a larger head-up display field of view, lower energy consumption, higher contrast, and an extended range of reproducible colours

Nichia plans to start shipping test samples from October 2014 and mass production from October 2015.

Compound Semiconductors to be worth $104.55 Billion in 2020

Market expected to grow at 12.63 percent CAGR from 2014 to 2020

According to a new report published by MarketsandMarkets, the compound semiconductor market is expected to grow at a CAGR of 12.63 percent from 2014 to 2020, reaching $104.55 billion in 2020.

The compound semiconductor market includes materials such as III-V, II-VI, IV-IV groups of compound semiconductors, and sapphire. Beneficial features such as direct gap, wide range of band gaps, higher electron mobility, and low power consumption, mean compound semiconductors are finding wide application in LEDs; high speed and high power devices; lasers; sensors; and IR-visible-UVs.

The report ‹*Compound Semiconductor Market by Type (III-V, II-VI, IV-IV, sapphire), Deposition Technology (CVD, MBE, HVPE, Ammonothermal, MOVPE, LPE, ALD), Product (Power, Opto-electronic), Application, and Geography-2013-2020*'› covers the overall compound semiconductor market segmented into five major segments: compound semiconductor types, deposition technology, products, application, and geography.

MarketsandMarkets is a global market research and consulting company based in the US.

Plessey expands GaN-on Si LED distribution network in Europe

CODICO partnership expands coverage in Central and East European, Italian and Danish markets for GaN-on-Si LED products

Plessey announced, that it has entered into a distribution agreement with CODICO GmbH, a distributor of electronic components, headquartered in Perchtoldsdorf, Austria and with offices across Europe. With CODICO, Plessey will be expanding its European network with coverage in Central and East European, Italian and Danish market for its GaN-on-Si LED products.

Sven Krumpel, president and CEO of CODICO GmbH, said: "CODICO is very pleased to announce this partnership with Plessey. We are convinced that the innovative technology of Plessey and CODICO's deep knowledge of the market will enable both companies to turn on a bright light within the solid state lighting market. I strongly believe that the GaN-on-Si technology is going to be the next revolution in the lighting field and that Plessey and CODICO will be driving it."

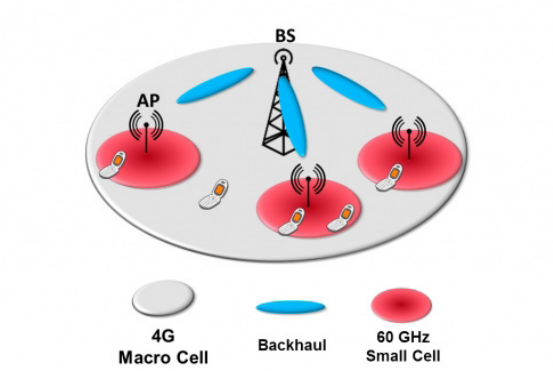
David Owen, Plessey's regional sales director, added: "CODICO's line card complements the Plessey LED portfolio in the lighting segment and together with its focused team that brings considerable knowledge of the lighting industry and customer base, will accelerate the time to market for Plessey GaN-on-Si LEDs in the region."

Plessey's MaGIC (Manufactured on GaN-on-Si 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.

RF Electronics

EU project to focus on millimeter-wave radio for 5G networks

Use of 60GHz and 71-86GHz bands promises multi-Gbps data rates for backhaul and user access



A consortium of 15 leading telecommunications operators, vendors, research centres and academic institutions have launched 'MiWaveS' (Millimeter-Wave Small Cell Access and Backhauling), a European collaborative project whose goal over the next three years is to develop millimeter-wave (mmW) key radio technologies to provide multi-Gbps data rates to future 5th Generation cellular mobile networks users.

The consortium includes CEA-Leti, Telecom Italia, Orange, Nokia, Intel Mobile Communications, National Instruments Dresden, STMicroelectronics, Sivers IMA, Optiprint, VTT, Tech. Univ. Dresden, Tecnologias Servicios Telematicos y Systemas, University of Rennes, and University of Surrey.

Global mobile data traffic is expected to increase by orders of magnitude in the next decade, driven by video streaming, web services, cloud computing and machine-to- machine applications. Data rates provided to mobile users are also expected to increase accordingly. The evolution of mobile networks towards these objectives is impeded by major bottlenecks, such as the scarcity of spectrum resources below 6GHz leading to high interference levels, the public concern about microwave EMF exposure in dense areas, the power consumption of the infrastructure, and the flexibility and robustness of the network.

Laurent Dussopt, MiWaveS project manager and Leti research engineer, explains that "the flexible spectrum usage of the mmW frequency bands at 60GHz and 71-86 GHz will enable data transmissions up to 10 Gbps for backhaul and 5 Gbps for mobile users access". He also said that MiWaveS' objectives lead to significant challenges on the system architecture, networking functions and algorithms, radio and antenna technologies.

MiWaveS is expected to have a major impact on the key enabling technologies for the next generation of heterogeneous wireless networks. The deployment of mmW small cells in dense urban areas will not only improve the flexibility of the access infrastructure, but also the spectral and energy efficiency by low-power access points using mmW spectrum resources.

The MiWaveS project is partially funded by the European Commission's Seventh Framework Program.(FP7), within the Work Programme for Information and Communication Technologies under the objective 'Network of the Future'. This objective supports the development of future network infrastructures that allow the convergence and interoperability of heterogeneous mobile, wired and wireless broadband network technologies as enablers of the future Internet.

The MiWaveS project started at the beginning of January 2014.

Hong Kong team integrates on-chip light source with III-nitride electronics

Approach holds promise for synchronous RF/optical comms and more...

Integrating III-nitride-based light-emitting and electronic control devices would help make more compact optoelectronics systems such as on-chip lighting control, synchronous RF/optical communications, and opto-couplers for power conversion. But attempts to grow LED and HEMT structures on the same substrate have been hampered by the incompatibility of their optimised growth temperatures and by the complexity of

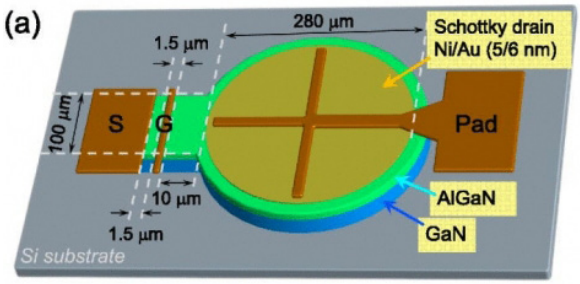
integrated devices with different active layers.

Now a team from Hong Kong University of Science and Technology has reported producing GaN band-edge ultraviolet emission at 3.4eV at room temperature, at a small forward bias larger than -2V, from a simple metal-AlGaN/GaN Schottky diode. Their findings were published in Applied Physics Letters **105** (2014).

Schottky-drain electrode in an AlGaN/GaN HEMT

The researchers' goal was to produce electroluminescence (EL) at room temperature from metal-AlGaN/GaN Schottky diodes on a conventional doping-free III-nitride heterostructure suitable for HEMTs. (EL was first discovered in a metal-SiC structure in 1907. EL emissions from Schottky diodes on Si, II-VI, and III-V semiconductor have also been reported by research groups over the last 30 years).

By employing a semi-transparent Schottky-drain electrode in an AlGaN/GaN HEMT, the team succeeded in building a UV high electron mobility light-emitting transistor (HEM-LET) in a relatively straightforward manner. Figure **a)** below presents the schematic device structure of the device demonstrated in this work.



The team used an AlGaN/GaN heterostructure consisting of a 21nm Al 0.25Ga 0.75 N barrier and 3.8µm GaN buffer, grown by MOCVD on a 4inch p-type S (111) substrate. The heterostructure contained a 2DEG channel of density $10^{13}/cm^{-2}$ and mobility $2080cm^2/V^{-1}s^{-1}$ at room temperature.

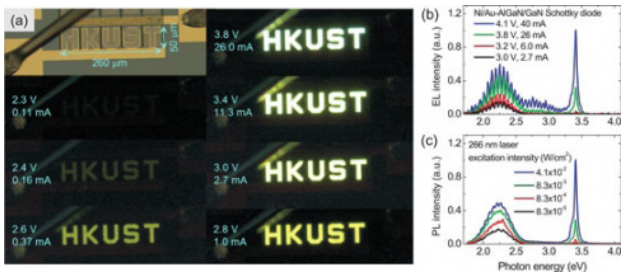
They defined the ohmic contacts using photolithography and formed them with Ti/Al/Ni/Au metallisation annealed at 850degC for 30s in N 2 ambience. Remote plasma pretreatment in an atomic-layer-deposition (ALD) machine was used to remove the residual native oxide and nitridise the surface. The passivation and surface protection layer was an AlN/SiN x (4/50nm) stack.

After the Schottky area was defined with photolithography, the SiN x was dry etched by a low-power plasma process and the AlN thin film removed by dilute alkaline solution. Then the semitransparent Schottky metal Ni/Au (5/6 nm) was deposited using an e-beam evaporator. A high electron mobility light-emitting transistor (HEM-LET) with ohmic source and semitransparent Schottky drain was made simultaneously.

Ni/Au (20/200 nm) was used as the gate metal and a SiN x/AlO (15/8 nm) stack insulator used as the gate dielectric for the HEM-LET, in order to single out the Schottky drain. Finally, the device was annealed at 400degC for 10 minutes in N2 ambience.

EL emission at room temperature

The team measured the current- voltage characteristics, and the EL and photoluminescence (PL) spectra. (A 266nm laser was used to excite the AlGaN/GaN heterostructure for the PL measurement).



With semi-transparent Ni/Au (5/6 nm) Schottky metal, the team reported clearly seeing EL emission from the Ni/Au-Al 0.25Ga 0.75 N/GaN Schottky diode at room temperature when the forward bias is higher than 2.2V. The EL intensity becomes stronger at a higher bias.

They found that the EL spectra consisted of not only yellow and blue luminescence but also a narrow GaN band-edge UV component at 3.4eV, similar to the PL spectra of the AlGaN/GaN heterostructure as shown in graph c) above.

Both the EL and PL spectra are from the GaN layer; no emission from the thin AlGaN barrier layer was detected. The yellow/blue is due to radiative transition of electronics from conduction band of a shallow donor to a deep acceptor in the GaN layer. Its relative intensity, compared with GaN band-

edge UV emissions decreased with increasing bias/current or laser excitation intensity in both the LE and PL spectra

The team also experimented with another Schottky metal, Pt/Au and found similar results concluding this is a general property of metal-AlGaN/GaN Schottky diodes.

From these results, the researchers think it would be possible to realise synchronous radio-frequency/optical communications using an AlGaN/GaN HEMLET, and an all-on-chip opto-coupler for III-nitride power electronics.

They also suggest that the metal-AlGaN/GaN light-emitting Schottky diode provides an alternative for micro-display with unique advantages. The back electrode is served by a high-mobility 2DEG channel, and the pixel is defined by the top Schottky contact, eliminating th mesa etching process and current spreading design and allowing for a higher resolution and smaller pixel size.

'P-doping-free III-nitride high electron mobility light-emitting diodes and transistors' by Baikui Li et al, appears i Appl. Phys. Lett. **105**, 032105 (2014); http://dx.doi.org/10.1063/1.4890238

Murata to Acquire RF specialist Peregrine for $471 million

Murata gets silicon-on-insulator process and IPR plus RF front end capability

Murata Electronics North America and Peregrine Semiconductor have announced that Murata will acquire all outstanding shares of Peregrine not owned by Murata. The total transaction value is $471 million ($465 million excluding Murata's existing holding).

Peregrine was formed as a fabless company in 1988. Since then its founding team have been perfecting UltraCMOS, a patented form of silicon-on-insulator (SoI) technology, designed to deliver the performance needed to solve tough RF challenges, such as linearity.

Peregrine's SoI products are challenging GaAs transistors in mobile phones: its switches have already driven the demise of GaAs pHEMTs, and the technology is now competing with the GaAs HBTs used in power amplifiers

The acquisition will deliver to Murata these advanced RF front-end capabilities and the SoI process technology, key areas for the growing integration of mobile technologies. Peregrine supplies many wireless markets, including: smartphones, test and measurement, automotive, public safety radio and wireless Infrastructure. Peregrine will also provide Murata with a strong portfolio of Intellectual Property Rights (IPR) covering the entire RF SOI front-end. Peregrine holds more than 180 filed and pending patents and has shipped over 2 billion UltraCMOS units.

"This acquisition will combine Murata's world-leading mobile RF module capabilities with Peregrine's best-in-class RF front-end products. Peregrine has a team of talented RF engineers," said Norio Nakajima, executive VP, director of communication business unit of Murata. "Peregrine invented RF SOI, has led its development for 20 years, and accomplished a large number of industry firsts. We have worked closely with them for many years. Their innovation, including the Global 1 all-silicon integrated RF front-end, is a key strategic area for the mobile industry. This transaction will deepen our existing partnership and position us to meet the expanding opportunities in this field."

"Murata is the world's leading RF module and filter provider, and we have benefited from our many years of partnership with them. The combination of Murata's leading products with Peregrine's leading-edge SOI products will position us to compete aggressively in our chosen markets," said Jim Cable, chairman and CEO of Peregrine Semiconductor. "As part of the Murata team, we will be able to expand our existing partnership and speed the industry's transition to an integrated, all-CMOS RF front-end. We remain committed to providing leading solutions to customers in all our current markets. We have huge respect for Murata's capabilities, and look forward to jointly accomplishing great things."

The transaction, which has been approved by both companies' boards of directors, is expected to close by the end of 2014 or early 2015, subject to Peregrine's stockholders' approval, regulatory approvals, and other customary closing conditions.

Peregrine will continue with its current business model as a wholly owned subsidiary of Murata.

APC Novacom extends Cree RF range for Europe

Now stocking all devices that do not require EU license, including GaN HEMT die

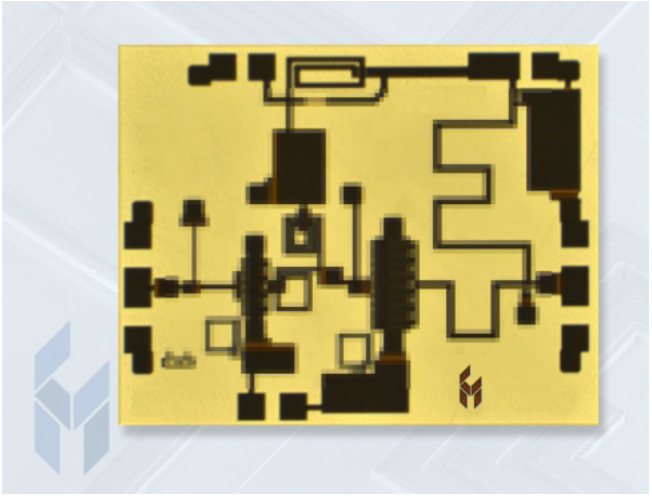
Specialist UK-based distributor APC Novacom is now stocking all Cree RF devices that do not require an EU license, including GaN HEMT die. It is actively supporting Cree's European market through both volume distribution and small volume stock for network representatives.

Suited for a wide range of RF communications applications including broadband amplifiers, radar, point-to-point radio, telecoms, and tactical data links, Cree GaN HEMTs provide higher breakdown voltage, higher saturated electron drift velocity, higher thermal conductivity, and higher efficiency than Si or GaAs die, says the company. The HEMTS also offer greater power density and wider bandwidths.

Cree RF products now available include: general purpose broadband die, general purpose 28V and 40V broadband GaN HEMTs, 28V and 50V telecom GaN HEMTs, 0.25 micron die, and a variety of GaN HEMTs for satellite communications and L-, S-, X-, and C-Band applications.

Custom MMIC adds new 14 to 18GHz GaN Power Amp

Offers high power, high linearity, and efficiency over 32 percent



Custom MMIC, a US developer of MMICs, has added a 14 to 18 GHz GaN power amplifier in die form, to its expanding product line.

The CMD216 delivers 16 dB of flat gain across the entire 14 to 18 GHz bandwidth, an output 1 dB compression point of +37dBm, and a saturated output power of +38dBm. The CMD216 requires a bias of Vdd = 28 V, 550mA, and Vgg = -3.4 V. Additionally, the amplifier boasts a power added efficiency of 32 percent or greater.

The CMD216 is a fully matched 50ohm matched design and only requires external bypass capacitors to complete the bias circuitry. The die is passivated for increased reliability and moisture protection. The CMD216 is ideally suited for Ku-band communications systems.

Custom MMIC, based in Westford, MA, offers both hands-on design through testing services, and a growing library of system-ready designs. It has experience in GaAs, GaN, SiC, InP, and InGaP HBT and has established relationships with the leading foundries in these technologies. The company specialises in RF through millimeter-wave circuits for satellite communications, radar systems, cellular infrastructure, consumer electronics, VSAT, and point-to-point radio systems.

GaAs IC Market to reach $8 billion in 2017

PA pricing to increase to $3.50 with LTE and AWS

A new market research report *'The GaAs IC Market'* by Information Network forecasts that the GaAs IC market will reach $8 billion in 2017.

The most important driver of the GaAs RF IC market is power amplifiers (PAs) and switches in the front-end of the handsets. 3G handsets often contain up to five PAs, and GaAs makes up 100 percent of the market, which is close to $5 billion.

According to the report, the number of PAs per handset is growing because of: complex 3G systems, global roaming support, and data roaming support. Pricing for PAs has increased from $0.80 per handset to $2.90 currently and is projected to increase to greater than $3.50 once Long Term Evolution (LTE) and Advanced Wireless Services (AWS) spectrum emerge in advanced handsets in the marketplace.

While industrialised countries are using 3G networks, today's world is a mixture of 2/2.5G and 3G networks, the heavy majority of subscribers are actually on 2G-based networks - and predicted to remain so for a number of years.

Between 70 to 80 percent of Skyworks' and RF Micro Device's GaAs business is in PAs. 2G handsets contain one PA, so it represents a sizable market. Because they aren't as technologically advanced as 3G cell phones, particularly smartphones, silicon is making inroads in the GaAs domain. For 2013, only 90 percent of PAs were made in GaAs, 5 percent in silicon CMOS, and 5 percent in silicon LDMOS.

This report, available from Reportbuyer.com, investigates the technology trends, applications, and market developments of GaAs ICs. US Japanese, and European applications such as telecom, computers, defense, consumers, are also reviewed.

Skyworks opens doors for tier one automotive firm

Ramping analogue and RFacross General Motors, Chrysler, Fiat and Toyota

Skyworks Solutions, which makes high performance analogue semiconductors, has announced that a tier-one automotive supplier is using its products for in-vehicle garage door openers across several car manufacturers.

The control system enables drivers to remotely activate garage door openers, entry door locks, home lighting, security systems and entry gates. Currently offered in all automotive brands, the platform is compatible with more than 99 percent of garage door opening systems as well as a wide variety of home safety and convenience products.

The three-button interface is located as an easy-to-install module in automobile rearview mirrors for a convenient, battery-free, programmable solution that eliminates the need for traditional clip-on transponders.

"Skyworks' advanced analogue and RF solutions are being leveraged across multiple in-vehicle applications that are enhancing safety and the overall driving experience," said John O'Neill, vice president of broad markets marketing at Skyworks. "As wireless technology in automobiles continues to rise, we are capitalising on the increasing number of addressable semiconductor opportunities that add value, minimise OEM costs and complexity, and improve time to market."

According to a report by Transparency Market Research entitled 'Connected Car Market: Global Industry Analysis, Size, Share, Growth, Trends and Forecast', the global connected car market is expected to reach $131.9 billion by 2019, growing

at a compound annual growth rate of 34.7 percent. The global connected car market is driven by safety and security services along with gaming, entertainment, traffic information, weather and location services.

Novati gets 'trusted foundry' stamp for US defence applications

One of only nine fabs to win DoD accreditation

Novati Technologies, a developer of photonics, MEMS, 2.5D/3D, III-V-on-silicon and nanotechnology products, has announced that its wafer fab in Austin, Texas has been accredited by the US Department of Defense (DoD) as a Category 1A Trusted Foundry.

The DoD accreditation distinguishes Novati as a trusted manufacturer of integrated circuits for US aerospace and defence applications. Category 1A has been granted to only nine CMOS fabs that exhibit the highest levels of process integrity and protection.

Novati builds MEMS, sensors, actuators, photonic and electro-optic devices, Infrared (IR) detectors, wide bandgap electronics, non-volatile memory, power semiconductors, RF devices and a range of 2.5D/3D devices for aerospace and defence customers.

"Today's security applications for DoD demand suppliers who can meet the most rigorous requirements for utilising non-traditional elements and support low-volume manufacturing," said David Anderson, president and CEO for Novati. "We've proven that customers with really tough problems that require innovative materials, combinations of heterogeneous devices and high-risk processing techniques come to Novati. We regularly help develop products from concepts that have never been built before. The Trusted Foundry accreditation reflects our focus and strong commitment to supporting aerospace and defense contractors."

The Trusted Foundry program, administred by the Defense Microelectronics Activity (DMEA) organisation on behalf of the DoD, ensures that the US government has guaranteed access to specialised, high-performance components.

MACOM Announces Highest Power GaN L-Band Radar HEMT

50W GaN on SiC transistor targets 1.2 to 1.4 GHzMacom has introduced a new GaN on SiC HEMT power transistor which it claims offers the highest peak power in the industry for a single-ended power transistor optimised for pulsed L-Band radar.

The MAGX-001214-650L00 guarantees 650W of peak power with a typical 19.5 dB of gain and 60 percent efficiency. The device also has a high breakdown voltage which allow customers reliable and stable operation at 50V under more extreme load mismatch conditions. The device is assembled in a ceramic flange package and has undergone MACOM's rigorous qualification and reliability testing.

"The MAGX-001214-650L00 is a clear leader in high pulsed power GaN technology with guaranteed 650 W of peak output power combined with excellent gain, efficiency and reliable performance," said Paul Beasly, product manager. "The device is an ideal candidate for customers looking to combine two power transistors and realise over 1,000 W of peak power in a single pallet for next generation L-Band radar systems that require increased performance in smaller footprints."

Operating between the 1200 to 1400 MHz Frequency range, the MAGX-001214-650L00 has a mean time to failure (MTTF) of 5.3 x10^6 hours.

Cree releases process design kit for GaN on SiC technology

Integrated suite of design and simulation tools for microwave and RF design

Cree has released a process design kit (PDK) that combines the latest version of Agilent Technologies' Advanced Design System (ADS) software with Cree's proprietary GaN on SiC process technology parameters and design rules.

Available free of charge, the Cree GaN PDK V4.01 is an integrated front-to-back system that provides microwave and RF design engineers with a comprehensive suite of design and simulation tools that helps accelerate their time to market.

The updated software features expanded layout and modeling options and enhanced rule-checking processes for improved design-to-build accuracy. Specifically, PDK V4.01 adds integrated support for: G50V3 (50V, 0.4μm), G28V4 (28V, 0.25μm), and G40V4 (40V, 0.25μm) device technologies; V3 and V4 passive switch HEMTs; and the Cree standard dielectric crossover.

The software also offers dual design panels - one for V3 and one for V4 - to support streamlined design with either technology, updated bulk resistor layouts and models to reflect current process and design requirements, and updated layout design rule checks (DRCs) to thoroughly and accurately verify requirements. Further, V4.01 corrects many of the inconveniences users noted in the previous PDK release.

TriQuint is first to achieve DoD manufacturing level 9 for RF GaN

Company processes meet full performance, cost and capacity goals

TriQuint Semiconductor has announced that it is the first GaN RF chip manufacturer to achieve the US Department of Defense's Manufacturing Readiness Level (MRL) 9.

The DoD's Manufacturing Readiness Assessment (MRA) ensures that manufacturing, production and quality assurance can meet operational mission needs. The aim is to provide guidance about the maturity and risk of a given technology. TriQuint demonstrated that its manufacturing processes met full performance, cost and capacity goals, with the capability in place to support full rate production.

To benchmark MRL 9, TriQuint applied the US Air Force Research Laboratory's rigorous manufacturing readiness assessment tool and criteria to its high frequency, high power GaN production line. TriQuint's ongoing development of GaN-based devices is leading to smaller, more efficient power amplifiers, typically used for military radar and electronic warfare programs as well as commercial wireless communications and infrastructure.

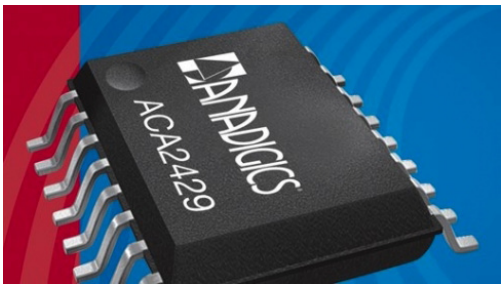
"TriQuint recently completed its Defense Production Act Title III GaN on silicon carbide (SiC) program and now we've proven that we provide the GaN maturity needed to support full-rate production programs," said vice president and general manager James Klein, Infrastructure and Defense Products.

Key to the company's assessment, TriQuint has shipped more than 170,000 0.25μm GaN power amplifier devices in support of an ongoing international radar production program. During phased array radar field testing, approximately 15,000 devices have accumulated more than 3.67 million device hours, with no reported device failures. TriQuint continues to demonstrate industry-leading reliability with a mean time to failure (MTTF) of greater than 70 million hours at 200 degrees Celsius, substantially greater than the industry standard of 1 million hours MTTF.

Anadigics ship volumes of GaN power doubler

Surface mount chip suits new DOCSIS 3.1 CATV equipmenrt

Anadigics has announced that it is shipping production volumes of its ACA2429 GaN power doubler surface mount IC in support of new DOCSIS 3.1 CATV infrastructure equipment.



CATV service providers are focused on expanding their customer base in the face of alternative broadband technologies, according to Tim Laverick, vice president of infrastructure products at Anadigics.

He said: "To help them succeed, network equipment manufacturers are leveraging our world-class DOCSIS 3.1 infrastructure solutions. The ACA2429 power doubler, now shipping in production volume to a leading European manufacturer, provides reliable, linear power amplification over an expanded frequency range to help CATV service providers offer higher data rates and take full advantage of all that DOCSIS 3.1 has to offer."

Anadigics' ACA2429 line amplifier is based on its MESFET technology and a GaN output stage. This power doubler provides 25dB gain with +60dBmV output power and 1.2GHz bandwidth, with 10W of power consumption.

With a combination of high gain, output power and linearity coupled with low current consumption and bit error rate (BER), Anadigics' ACA2429 line amplifier enables higher data speeds as well as distortion-free video and audio, according to the company.

MACOM Launches High Power GaAs Amplifier for Radar use

Amplifier offers up to 42 dBm of peak power

Macom has announced a new high power amplifier for X-Band communication and radar applications.

The MAAP-015036, a two stage 8.5 to 10.5GHz GaAs MMIC, has a saturated pulsed output power of 42dBm, a signal gain of 17dB and a typical 43 percent power added efficiency. The power amplifier can be biased using a direct gate voltage or using an on-chip gate bias circuit. Furthermore, the device offers dual sided bias architecture for optimum flexibility in assembly and board design.

"The MAAP-015036 is our highest power amplifier in our family of new, high efficiency GaAs MMIC X-Band power amplifiers," said Paul Beasly, product manager. "The combination of high power, high gain and excellent power added efficiency performance, along with versatile biasing options makes the device ideal for a wide range of X-band pulsed applications such as marine, weather and surface-movement radar, as well as perimeter security and communication links".

Saab showcases fighter aircraft featuring GaN technology

Saab's Gripen programme features at 2014 Farnborough International Airshow

At the Farnborough International Airshow, Saab Electronic Defence Systems (EDS) is showcasing its next-generation Gripen programme, including the Gripen E aircraft, which will use GaN antenna technology in its wingtip electronic warfare systems.

Saab, which has been working on GaN technologies since 2005, is also using GaN devices in its new Giraffe active electronically scanned array (AESA) radar systems. The Giraffe AESA range, announced in May this year, includes three land-based systems and two naval variants in X- and S-band frequencies. The medium range 4A and long range 8A versions of Giraffe have been

described by the company as the first GaN-based full 2D systems (simultaneous air-defence, air-surveillance, and weapon-locating) for 3D AESA multifunction radar.

BeRex Adds New High Performance MESFET Chips

Low phase noise, high linearity MESFETs complement popular line of pHEMTs

BeRex has begun shipping a new family of GaAs MESFET chips, the BCF-series, which addresses the need for low phase noise with high gain and power in applications such as single and multi-stage amplifiers, oscillators, synthesizers, etc. ranging in frequency from DC to 26.5GHz.

“These parts along with our existing pHEMT family of packaged and bare-die FET products go a long ways towards fulfilling the commitment to our clients of becoming their one-stop source for their RF and microwave FET needs”, said Alex Yoo, VP of research and development at BeRex.

The BeRex BCF-series of MESFET chips are suited to both broadband and narrow band applications from DC to 26.5GHz. Typical application requires a high level of OIP3 (Output Third-Order Intercept Point) linearity and a low phase noise that cannot be easily achieved with other technologies.

This BCF-series family consists of seven devices, each is built using a 0.25µm gate length and with a gate width of 200µm, 300µm, 400µm, 600 µm, 800µm, 1200µm or 2400µm, depending on the clients gain and power requirements (up to 1W for the largest 2400µm device).

The BeRex BCF-series chips are are now available in sample and production volumes.

Raytheon demos prototyping of AESA/GaN technologies into Patriot radar

Technology promises 360 coverage, better reliability, and lower life cycle costs

Raytheon has demonstrated successful prototyping of Active Electronically Scanned Array (AESA) and GaN technologies into the US Patriot Air and Missile Defense System radar. In addition to enabling future 360 sensor coverage, these technologies will increase the defended area and decrease the time to detect, discriminate and engage threats, says Raytheon. GaN-based AESA technologies will also further improve reliability and lower life cycle costs for the Patriot radar.

“GaN-based AESA technologies represent the future of ground-based sensors and will have future application to Raytheon’s entire sensor portfolio,” said Ralph Acaba, vice president of Integrated Air and Missile Defense at Raytheon’s Integrated Defense Systems business.

Raytheon has been developin GaN for 15 years and has invested over $150 million to get this latest technology in the hands of the warfighter faster and at lower cost and risk. Raytheon has demonstrated the maturity of the technology in a number of ways, including exceeding the reliability requirement for insertion into the production of military systems. This maturation of GaN resulted in a Manufacturing Readiness Level (MRL) production capability of “8,” the highest level obtained by any organisation in the defense industry for this technology.

Raytheon is the prime contractor for both domestic and international Patriot Air and Missile Defense Systems and system integrator for Patriot Advanced Capability-3 missiles. The Patriot system is used by 12 nations around the globe.

EPC Introduces A4WP Compliant Wireless Power Transfer Demo Kit

GaN FET evaluation kit for 6.78MHz, 35W wireless power transfer systems

Efficient Power Conversion Corporation (EPC) has announced the availability of a complete demonstration wireless power transfer kit. The 40V (EPC9111) or 100V (EPC9112) wireless kits comprise a source (or amplifier) board, a Class 3 A4WP compliant source (or transmit) coil, and a Category 3 A4WP compliant device (or receiving) board including coil

The system is capable of delivering up to 35W into a DC load while operating at 6.78MHz (the lowest ISM band). The kit simplifies the evaluation

process of using eGaN FETs for wireless power transfer. The EPC9111 and EPC9112 utilise the high frequency switching capability of EPC gallium nitride transistors to facilitate wireless power systems with greater than 75 percent efficiency.

Wireless energy transfer systems need high efficiency, low profile, robustness to changing operating conditions and, in some cases, low weight. This means designs should be efficient and able to operate at high switching speeds without a bulky heatsink. Furthermore the design must be able to operate over a wide range of coupling and load variations. The fast switching capability of eGaN FETs, says EPC, is ideal for highly resonant power transfer applications.

The popularity of highly resonant wireless power transfer is increasing rapidly, particularly for applications targeting portable device charging. The end applications are varied and evolving quickly from mobile device charging, to life-extending medical implementations, to safety-critical hazardous environments.

The source board is a A4WP compliant, Zero Voltage Switching (ZVS), Class-D amplifier featuring either the 40V EPC2014 (EPC9111) or the 100 V EPC2007 (EPC9112) eGaN FET. It is configured in an optional half-bridge topology (for single-ended configuration) or default full-bridge topology (for differential configuration), and include the gate driver(s) and oscillator that ensure operation of the system at 6.78MHz. These amplifier boards are available separately as EPC9506 and EPC9507 for evaluation in existing customer systems.

The source coil, as well as the device coil, are Rezence (A4WP) compliant and have been pre-tuned to operate at 6.78MHz. The device board includes a high frequency Schottky diode based full-bridge rectifier and output filter to deliver a filtered unregulated DC voltage. The device board comes equipped with two LED's, one to indicate the power is being received and a second LED, which indicates that the output voltage has reached the maximum and is above 37 V.The device board can also be configured as a half-bridge rectifier that allows for double output voltage operation.

National Research Council of Canada announces GaN design kit

Software gives access to NRC's GaN electronics fabrication service

The National Research Council of Canada (NRC) is now offering the second version of its gallium nitride GaN500v2 Design Kit software. Combined with Canada›s only foundry for GaN electronics, the kit will enable industry and academics to create revolutionary technologies and device designs, according to the NRC.

The NRC provides complete fabrication processing from 3in GaN on SiC wafers through to characterisation and wafer dicing. Devices are fabricated with 0.5 micron gate length. Partners can choose full wafer runs (one customer›s designs only) or shared wafer runs, which consolidate demand on three or more fabrication runs per year. The latter service is offered in partnership with CMC Microsystems.

The GaN500v2 Design Kit includes both a design manual and a physical design kit, based on Agilent›s ADS CAD tool. The design manual includes the process description and design rules for all supported devices for the GaN technology and the related foundry services available through the Canadian Photonics Fabrication Centre of the NRC of Canada. The technology is appropriate for, but not limited to, RF and microwave devices.

The minimum ADS CAD bundle required for running the kit includes the ADS core and layout module. The design kit is compatible with ADS 2014 and earlier.

Compound Semiconductors to be worth $104.55 Billion in 2020

Market expected to grow at 12.63 percent CAGR from 2014 to 2020

According to a new report published by MarketsandMarkets, the compound semiconductor market is expected to grow at a CAGR of 12.63 percent from 2014 to 2020, reaching $104.55 billion in 2020.

The compound semiconductor market includes materials such as III-V, II-VI, IV-IV groups of compound semiconductors, and sapphire. Beneficial features such as direct gap, wide range of band gaps, higher electron mobility, and low power consumption, mean compound semiconductors are finding wide application in LEDs; high speed and high power devices; lasers; sensors; and IR-visible-UVs.

The report ‹*Compound Semiconductor Market by Type (III-V, II-VI, IV-IV, sapphire), Deposition Technology (CVD, MBE, HVPE, Ammonothermal, MOVPE, LPE, ALD), Product (Power, Opto-electronic), Application, and Geography-2013-2020'*› covers the overall compound semiconductor market segmented into five major segments: compound semiconductor types, deposition technology, products, application, and geography.

MarketsandMarkets is a global market research and consulting company based in the US.

Lasers

Taiwanese researchers improve InGaN VCSELs

Composition-graded electron blocking layer boosts output power

Researchers from the National Chiao Tung University, the National Changhua University of Education, Advanced Optoelectronic Technology Inc, and the Research center for Applied Science in Taiwan have designed and made an InGaN VCSEL with a composition-graded electron blocking layer (GEBL).

In their study, published in *Laser Physics Letters*, they been demonstrated that laser output performance is improved by using a GEBL when compared to the typical VCSEL structure of a rectangular electron blocking layer.

The output power obtained at 20kAcm^{-2} is enhanced by a factor of 3.8 by the successful reduction of threshold current density from 12.6 to 9.2kA cm^{-2} and the enlarged slope efficiency.

Numerical simulation results also suggest that the improved laser output performances are due mainly to the reduction of electron leakage current and the enhanced hole injection efficiency in the multiple-quantum-well (MQW) active region.

‹*Design and fabrication of a InGaN vertical-cavity surface-emitting laser with a composition-graded electron-blocking layer'* by BC Lin et al, appeared in Laser Phys. Lett. **11** 085002 doi:10.1088/1612-2011/11/8/085002

VI Systems gets US patent for 40G VCSEL technology

Patent also applies to visible and infrared LEDs

VI Systems GmbH, a developer and producer of optical devices for data transmission, has received a US patent covering the material composition of optoelectronic devices including VI Systems' 40 Gbit/s vertical cavity surface emitting laser (VCSEL).

The patent *'Optoelectronic Device with a Wide Bandgap and Method of Making Same'*, protects the company's proprietary concept of ultra high-speed vertical VCSELs. The invention relates to semiconductor light emitting devices for visible and infra-red spectral ranges, and can therefore also be applied to LEDs targeting the bright red, orange, yellow, or green spectral ranges.

VI Systems' offers engineering samples of its 40 Gbit/s VCSEL at 850nm wavelength as bare die chips or as fibre coupled test modules.

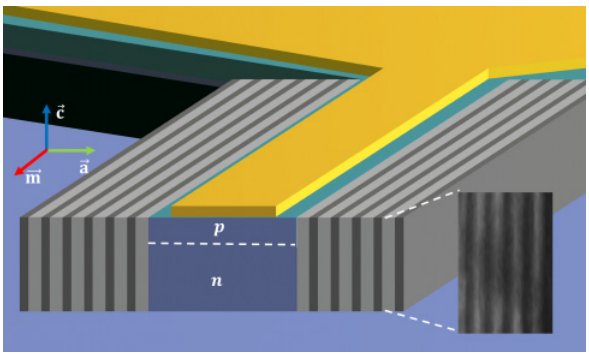
US researchers develop room temperature Polariton Laser

Device could be future optical replacement for on-chip wires

Scientists from the University of Michigan and Intel Corporation in the US have demonstrated what appears to be the first electrically powered, room-temperature polariton laser. The device, based on a GaN-based microcavity diode, could advance efforts to replace on-chip wire connections with lasers, leading to smaller and more powerful electronics, say the researchers.

A polariton is a quasiparticle that results from a coupling between a photon and an electron-hole pair (an "exciton") in a semiconductor material. In 1996, researchers realised that-under certain conditions-polaritons will condense into a single quantum state, from which they will spontaneously emit coherent, monochromatic light. In contrast to stimulated lasing, the polariton emitters do not need to be constantly pumped up into excited states (so-called population inversion). As a consequence, polariton lasers begin lasing at a relatively low threshold power.

Experimental realisations of polariton lasers have so far required either low temperatures or a pump laser to create the initial polaritons. Described in the journal *Physical Review Letters*, the room temperature polariton laser produced a beam of UV laser light at a threshold current density of 169 A/cm^2, which is almost a factor of 100 less than for conventional GaN-based lasers.



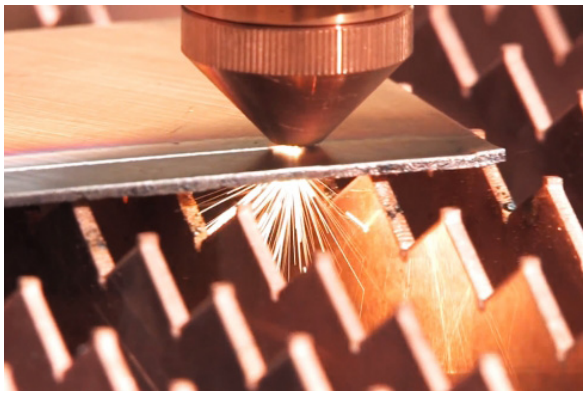
The device consists of a thin strip of gallium nitride, sandwiched between stacks of metal oxide mirrors. *(In the diagram above, the mirrors are represented by the grey bars. The yellow is the electrode through which the researchers stimulate the laser. The purple is the gallium nitride semiconductor).* When electric current enters such a microcavity, it can generate polaritons. But unlike previous designs in which electricity passed through or around the high-resistance mirrors, the team injects current orthogonally to the microcavity's emitting direction, thus avoiding overheating the device and destroying the lasing.

'Room Temperature Electrically Injected Polariton Laser' by P Bhattacharya et al, Phys. Rev. Lett. 112, 236802 (2014)

TeraDiode ships multi kilowatt diode laser

Beam quality suitable for high throughput steel cutting

TeraDiode, a spinout from MIT, has announced shipment of its first 4kW high brightness TeraBlade diode laser. The 970nm laser has a beam-parameter-product (BPP) of 4mm-mrad, making it suitable for high throughput cutting of steel over the range of thicknesses cut by laser cutters in job shops around the world, says the company. TeraDiode has already demonstrated diode lasers capable of cutting 12.7mm mild steel with cut quality and speed comparable to disk and fibre lasers.



Parviz Tayebati, CEO of TeraDiode, said: "In the short time since our first industrial shipments, we doubled the power of our laser modules from 600W to 1.2kW. These modules, which we use in our multi-kilowatt systems, reduce our production cost to just below that of the incumbents who have needed years of shipping in high volume to reach these levels. From here, increasing our production

will accelerate further improvements to widen the gap in efficiency, reliability and cost of ownership over the incumbents."

Diode lasers - used in laser pointers, barcode scanners, DVD players, and other low-power applications - are amongst the most efficient, compact, and low-cost lasers available. Attempts have been made over the years to increase their brightness for industrial applications, such as welding and cutting metal, but boosting power usually meant decreasing beam quality, or focus.

TeraDiode has made these lasers powerful enough to cut steel using a combination of semiconductor diode laser array chips and a power-scaling technique, called wavelength beam combining (WBC), developed at MIT. WBC manipulates individual diode laser beams into a single output ray to boost the power of a diode laser, while preserving a very focused beam. TeraDiode believes that direct-diode lasers using this technology will, in time, replace fibre, disk and other lasers for the most demanding material processing applications.

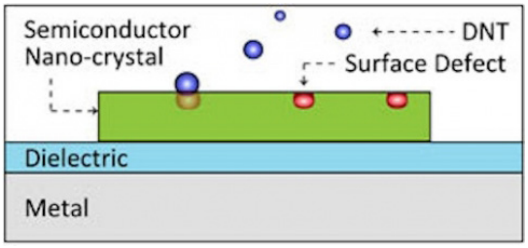
WBC can be thought of as the spatial and directional superposition of many independent diode laser external cavities, says the company. The angle-to-wavelength conversion property of a diffraction grating is used to provide feedback to each emitter in an array, via a series of lenses, at different wavelengths. The laser resonator is formed between the HR coated back facet of the emitter and the output coupler. WBC allows for brightness scaling of an emitter array because all of the laser elements are spatially overlapped at the output coupler, maintaining the output beam quality of a single element while scaling the output power by the number of elements in the array.

Laser sensor could lead way to handheld bomb-detectors

Tiny plasmon-based sensor detects minute traces of explosives in the air

A team at University of California, Berkeley led by Xiang Zhang, professor of mechanical engineering, has shown that a plasmon laser sensor can be used to detect minute concentrations of explosives in the air, including a hard-to-detect plastic explosive called PETN popular among terrorists. The results were published in the journal *Nature Nanotechnology*.

Plasmon lasers work by coupling electromagnetic waves with the electrons that oscillate at the surface of metals to squeeze light into nanoscale spaces far past its natural diffraction limit of half a wavelength. The UC Berkeley plasmon laser is based on a cadmium suphide semiconductor square measuring around 50nm thick and 1000nm long, placed on a silver surface and separated by a 8nm gap of magnesium fluoride. The most intense electric fields of the device reside in the magnesium fluoride gap.



In designing the sensor device, the researchers took advantage of the chemical makeup of many explosives, particularly nitro-compounds such as DNT and its more well-known relative, TNT. Their unstable nitro groups are characteristically electron deficient, which increases the interaction of the molecules with natural surface defects on the semiconductor. The sensor works by detecting the increased intensity in the light signal that occurs as a result of this interaction.

The engineers put the sensor to the test with various explosives - 2,4-dinitrotoluene (DNT), ammonium nitrate and nitrobenzene - and found that the device successfully detected the airborne chemicals at concentrations of 0.67 parts per billion, 0.4 parts per billion and 7.2 parts per million, respectively. One part per billion would be akin to a blade of grass on a football field. These results, which are much more sensitive than those published to date for other optical sensors, were published in the advanced online publication of the journal Nature Nanotechnology.

The researchers hope that their plasmon laser sensor could detect pentaerythritol tetranitrate, or PETN, a plastic explosive favoured by terrorists because small amounts of it pack a powerful punch and it escapes x-ray machines when not connected to a detonator. It is the explosive found in Richard Reid's shoe bomb in 2001 and Umar

Farouk Abdulmtallab's underwear bomb in 2009. PETN has more nitro functional groups and is more electron deficient than the DNT we detected in our experiments, so the sensitivity of their device should be even higher than with DNT, say the researchers.

"The ability to magnify such a small trace of an explosive to create a detectable signal is a major development in plasmonsensor technology, which is one of the most powerful tools we have today, " said Zhang.

The sensor device builds upon earlier work on plasmon lasers by Zhang's lab that uses reflectors to bounce the surface plasmons back and forth inside the sensor (similar to the way sound waves are reflected across the room in a whispering gallery) and using the optical gain from the semiconductor to amplify the light energy.

Zhang said the amplified sensor creates a much stronger signal than the passive plasmon sensors currently available, which work by detecting shifts in the wavelength of light. "The difference in intensity is similar to going from a light bulb for a table lamp to a laser pointer," he said. "We create a sharper signal, which makes it easier to detect even smaller changes for tiny traces of explosives in the air."

Co-lead author Ren-Min Ma, an assistant professor of physics at Peking University who did this work when he was a postdoctoral researcher in Zhang's lab, said: "Our technology could lead to a bomb-detecting chip for a handheld device that can detect the tiny-trace vapour in the air of the explosive's small molecules."

The sensor also could be developed into an alarm for unexploded land mines that otherwise are difficult to detect, the researchers said.

The US Air Force Office of Scientific Research Multidisciplinary University Research Initiative program helped support this work.

'Explosives detection in a lasing plasmon nanocavity' by Ren-Min Ma et al, appears in Nature Nanotechnology (2014), doi:10.1038/nnano.2014.135

Daylight Defense to Develop Ultraviolet Lasers for US Army

Next generation compact UV lasers to protect future aircraft

The US Army has chosen Daylight Defense LLC to develop next-generation high-power ultraviolet (UV) lasers. The Army is interested in laser sources in the near-UV for LIDAR (remote sensing by analysing the reflected light bouncing of an object) and other applications to do with protecting aircraft. Additional uses of near-UV sources include battlefield awareness, trace detection using LIDAR backscatter and/or bio-fluorescence, and data storage.

Daylight Defense received the award under the US Army Small Business Innovation Research (SBIR) program, which provides high-tech US businesses (with less than 500 employees) the opportunity to provide innovative research and development solutions in response to critical Army needs.

A specialist in military systems based on its patented quantum cascade laser (QCL) technology, Daylight is working with Northrop Grumman within the US Army's Common Infrared Countermeasures (CIRCM) program to develop the next generation of aircraft survivability equipment to defend helicopters against 'man-portable' air-defence systems and other heat-seeking munitions. When countering such hostile threats, applying multiple spectrums including IR, acoustic, ultraviolet, RF, and visual light to distinguish and characterise them increases the detection, identification, and geo-location accuracy.

Timothy Day, CEO for Daylight Solutions said: "The development of compact, ruggedised UV laser modules fits well within our product roadmap to bring advanced capabilities to the warfighter."

VCSEL market to reach over $2 billion in 2018

Report estimates a CAGR of 33.1 percent from 2013 through 2018

In its latest report, *Vertical-Cavity Surface-Emitting Lasers (VCSEL): Technologies and Global Markets*, BCC Research estimates that the VCSEL market will grow from $501.0 million in 2013 to nearly $2.1 billion in 2018, a compound annual growth rate (CAGR) of 33.1 percent from 2013 through 2018.

Optical fibre data transmission is the largest segment of the global VCSELs market, with a market share of $158.1 million in 2013. This market is projected to increase to about $615.1 million by 2018, a CAGR of 31.2 percent for the period of 2013 to 2018. The global market for analogue broadband signal transmission will increase at a CAGR of 37.3 percent to reach about $292.8 million in 2018, up from an estimated $60.0 million in 2013.

Extensive research and development into VCSELs has resulted in high-power conversion efficiency of 63.4 percent in the current year. Other types of commercially available lasers have typical power conversion of around 20 to 25 percent, according to the report.

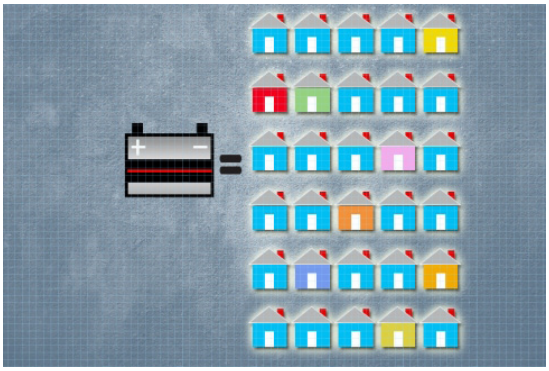
BCC Research's report analyzes the global market trends, market drivers, restrains and opportunities, along with compound annual growth rates through 2018. VCSELs in optical communications market are expected to be a dominant source in coming years. Other technologies such as gesture recognition and industrial sensing will spur the demand of VCSELs in the future.

In this report the VCSEL market is segmented into applications; materials (GaN, GaAs, InP and others AlGaAs, InGaAsN, etc); colours (red, green, blue-violet, infrared etc); and geography. There is also analysis of industry, competition and patents.

Solar

MIT looks to old batteries for perovskite solar cells

Lead from a single car battery could power 30 households.



A system proposed by researchers at MIT recycles materials from discarded car batteries - a potential source of lead pollution - into new, long-lasting solar panels that provide emissions-free power.

The system is described in a paper in the journal *Energy and Environmental Science*, co-authored by Angela Belcher and Paula Hammond, Po-Yen Chen, and three others. It is based on a recent development in solar cells that makes use of perovskite – in this case organolead halide perovskite - a technology that has rapidly progressed from initial experiments to a point where its efficiency is nearly competitive with that of other types of solar cells.

"It went from initial demonstrations to good efficiency in less than two years," says Belcher. Already, perovskite-based photovoltaic cells have achieved power-conversion efficiency of more than 19 percent, which is close to that of many commercial silicon-based solar cells.

Initial descriptions of the perovskite technology identified its use of lead, whose production from raw ores can produce toxic residues, as a drawback. But by using recycled lead from old car batteries, the manufacturing process can instead be used to divert toxic material from landfills and reuse it in photovoltaic panels that could go on producing power for decades.

Because the perovskite photovoltaic material

takes the form of a thin film just half a micrometer thick, the team's analysis shows that the lead from a single car battery could produce enough solar panels to provide power for 30 households.

As an added advantage, the production of perovskite solar cells is a relatively simple and benign process. "It has the advantage of being a low-temperature process, and the number of steps is reduced" compared with the manufacture of conventional solar cells, Belcher says.

Battery pileup ahead

One motivation for using the lead in old car batteries is that battery technology is undergoing rapid change, with new, more efficient types, such as lithium-ion batteries, swiftly taking over the market. "Once the battery technology evolves, over 200 million lead-acid batteries will potentially be retired in the United States, and that could cause a lot of environmental issues," Belcher says.

Today, she says, 90 percent of the lead recovered from the recycling of old batteries is used to produce new batteries, but over time the market for new lead-acid batteries is likely to decline, potentially leaving a large stockpile of lead with no obvious application.

In a finished solar panel, the lead-containing layer would be fully encapsulated by other materials, as many solar panels are today, limiting the risk of lead contamination of the environment. When the panels are eventually retired, the lead can simply be recycled into new solar panels.

"The process to encapsulate them will be the same as for polymer cells today," Chen says. "That technology can be easily translated."

"It is important that we consider the life cycles of the materials in large-scale energy systems," Hammond says. "And here we believe the sheer simplicity of the approach bodes well for its commercial implementation."

Hanergy Completes Acquisition of GaAs solar firm Alta

Plans to push thin film GaAs solar technology into mobile markets

Beijing–based Hanergy Holding Group, which makes thin-film solar devices, has completed the acquisition of Alta Devices, whose thin film gallium arsenide solar technology has a conversion efficiency of 30.8 percent, the highest among the solar energy technologies currently available.

Both companies' R&D teams will join forces to develop Alta Devices' technology. Hanergy plans to actively expand the application of Alta Devices' products in mobile and wearable power application areas, ranging from emergency charging of mobile phones, to the automotive sector and the Internet of Things.

Alta Devices' use of GaAs allows its dual- and single-junction solar cells to produce record-breaking conversion efficiencies of 30.8 percent and 28.8 percent respectively, as certified by the US National Renewable Energy Laboratory (NREL). On a same surface area basis, its cells produce a power output two to three times higher than standard flexible thin-film cells, 8 percent higher than mass-produced monocrystalline silicon cells, and 10 percent higher than multicrystalline silicon cells.

Chairman and CEO of Hanergy Li Hejun said: "Alta Devices' thin film solar technology allows more energy to be produced in lower light conditions than any other type of solar cell, giving it greater potential to power a wide range of mobile devices and equipment from phones to cars. It has the potential to change the way solar energy is used. This acquisition advances Hanergy's goal to become the world leader in the solar technology of the future."

Chris Norris, president and CEO of Alta Devices, said: “This successful acquisition is built upon Alta Devices’ and Hanergy’s shared belief that flexible, thin-film solar technology represents the future of the solar industry. The combination of our world-class solar cell R&D capability and Hanergy’s technology, research and capital resources will help us further improve the performance of our technology, increase production capacity and expand applications.”

Alta Devices’ single-junction GaAs thin-film solar cells are already in production. Following the acquisition, Alta Devices will continue to operate independently as a wholly-owned subsidiary of Hanergy. Hanergy will also work with Alta Devices to develop international markets and enhance its cooperation with key strategic customers.

In 2014 Hanergy was the only Chinese energy company named among the ‘World’s Smartest Companies’ by the MIT Technology Review. In 2012 and 2013, the same publication named Alta Devices among the ‘World’s Most Disruptive Companies’.

US SunShot initiative a boost for CIGS focused SoloPower

SoloPower Systems has announced that it is collaborating with the US Photovoltaic Manufacturing Consortium (PVMC) as a strategic technology partner. Under the agreement, PVMC will provide specialised technology services to SoloPower Systems to develop thin-film solar.

SoloPower Systems’ CTO Chris Eberspacher commented on the DoE opportunity: “Our collaboration with PVMC will accelerate the commercial manufacturing ramp-up at Systems’ factory in Portland, and will support the continuing advancement of our products. We look forward to this partnership which will not only expand our thin-film production capabilities, but also serve to ensure SoloPower technology remains a leader in this market.”

Created as part of the US Department of Energy’s SunShot Initiative, PVMC has extensive experience and know-how in photovoltaic technologies, including roll-to-roll copper indium gallium selenide (CIGS) PV technology, in both research laboratory and industrial production environments. CIGS-based thin-film uses layers of semiconductor materials that are only a few micrometers thick; the materials can be deposited on solid or flexible lightweight substrates, offering capabilities that are more versatile than traditional solar panels. This technology could also prove to be more cost-effective to produce in high-volume.

“We are excited that interest in the U.S. Photovoltaic Manufacturing Consortium continues to grow, further supporting PVMC’s mission to power the research, development, and deployment of sustainable, solar energy-focused solutions,” said Chief Operating and Technology Officer of PVMC Pradeep Haldar. “We welcome SoloPower to the consortium where they will be able to tap into advanced solar energy research and expertise to enable high-tech innovation, which continues to be fueled by New York Governor Andrew Cuomo’s commitment to developing next generation, clean energy technologies.”

PVMC is also developing roadmaps and standards to forge industry consensus and address broad issues related to power electronics, module advancements, building integration, testing, and reliability. Additionally, it offers a proving ground for innovative solar technologies and manufacturing processes.

US lab offers insights into new class of semiconductors

Hybrid perovskites are ‘best of both worlds’ for light harvesting

A paper published in the August 10th edition of the journal *Nature Photonics* by researchers at the University of Notre Dame in Indiana, describes their investigations into the fundamental optical properties of a new class of semiconducting materials known as organic-inorganic ‹hybrid› perovskites. They conclude that the materials offer the best compromise between cost and performance for light harvesting.

‹Perovskites› refers to the structural order these materials adopt upon drying and assembling in the solid state. In solid-state thin film solar cells, hybrid perovskites have recently shown light-to-electricity conversion efficiencies approaching 20 percent, rivaling that of commercial solar cells based on polycrystalline silicon. More importantly, these materials are easy and cheap to process using coating and or printing in contrast to solar technologies that typically require high purity materials, especially for silicon solar cells, and high-temperature processing.

However, the scientific community does not yet fully know how these unique materials interact with light on a fundamental level.

In this study, Joseph Manser under the direction of Prashant Kamat, present new insights into the excited-state properties of hybrid methylammonium lead iodide ($CH_3NH_3PbI_3$) thin films through a technique known as ‹transient absorption pump-probe spectroscopy› . This approach was used to examine the events that occur trillions of a second after light absorption in the hybrid methylammonium lead iodide. They analysed both the relaxation pathway and spectral broadening in photoexcited hybrid methylammonium lead iodide and found that the excited state is primarily composed of separate and distinct electrons and holes known as free carriers.

«The fact that these separated species are present intrinsically in photoexcited hybrid methylammonium lead iodide provides a vital insight into the basic operation of perovskite solar cells,» Manser said. «Since the electron and hole are equal and opposite in charge, they often exist in a bound or unseparated form known as an ‹exciton.› Most next-generation photovoltaics based on low-temperature, solution-processable materials are unable to perform the function of separating these bound species without intimate contact with another material that can extract one of the charges.»

This separation process siphons energy within the light-absorbing layer and restricts the device architecture to one of highly interfacial surface area. As a result, the overall effectiveness of the solar cell is reduced. «However, from our study, we now know that the photoexcited charges in hybrid perovskites exist in an inherently unbound state, thereby eliminating the additional energy loss associated with interfacial change separation,» Manser said. «These results indicate that hybrid perovskites represent a ‹best of both worlds› scenario, and have the potential to mitigate the compromise between low-cost and high-performance in light-harvesting devices.»

Although the research was on the fundamental optical and electronic properties of hybrid perovskites, it does have direct implications for device applications. Understanding how these materials behave under irradiation is necessary if they are to be fully optimised in light-harvesting assemblies.

Manser and Kamat›s research was supported by the Department of Energy›s Office of Basic Energy Science.

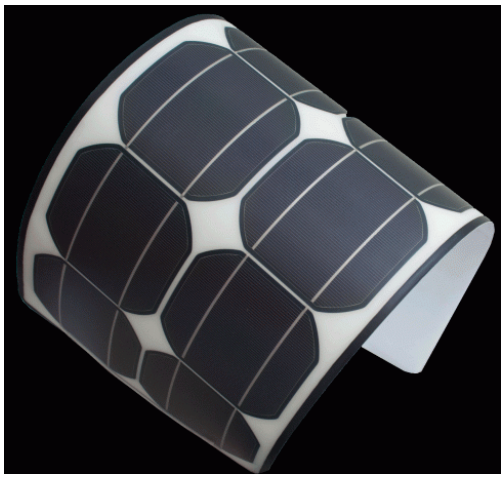
The paper *‹Band filling with free charge carriers in organometal halide perovskites›* by J Manser et al, appears in Nature Photonics (2014) doi:10.1038/nphoton.2014.171

CIGS cells set Swedish fuel efficiency record in Shell Eco Marathon

KTH uses Midsummer's solar technology to achieve 181.5 km/kWh

The Swedish Royal Institute of Technology (KTH) has set a new Swedish fuel efficiency record achieving 181.5 km/kWh in the Shell Eco Marathon competition for a solar powered car called 'Elba'.

In the race, European universities to compete with innovative solutions for how far a vehicle can travel with the energy equivalent to a litre of fuel. KTH's car was fitted with thin solar cells made by Midsummer, a supplier of production lines for cost effective manufacturing of flexible thin film solar cells, CIGS (copper, indium, gallium and selenide). It came fifth.



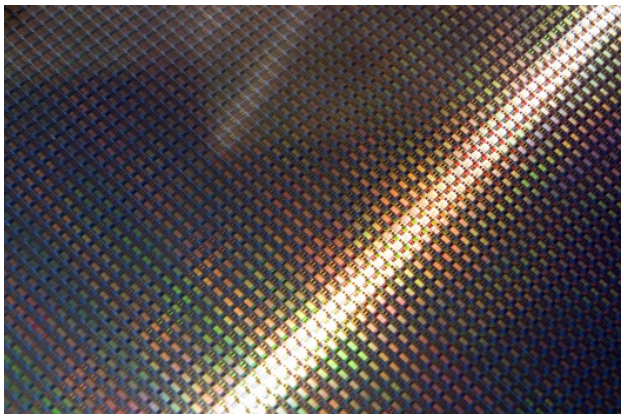
In the contest, which was held in Rotterdam in the Netherlands, the new improved 'Elba' was able to set a new Swedish record of 181.5 km/kWh, which can be compared to a car that drives a distance of 158 kilometres for a total cost of around 1 Swedish Krona (0.11 EUR or USD 0.15).

"The solar cells needed to be integrated into the car's design," said Alex Witt, production manager at Midsummer. "The only possible solar solution that would integrate in Elba's aerodynamic shape was Midsummer's flexible thin film solar cells on stainless steel, which could easily follow the curved body of the vehicle without cracking. This solution would have been impossible with silicon solar cells as they crack easily."

"In this year's competition KTH used last year's car 'Elba', which was rebuilt. The custom-made flexible solar cell modules were placed strategically on the vehicle to optimise the exposure of the sun and thereafter connected in series to generate as high voltage as possible into the system," Witt added.

Midsummer has developed a rapid process for the production of CIGS solar cells using sputtering of all layers of the solar cell.

First Solar surpass CdTe thin film efficiency again with 21%



First Solar has announced it has set a world record for cadmium-telluride (CdTe) photovoltaic (PV) research cell conversion efficiency, achieving 21 percent efficiency certified at the Newport Corporation's Technology and Applications Center (TAC) PV Lab. The record-setting cell was constructed at the company's Perrysburg, Ohio manufacturing factory and Research & Development Center, using processes and materials designed for commercial-scale manufacturing.

The record has been documented in the US Department of Energy's National Renewable

Energy Laboratory (NREL) “Best Research Cell Efficiencies” reference chart.

This certified result bests the previous CdTe record of 20.4 percent conversion efficiency, which was set by First Solar in February of 2014, and represents the seventh substantial update to CdTe record efficiency since 2011. The achievement also places First Solar’s CdTe research cell efficiency above copper indium gallium diselenide based solar cells (CIGS) at 20.9 percent, and well above multicrystalline silicon (mSi), which peaked at 20.4 percent in 2004.

“We have just begun to reveal the true unrealized potential of CdTe PV,” said Raffi Garabedian, First Solar’s Chief Technology Officer. “Our Advanced Research team continues to deliver extraordinary results by creating practical devices capable of commercial scale production. Not only have we have now demonstrated the highest single junction thin film cell on record, but just as important, our record cells are based on the same scalable manufacturing processes and commodity materials that we have proven through years of volume production.”

Garabedian noted that while competing technologies are using increasingly costly materials and cell processes in order to deliver moderate performance gains, First Solar is establishing a rapid path to industry-leading energy densities, while simultaneously improving manufacturing metrics.

“Our significant investment in development of CdTe thin-film technology has enabled a rapid rate of improvement and gives us tremendous confidence in the future,” said Markus Gloeckler, First Solar Vice President for Advanced Research. “We have made outstanding improvements in all aspects of our thin-film solar cells and are aggressively pursuing the commercialization of these advanced technologies in our product.”

At an analyst briefing last March, First Solar presented a technology roadmap anticipating a 22 percent research cell efficiency milestone in 2015. This announcement indicates First Solar is steadily tracking to achieve that goal ahead of schedule.

First Solar has continued to transfer its success in the R&D lab into its commercially produced modules, increasing its average production module efficiency to 14 percent in the second quarter of 2014, up 0.5 percent from the first quarter of the year, and up 0.7 percent from FY2013. The company’s lead line was producing modules with 14.1 percent average efficiency at the end of the second quarter of 2014.

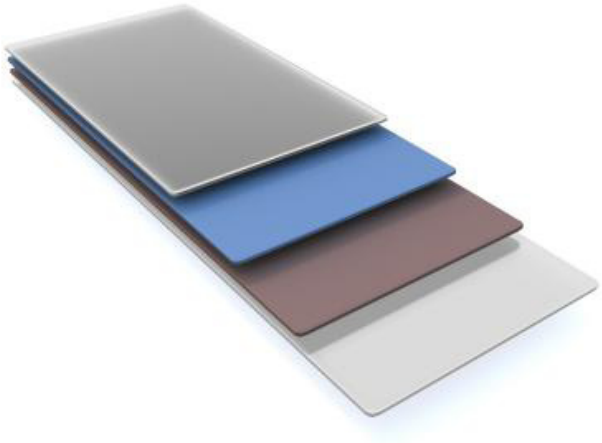
Sheets of stapled semiconductors could make ultra thin solar cells

Researchers combine tungsten diselenide with molybdenum disulphide to create ‘designer’ optoelectronic material

Researchers at the Vienna University of Technology have used two ultra-thin layers to create a new semiconductor structure suited for photovoltaic energy conversion.

Several months ago, Marco Furchi, Thomas Mueller, and Andreas Pospischil (pictured l-r) produced an ultra-thin layer of the photoactive crystal tungsten diselenide. Now, they have combined this semiconductor with another layer made of molybdenum disulphide, creating a material that shows potential for a new kind of solar cell technology, they say, that is extremely thin, semi-transparent, and flexible.

Two layers with different functions



Tungsten diselenide is a semiconductor which consists of three atomic layers. One layer of tungsten is sandwiched between two layers of selenium atoms. (The image shows the two semiconductor layers in the middle, connected to electrodes on either side).

When light shines on a photoactive material single electrons are removed from their original position. A positively charged hole remains, where the electron used to be. Both the electron and the hole can move freely in the material, but they only contribute to the electrical current when they are kept apart so that they cannot recombine.

To prevent recombination of electrons and holes, metallic electrodes can be used, through which the charge is sucked away - or a second material is added. “The holes move inside the tungsten diselenide layer, the electrons, on the other hand, migrate into the molybednium disulphide”, says Mueller. Thus, recombination is suppressed.

This is only possible if the energies of the electrons in both layers are tuned exactly the right way. In the experiment, this can be done using electrostatic fields. Florian Libisch and Joachim Burgdörfer (TU Vienna) provided computer simulations to calculate how the energy of the electrons changes in both materials and which voltage leads to an optimum yield of electrical power.

Tightly packed layers

“One of the greatest challenges was to stack the two materials, creating an atomically flat structure”, says Thomas Mueller. “If there are any molecules between the two layers, so that there is no direct contact, the solar cell will not work.” Eventually, this feat was accomplished by heating both layers in vacuum and stacking it in ambient atmosphere. Water between the two layers was removed by heating the layer structure once again.

Part of the incoming light passes right through the material. The rest is absorbed and converted into electric energy. The material could be used for glass fronts, letting most of the light in, but still creating electricity. As it only consists of a few atomic layers, it is extremely light weight (300 square meters weigh only one gram), and very flexible. Now the team is working on stacking more than two layers - this will reduce transparency, but increase the electrical power.

2D materials

Ultra-thin 2D materials, which consist only of one or a few atomic layers are a hot topic. Research on such materials started with graphene, which is made of a single layer of carbon atoms. Mueller and his team applied their knowledge gained in handling, analysing and improving ultra-thin layers of graphene to other ultra-thin materials to do this work. The team was the first to combine two different ultra-thin semiconductor layers and study their optoelectronic properties.

Researchers make spray-painted perovskite solar cells

Method could be used for low cost, high volume manufacturing

A team of scientists at the University of Sheffield, UK, claim to be the first to make perovskite solar cells using a spray-painting process – a discovery

they say could help cut the cost of solar electricity.

Perovskite (a calcium titanium oxide mineral with the formula CaTiO3) is a promising new material for solar cells, combining high efficiency with low materials costs. Efficient organometal halide perovskite based photovoltaics were first demonstrated in 2012.

“There is a lot of excitement around perovskite based photovoltaics. Remarkably, this class of material offers the potential to combine the high performance of mature solar cell technologies with the low embedded energy costs of production of organic photovoltaics,” said lead researcher David Lidzey.

He added: “The best certified efficiencies from organic solar cells are around 10 per cent. Perovskite cells now have efficiencies of up to 19 per cent. This is not so far behind that of silicon at 25 per cent - the material that dominates the world-wide solar market.”

According to the researchers, the spray-painting process wastes very little of the perovskite material and can be scaled to high volume manufacturing – similar to applying paint to cars and graphic printing. Experts from the University’s Department of Physics and Astronomy and Department of Chemical and Biological Engineering have previously used the spray-painting method to produce solar cells using organic semiconductors - but using perovskite is a major step forward.

The perovskite devices created still use similar structures to organic cells. “What we have done is replace the key light absorbing layer - the organic layer - with a spray-painted perovskite. Using a perovskite absorber instead of an organic absorber gives a significant boost in terms of efficiency,” said Lidzey.

Emcore Awarded Long-Term Contract by Lockheed Martin

High efficiency, multi-junction Coverglass cells for satellite program

Emcore, a provider of compound semiconductor-based components and subsystems for fibre optics and space solar power markets, has announced today that it has entered into a new, long-term supply agreement with Lockheed Martin Space Systems to design and manufacture high-efficiency, multi-junction Coverglass Interconnected Cells (CICs). The CICs will be produced at Emcore’s state-of-the-art manufacturing facility located in Albuquerque, USA, and are for Lockheed Martin’s satellite program.

Emcore has been a supplier of CICs for many previous space missions featuring satellites and spacecraft developed by Lockheed Martin. The CICs to be delivered under this new long-term supply agreement are based on Emcore’s latest generation ZTJ triple-junction solar cells. These InGaP/InGaAs/Ge solar cells are the result of years of research and development in high-efficiency, multi-junction solar cell technology for Lockheed Martin and several other major aerospace companies.

“This agreement with Lockheed Martin is one of the most significant contract awards in Emcore’s recent history and results from many years of productive collaboration between our two companies,” commented Brad Clevenger, executive vice president and general manager of Emcore’s Photovoltaics Division. “We are very pleased to enter into this next phase of our relationship and look forward to powering Lockheed Martin’s next generation of programs for many years to come.”

With a Beginning-Of-Life (BOL) conversion efficiency nearing 30 percent and the option for a patented, onboard monolithic bypass diode, Emcore’s industry-leading multi-junction solar cells provide the highest levels of performance to interplanetary spacecraft and earth orbiting satellites.

Since 2001 Emcore solar cells or panels have supplied primary power to over 130 successful space missions with zero on-orbit failures. The Company's proven manufacturing capability, technology leadership and unsurpassed reliability make Emcore the supplier of choice for demanding space programs

Magnolia is applying nanotechnology to boost solar cell performance

Nano-structured coatings to cut reflection losses and trap more light in CIGS and III-V cells

Magnolia Solar has announced that it is pioneering the application of nanotechnology for both flexible CIGS and III-V solar cells in order to boost performance and lower costs, using nano-structured optical coatings that can minimise reflection losses and enhance light trapping.

The US company also says it is developing a way to apply novel nano structured designs to the absorber layer of high-performance III-V and CIGS solar cells in order to reduce recombination losses and increase the capture of low-energy photons.

"Emerging technical approaches for achieving flexible photovoltaic power include the growth of copper indium gallium diselenide (CIGS) cells on flexible substrates and the epitaxial liftoff (ELO) of III-V devices onto thin metal film," said Roger Welser, Magnolia's CTO.

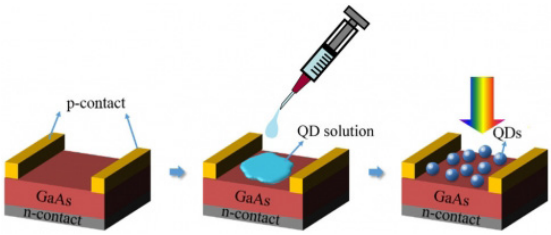
The company is working closely with the newly merged SUNY College of Nanoscale Science and Engineering (CNSE) / SUNY Institute of Technology (SUNYIT) institution. "Our office in the Albany NanoTech complex allows our technical staff to work very closely with top researchers at the CNSE/SUNYIT facilities which have directly led to innovative patent pending designs using nanotechnology. This is helping us to meet our goals of high-efficiency thin film solar cells," said Ashok K. Sood, president and CEO of Magnolia Solar Corporation

Based in Albany, NY and Woburn MA, Magnolia is targeting a variety of civilian and defense applications for its photovoltaic solar cells.

Quantum dots boost conversion efficiency of GaAs Solar cells

Dots act as luminescent downshifters

A team of scientists from Taiwan has shown that adding CdS or CdSe quantum dots (QDs) to GaAs solar cells could increase their efficiency by nearly 25 percent. The results were reported in *Nature* last week.



GaAs-based single-junction solar cells already hold the photovoltaic world record for the highest power conversion efficiency (PCE) at 28.8 percent. Boosting conversion efficiency in GaAs solar cells further requires reducing surface reflection and using the full solar spectrum, especially in the ultraviolet (UV) range.

High-energy photons can be easily absorbed at short distances, but the generated electron-hole pairs are close to the semiconductor surface, where recombination loss is strong. One way of solving this is to find a way to transform high-energy photons into lower-energy photons in process called luminescent downshifting.

Organic dyes have previously been used as downshifters but dye molecules have poor photon stability and narrow absorption spectrum bands. The researchers from National Chiao Tung University and the Industrial Technology Research Institute, in Hsinchu, Taiwan, used various QDs as the downshifting agents. The resultant hybrid design offers antireflective features to boost photon harvesting at long wavelengths while enhancing the collection of photogenerated carriers in the ultraviolet region.

They measured and analysed several photovoltaic parameters, including short-circuit current density, open circuit voltage, and external quantum efficiency to investigate the performance of the hybrid device. The results, they say, showed that

quantum dots effectively enhanced overall power conversion efficiency by as high as 24.65 percent compared with traditional GaAs-based devices. Further analysis of the quantum efficiency response showed that the luminescent downshifting effect can be as much as 6.6 percent of the entire enhancement of photogenerated current.

This is a brief overview of *'A Highly Efficient Hybrid GaAs Solar Cell Based on Colloidal-Quantum-Dot-Sensitization'* by Hau-Vei Han et al, Nature Scientific Reports **4**, Article number: 5734 doi:10.1038/srep05734

UK Power Plant to be based on Solar Frontier's CIGS technology

Solar Frontier to provide solar panels for 8.1 megawatt power station in Banwell, UK

Tokyo-based Solar Frontier, which makes CIGS (copper, indium, gallium and selenium) solar panels, will work with German firm New Energy for the World on an 8.1 megawatt solar power plant in Banwell, UK.

Solar Frontier will provide the electronic components, including CIGS solar modules, which are expected to deliver 9.1 GWh of electricity per year. The contract was signed at the recent Intersolar trade show in Munich, and construction is scheduled to start in September, 2014.

World Record for Concentrator Photovoltaics

36.7 percent efficiency for module using highly efficient multi-junction solar cells

Researchers at the Fraunhofer Institute for Solar Energy Systems ISE have announced a world record efficiency of 36.7 percent for the Institute's concentrator photovoltaic (CPV) technology, which is the basis of the FLATCON module. The technology, which uses Fresnel lenses to collect sunlight and focus it onto miniature highly efficient solar cells, has been improved by adapting the concentrating lens to a new solar cell structure.

Key to this achievement was Soitec's four-junction solar cell based on wafer bonding technology and developed in cooperation with Fraunhofer ISE. This four-junction solar cell was implemented into the FLATCON module. The module aperture area, defined as the surface area of the module exposed to light, is 832 cm^2. The sunlight is concentrated by a factor of 230 suns onto fifty-two 7 mm^2 miniature solar cells with the help of fifty-two 16 cm^2 Fresnel lenses.

The high module efficiency was measured under Concentrator Standard Testing Conditions, or CSTC, and marks the best value ever achieved for a photovoltaic module.

«Naturally we are incredibly excited about this high module efficiency,» says Andreas Bett, who has led the CPV research at Fraunhofer ISE over many years. For his efforts Bett has received many awards, among them the German Environmental Award 2012, together with Hansjörg Lerchenmüller of Soitec Solar. «This success shows that the high efficiencies of Soitec›s novel four-junction solar cells can be transferred to the module level.»

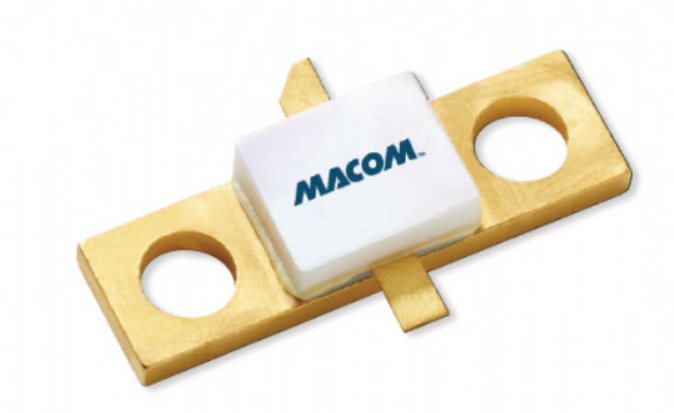
Only several months ago, Fraunhofer ISE together with Soitec, the French research center CEA-Leti, and the Helmholtz Center in Berlin announced a new solar cell world record of 44.7 percent under concentrated light. This record cell consisted of four sub-cells made up of the compound semiconductors GaInP, GaAs, GaInAs and InP respectively. In comparison to standard silicon solar cells, the manufacture of four-junction solar cells is more expensive so that up to now their terrestrial applications have been exclusively in concentrator systems.

Concentrator photovoltaic systems (CPV) are installed in sun-rich regions, where such systems produce solar electricity for less than 8 eurocents per kilowatt-hour. Key to this technology is the solar cell efficiency and the concentrating optic. In the record module, the newly developed four-junction solar cell was combined with Fresnel lenses, which were manufactured by the industry partner ORAFOL Fresnel Optics based on a new design developed at Fraunhofer ISE. The successful transfer of this high module efficiency to commercially manufactured modules is expected within one to two years.

Power Electronics

MACOM adds 15W GaN on SiC Pulsed Power Transistor

HEMT delivers 63 percent drain efficiency with 50V operation over DC to 3.5GHz



MACOM, the supplier of RF, microwave, and millimeter wave products, has announced new GaN on SiC HEMT pulsed power transistors.

Suitable for both civilian and military radar pulsed applications, the MAGX-000035-015000 and MAGX-000035-01500S are gold-metalised unmatched RF power transistors that provide a typical 17W of peak output power with 15.5dB of power gain and 63 percent efficiency.

The company says that they provide high gain, efficiency, bandwidth, and ruggedness over multiple octave bandwidths.

“The new 15 W peak GaN power transistor offers a versatile and high performance solution for pulsed driver and power applications over a broad frequency range,” said Paul Beasly, product manager. “The device is an ideal driver stage for MACOM’s higher power GaN transistors for L-Band and S-Band pulsed radar applications.”

Operating between the DC and 3.5GHz, the devices have a mean time to failure (MTTF) of 600 years. The product is offered in both an enhanced flanged (Cu/W) and flangeless (Cu) ceramic package which provide excellent thermal performance.

Transphorm Partners With Tata on solar inverters

Highly efficient inverters for India will use GaN technology

Transphorm has announced that it is working with Tata Power Solar to introduce India’s most efficient solar inverter using Transphorm’s patented EZ-GaN technology.

Transphorm has established the industry’s first and only qualified 600V GaN device platform with its TPH Series portfolio of products, backed by its GaN power IP portfolio.

Under the partnership, Transphorm will supply GaN transistors, while Tata Power Solar will locally manufacture and market the GaN-powered solar inverters. The first PV Inverter product is scheduled to be released in early 2015.

“We are pleased to partner with Transphorm to develop indigenous world-leading solar conversion,” said Ajay Goel, CEO, Tata Power Solar. “Our intent

is to lead in green energy. The inverter technology being developed has broad applications beyond solar conversion and we anticipate these energy efficient applications will find usage across various Tata companies."

"By designing our solar inverter product family with Transphorm's industry-leading and qualified EZ-GaN platform, Tata Power Solar will provide the Indian energy sector with a compact and higher efficiency PV Inverter as well as a roadmap of higher performance and smaller form factor solar PV power," said Dr. Arul Shanmugasundram, EVP Projects and CTO for Tata Power Solar. "This world-leading product family will accelerate India's adoption of solar energy, enabling the goal of using renewables to power 20 percent of India's energy needs by 2020."

"Tata's partnership with Transphorm is a testament to continued validation of Transphorm's undisputed leadership in addressing global power conversion needs," said Umesh Mishra, chairman, Transphorm. "We look forward to working with TATA to bring energy savings directly to enterprises and consumers."

According to Transphorm, the company's access to automotive class, high volume foundry manufacturing through its partnership with Fujitsu enables it to meet growing demand from global customers adopting energy-saving GaN power conversion products.

Ammono cuts prices for Google's Little Box Challenge

50 percent off GaN substrates for participants

Ammono is reducing GaN substrate prices by 50 percent for participants of '*The Little Box Challenge'*, a competition to build a much smaller power inverter, with a $1M prize launched by Google and the IEEE last month.

The use of wide bandgap semiconductors, such as GaN and SiC, which allow higher power densities, is one way for achieving the miniaturisation of inverters.

The winning device will be the one that achieves the highest power density while undergoing testing for 100 hours.

IEEE to host Webinar by EPC on GaN FETs

GaN expert Johan Strydom to present on envelope tracking

IEEE Power Electronics Society (PELS) will offer a webinar discussing the contribution of GaN power transistors to meet the demanding system bandwidth requirements of envelope tracking power circuit design and applications.

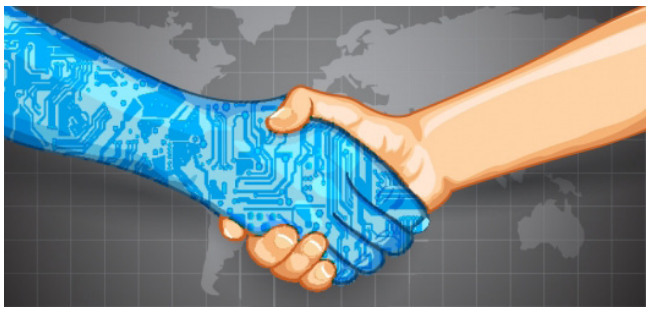
Presented by Johan Strydom, an expert on the subject from the company Efficient Power Conversion Corporation (EPC)).

Discrete GaN power devices can offer superior hard-switching performance to MOSFETs and are considered important in the development of switching converters for envelope tracking. In this seminar, Strydom will present the latest family of high frequency enhancement-mode GaN transistors on silicon (eGaN FETs) in a few multi-megahertz buck converters. He will also discuss different system-level parasitics and evaluate their impact based on the experimental results.

Johan Strydom, EPC's vice president of applications engineering, is widely published in the industry, including being co-author of *GaN Transistors for Efficient Power Conversion*, the first textbook on the design and applications of GaN transistors.

Infineon to acquire International Rectifier for $3B

'Super power' company will make Si-, SiC- and GaN- based devices



Infineon Technologies AG will acquire International Rectifier for around $3 billion ($40 per share in an all-cash transaction), the companies announced today. The combination promises to create a 'super power' company supplying Si-, SiC- and GaN-based power devices and integrated circuits.

Reinhard Ploss, CEO of Infineon Technologies AG, said: "The acquisition of International Rectifier is a unique opportunity. With their great knowledge of specific customer needs and their application understanding, International Rectifier employees will contribute to Infineon's strategic development from product thinking to system understanding and system solutions. The combination of Infineon's and International Rectifier's products, technological and innovative excellence, as well as distributional strength will unleash great potential."

Oleg Khaykin, president and CEO of International Rectifier, said: "This transaction provides significant value to our stockholders and opens new strategic opportunities for both our customers and employees. By combining two complementary providers in power management solutions, International Rectifier will benefit from Infineon's products and technologies, manufacturing and operational excellence and greater R&D scale."

The acquisition complements Infineon's expertise in power semiconductors and adds system know-how in power conversion, while expanding its expertise in compound semiconductors and driving economies of scale in production.

With International Rectifier, Infineon acquires an advanced manufacturer in GaN-on-Si power semiconductors. International Rectifier's expertise in low-power, energy-efficient IGBTs and Intelligent Power Modules, power MOSFETs and digital power management ICs will also integrate well with Infineon's offering in power devices and modules.

The integration of International Rectifier will generate economies of scale through optimisation of the combined entity's operating expense structure and through the acceleration of the ramp-up of Infineon's leading 300-millimeter thin wafer manufacturing capability.

Infineon will also have a much broader and stronger regional scope. International Rectifier has a strong presence in the US, the important center of innovation especially in the Connected World, and will also help to improve Infineon's position in Asia. The increase in exposure to the distribution channel will allow Infineon to meet the needs of a broader range of customers.

Commenting on the acquisition, Alex Lidow, former CEO of International Rectifier and now CEO of Efficient Power Conversion said: "We are gratified to see that Infineon recognises the excellent technology developed by International Rectifier. Especially significant is International Rectifier's excellent GaN technology. GaN-on-silicon transistors are in the process of replacing silicon-based power MOSFETs and iGBTs, and Infineon, through this acquisition, is showing their recognition of this major technology shift."

The closing of the transaction is subject to regulatory approvals in various jurisdictions and customary closing conditions, as well as approval of International Rectifier stockholders. The transaction is expected to close late in the calendar year 2014 or early in the calendar year 2015 subject to regulatory approval.

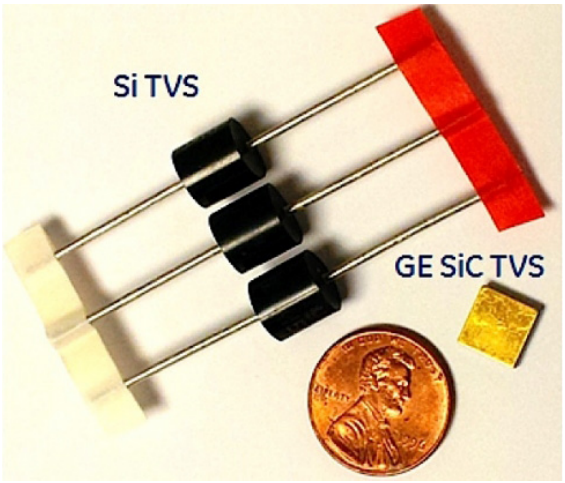
GE researchers develop 250degC+ SiC Transient Voltage Suppressor

Compact chip can replace multiple silicon TVS devices

Transient voltage suppressors (TVS) are critical components for protecting sensitive electronics from lightning, EMI and other temporary over-voltage

events that may occur within the system. However, COTS silicon TVS devices are limited in operation to temperatures of about 150degC. At higher temperatures, leakage currents become excessive and the surge current is highly de-rated.

To address this lack of performance at high temperatures, a team led by Avinash Kashyap at the General Electric Global Research Center at Niskayuna, NY has developed a punch-through physics SiC-based TVS device. This could serve aviation, down-hole applications and high performance power electronics.



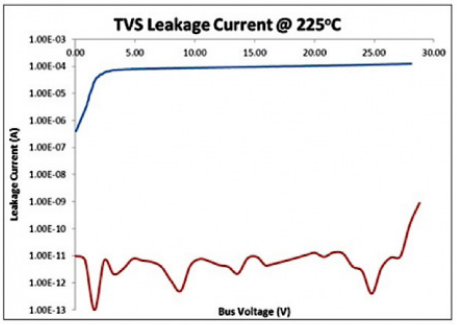
Currently, the prevailing design technique for reaching the intended protection specifications using silicon TVS devices (when optimal combinations of breakdown voltage and power ratings may not be available) is to connect several parts in series and/or parallel. This takes up valuable board area in space-limited applications, while drastically reducing reliability due to a combination of: increased number of components; and non-ideal current sharing between the devices under short pulse durations, leading to premature failure.

Multiple devices also increase the cost, not only because of the obvious reasons of using more than one part, but also due to increased component up-screening requirements - as the devices have to be closely matched to one another, leading to lower yields.

The punch-through physics based SiC TVS developed by Avinash Kashyap and his team, can replace multiple Si TVS devices with a single, smaller SiC device (shown in a hermetic package above) in certain applications.

The SiC device is capable of operating at 250degC and beyond, with minimal de-rating in the surge capability. Surge testing also demonstrated the device conducting current at over 10 kA/cm^2, at elevated temperatures (225degC).

The high current density capability allows the SiC devices to be several times smaller than their silicon counterparts, lending themselves towards miniaturisation. Even at these high current densities, the resistance of the device is low, leading to low clamping voltages (about twice the breakdown voltage at 10 kA/cm^2). Therefore, it is possible to afford a higher level of protection to downstream electronics because their de-rating can then be decreased, allowing for the maximum utilisation of the transistors.



Pictured above: Comparison of leakage currents of Si (blue) and SiC (red) TVS at 225degC. Note the several orders of magnitude lower leakage for the GE SiC device.

According to Kashyap, these new SiC TVS parts can also pass all the DO-160 surge requirements (up to waveform 5, level 5) for aviation electronics and can hence be used in composite aircrafts requiring enhanced lightning surge protection. Since a single device can be used for passing any DO-160 level, it eliminates the need to parallel several parts, and thereby increases the reliability of the overall system.

The smaller size has another unintended benefit - lower capacitance compared to equivalent silicon devices, thereby not loading communication buses or in some cases, obviating the need to connect pn-diodes in series.

The ruggedness of the SiC TVS devices were demonstrated thorough multiple DO-160 hits, back-to-back in one minute intervals with no apparent degradation in the electrical characteristics. Some

of the devices were tested up to 50 consecutive hits with no failures. The die temperature increases to high values during surge events, but the unique material properties of SiC (~1.5 times the thermal conductivity of silicon and 17 times lower intrinsic carrier concentration) allows the device to operate without causing thermal runaway even under extreme ambient conditions (>200degC), which would simply not be possible in silicon.

A validation of these facts are the results from long term HTRB tests that have shown no degradation in the leakage current or breakdown voltage at 225degC after over 8000 hours of stress.

This is the first known wide bandgap transient suppressor device that has successfully undergone surge testing not just in terms of high current densities (which can be achieved through small devices), but also high absolute values of current (~3kA with an 8μs/20μs surge waveform), clearly establishing that the GE design can be scaled to large area die with no apparent current sharing shortcomings.

This work will be presented at the IEEE Workshop on Wide Bandgap Power Devices and Applications to be held at Knoxville, TN in Oct. 2014.

GaAs IC Market to reach $8 billion in 2017

PA pricing to increase to $3.50 with LTE and AWS

A new market research report *'The GaAs IC Market'* by Information Network forecasts that the GaAs IC market will reach $8 billion in 2017.

The most important driver of the GaAs RF IC market is power amplifiers (PAs) and switches in the front-end of the handsets. 3G handsets often contain up to five PAs, and GaAs makes up 100 percent of the market, which is close to $5 billion.

According to the report, the number of PAs per handset is growing because of: complex 3G systems, global roaming support, and data roaming support. Pricing for PAs has increased from $0.80 per handset to $2.90 currently and is projected to increase to greater than $3.50 once Long Term Evolution (LTE) and Advanced Wireless Services (AWS) spectrum emerge in advanced handsets in the marketplace.

While industrialised countries are using 3G networks, today's world is a mixture of 2/2.5G and 3G networks, the heavy majority of subscribers are actually on 2G-based networks - and predicted to remain so for a number of years.

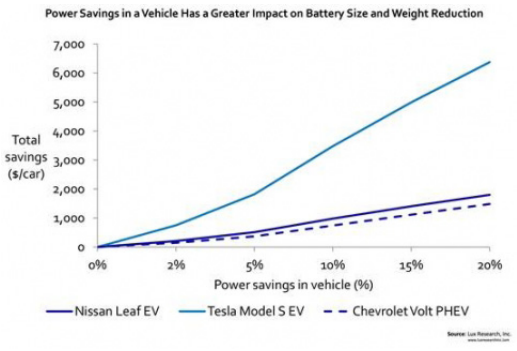
Between 70 to 80 percent of Skyworks' and RF Micro Device's GaAs business is in PAs. 2G handsets contain one PA, so it represents a sizable market. Because they aren't as technologically advanced as 3G cell phones, particularly smartphones, silicon is making inroads in the GaAs domain. For 2013, only 90 percent of PAs were made in GaAs, 5 percent in silicon CMOS, and 5 percent in silicon LDMOS.

This report, available from Reportbuyer.com, investigates the technology trends, applications, and market developments of GaAs ICs. US Japanese, and European applications such as telecom, computers, defense, consumers, are also reviewed.

SiC to replace silicon power devices in cars by 2020

Wide bandgap materials key to cutting battery costs

Wide bandgap materials such as silicon carbide and gallium nitride are best positioned to address emerging power electronics performance needs in electric vehicles (EVs), with SiC displacing silicon as early as 2020, according to a new report by Lux Research.



As silicon struggles to meet higher performance standards, wide bandgap (WBG) materials are benefiting from evolving battery economics. On a Tesla Model S car, for example, a 20 percent power

savings can result in gains of over $6,000 in battery cost, or 8 percent of the vehicle's cost.

"Efficient power electronics is key to a smaller battery size, which in turn has a positive cascading impact on wiring, thermal management, packaging, and weight of electric vehicles," said Pallavi Madakasira, Lux Research Analyst and lead author of the report '*Silicon vs. WBG: Demystifying Prospects of GaN and SiC in the Electrified Vehicle Market.'*

"In addition to power electronic modules, opportunities from a growing number of consumer applications - such as infotainment and screens - will double the number of power electronic components built into a vehicle," she added.

Lux Research analysts have evaluated system-level benefits WBG materials are bringing to the automotive industry, and predicted a timeline for commercial roll-outs of WBG-based power electronics.

Among their findings were that at 2 percent power savings, if battery costs fall below $250/kWh, SiC diodes will be the only economic solution in EVs requiring a large battery. For plug-in electric vehicles (PHEVs), the threshold power savings needs to 5 percent.

They also forecast that SiC diodes will attain commercialisation sooner than GaN, being adopted in vehicles by 2020.

Government funding, they add, is driving WBG adoption. The US, Japan and the UK, among others, are funding research and development in power electronics. The US Department of Energy's Advanced Power Electronics and Electric Motors is spending $69 million this year and defining performance and cost targets; the Japanese government funds a joint industry and university R&D program that includes Toyota, Honda and Nissan.

Swedish scientists build 500° C SiC bipolar op amp

First high temperature operation of fully integrated device

Scientists at the KTH Royal Institute of Technology in Sweden have built a monolithic bipolar operational amplifier fabricated in SiC technology with a 4H crystal structure.

Published in the IEEE's Electron Device Letters, this is the first report on high temperature operation of a fully integrated SiC bipolar opamp. According to the team, it demonstrates the feasibility of this technology for high temperature analogue integrated circuits.

The op amp has been used in an inverting negative feedback amplifier configuration. Wide temperature operation of the amplifier is demonstrated from 25 to 500°C.

The measured closed loop gain is around 40 dB for all temperatures whereas the 3dB bandwidth increases from 270kHz at 25°C to 410kHz at 500°C. The opamp achieves 1.46 V/µs slew rate and 0.25 percent total harmonic distortion.

Full details of the work are detailed in ‹*A Monolithic, 500 °C Operational Amplifier in 4H-SiC Bipolar Technology'* by R. Hedayati et al, Electron Device Letters, IEEE (Volume: **35**, Issue: 7)

Japanese group reduces defects in SiC transistors

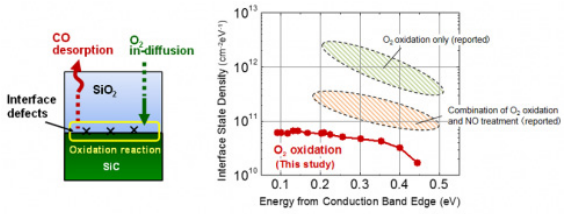
Dielectric film growth technique could improve next generation SiC power devices

A research group at the University of Tokyo Graduate School of Engineering has found a way to reduce defects in silicon carbide devices to improve performance.

SiC devices offer the potential for lower energy loss than conventional silicon devices, but SiC transistors suffer from high resistance and low reliability, mainly due to defects formed at the interface between SiC gate dielectric film. Such defects, caused by impurities and atomic excess or deficiency at the interface, need to be reduced to

improve the performance.

The Tokyo University group led by Koji Kita found that the density of interface defects is significantly reduced by employing reaction conditions where the by product carbon is ejected as carbon monoxide when creating the gate dielectric film. The group achieved the lowest defect density in a metal-oxide-semiconductor test structure employing these conditions.



The diagrams above show: (left) a schematic of oxidation of SiC/SiO_2 interface; and (right) Interface state density of 4H-SiC/SiO_2 observed in this study, compared with previously reported typical values (hatched areas). The horizontal axis shows the energy levels of defect states referred to the conduction band edge of SiC.

This technique provides a high quality SiC interface without any extra processes such as addition of nitrogen-containing gases, assuring the easy industrial application of this method. This technique is expected to improve the performance and accelerate the spread of SiC power devices, contributing to energy saving in a variety of applications, including electric power transmission, electric vehicles, and factory machines.

The work was published as *"Fabrication of SiO_2/4H-SiC (0001) Interface with Nearly-Ideal Capacitance-Voltage Characteristics by Thermal Oxidation"* by Richard Heihachiro Kikuchi and Koji Kita, in Applied Physics Letters **105,** 032106 (2014).

Novati gets 'trusted foundry' stamp for US defence applications

One of only nine fabs to win DoD accreditation

Novati Technologies, a developer of photonics, MEMS, 2.5D/3D, III-V-on-silicon and nanotechnology products, has announced that its wafer fab in Austin, Texas has been accredited by the US Department of Defense (DoD) as a Category 1A Trusted Foundry.

The DoD accreditation distinguishes Novati as a trusted manufacturer of integrated circuits for US aerospace and defence applications. Category 1A has been granted to only nine CMOS fabs that exhibit the highest levels of process integrity and protection.

Novati builds MEMS, sensors, actuators, photonic and electro-optic devices, Infrared (IR) detectors, wide bandgap electronics, non-volatile memory, power semiconductors, RF devices and a range of 2.5D/3D devices for aerospace and defence customers.

"Today's security applications for DoD demand suppliers who can meet the most rigorous requirements for utilising non-traditional elements and support low-volume manufacturing," said David Anderson, president and CEO for Novati. "We've proven that customers with really tough problems that require innovative materials, combinations of heterogeneous devices and high-risk processing techniques come to Novati. We regularly help develop products from concepts that have never been built before. The Trusted Foundry accreditation reflects our focus and strong commitment to supporting aerospace and defense contractors."

The Trusted Foundry program, administred by the Defense Microelectronics Activity (DMEA) organisation on behalf of the DoD, ensures that the US government has guaranteed access to specialised, high-performance components.

Raytheon to provide power systems for future electric aircraft

High temperature SiC technology central to MEA project

Raytheon has been selected to provide power systems expertise as part of several major aerospace industry consortia, which are developing the More Electric Aircraft (MEA) of the future. This marks the company's formal entry into the MEA market following Raytheon's significant investment in commercial aviation power solutions.

Driven by demands to optimise aircraft performance, decrease operating and maintenance costs, and reduce gas emissions, the MEA concept provides for the utilisation of electric power for all non-propulsive systems that were traditionally driven by a combination of different secondary power sources such as hydraulic, pneumatic, mechanical and electrical.

Under the Aerospace Growth Partnership (a collaboration between Government and industry working together to secure the future of UK Aerospace), Raytheon's involvement spans the full range of power architecture and product collaborative initiatives. which include: Power Off-take and Power Conversion for the More Electric Engine (SILOET II, Rolls-Royce), Electric Engine Start power delivery (POMOVAL, Labinal Power Systems), Motor Drive power delivery sub-systems (LAMPS, UTC), Dedicated HiTSiC Power Modules (R-PSM, Raytheon), and the Harsh Environment Health Monitoring Devices (HEEDS, AEC).

Central to Raytheon's strategy is leveraging its unique HiTSiC (High Temperature Silicon Carbide) produced at its UK foundry, which excels at optimal power delivery in high density, high temperature power supplies.

Existing modules have a maximum operating temperature of around 150degC due to the limitations of silicon devices. As a result, large, heavy liquid cooling systems are required. Raytheon's new silicon carbide can operate at temperatures of above 300degC, allowing more compact modules and greater efficiency, which is perfect for commercial aircraft, breaking away from the traditional tradeoffs while providing great value for money.

Steven Doran, Managing Director of Power and Control, Raytheon UK, commented: "Raytheon has a 25 year track record in electronic systems for harsh operating conditions where high current, power density, temperature and value are the key factors. The SWAP-V (Size, Weight, Power - Value) goal is being achieved through greater collaboration, with industry and academic experts in emerging technologies for harsh environments."

Google's $1m challenge to shrink inverters

Hint to competitors: use wide band gap semiconductors such as GaN and SiC

Google and the IEEE have announced an open competition *'The Little Box Challenge›* to build a smaller power inverter, with a $1m prize. The winning device will be the one that achieves the highest power density (plus a list of other specifications) while undergoing testing for 100 hours.

Google and IEEE are pointing to wide bandgap semiconductors such as Gallium Nitride (GaN) and Silicon Carbide (SiC) as the technologies most likely to achieve the power densities required. Wide bandgap suppliers Cree, EPC, GaN systems, Monolith Semiconductor, NXP, Rohm, Transphorm, and USCi are supporting the competition and have made web pages describing their technology, how it might enable contestants to win the competition, and opportunities for obtaining some of their devices.

Applicants contemplating competing in the prize

must register their team by the September 30, 2014, on the website https://www.littleboxchallenge.com/

Inverters are the essential boxes that take direct current from devices such as solar panels and batteries and turn it into alternating current for use in homes, businesses, and cars. But household inverters are big - roughly the size of a picnic cooler. Shrinking them down to something smaller than a small laptop, says Google, would enable more solar-powered homes, more efficient distributed electrical grids, and could help bring electricity to the most remote parts of the planet.

Allegro MicroSystems Announces New SiC Schottky Barrier Diodes

Designed to Minimise Power Supply Loss in Large Data Processing Servers

Allegro MicroSystems has announced the release of a next generation series of SiC schottky barrier diodes, manufactured by Sanken Electric, Japan. The FMCA series achieves low leakage current and high speed switching at high temperatures. It is targeted at industrial and computer markets with end applications to include servers and those that require high frequency rectification circuits.

The FMCA series uses the next generation of power semiconductor SiC and a 650V breakdown voltage in a schottky barrier configuration, making it suitable for continuous current mode PFC circuits. These devices are capable of reducing the power loss that results from the recovery current. The diode's high-speed switching capability and energy-saving functionality allows for the potential downsizing of equipment, says Allegro.

Key features include improved efficiency of the power supply with low recovery loss characteristics of the SiC-SBD, low-resistance with a high-speed switching SiC-MOSFET that realises a compact and highly efficient power supply and an increased current within high temperature environments to maintain stable switching due to the elimination of thermal runway. The FMCA series is available in a TO-220F package.

Raytheon demos prototyping of AESA/GaN technologies into Patriot radar

Technology promises 360 coverage, better reliability, and lower life cycle costs

Raytheon has demonstrated successful prototyping of Active Electronically Scanned Array (AESA) and GaN technologies into the US Patriot Air and Missile Defense System radar. In addition to enabling future 360 sensor coverage, these technologies will increase the defended area and decrease the time to detect, discriminate and engage threats, says Raytheon. GaN-based AESA technologies will also further improve reliability and lower life cycle costs for the Patriot radar.

"GaN-based AESA technologies represent the future of ground-based sensors and will have future application to Raytheon's entire sensor portfolio," said Ralph Acaba, vice president of Integrated Air and Missile Defense at Raytheon's Integrated Defense Systems business.

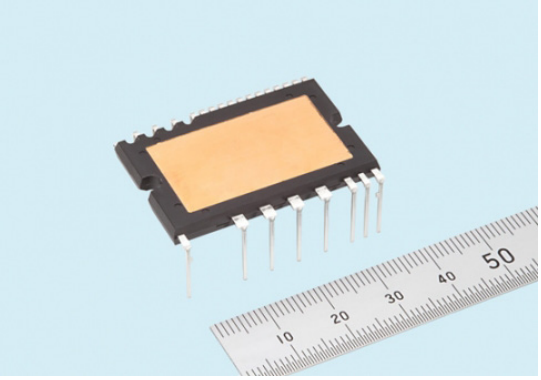
Raytheon has been developin GaN for 15 years and has invested over $150 million to get this latest technology in the hands of the warfighter faster and at lower cost and risk. Raytheon has demonstrated the maturity of the technology in a number of ways, including exceeding the reliability requirement for insertion into the production of military systems. This maturation of GaN resulted in a Manufacturing Readiness Level (MRL) production capability of "8," the highest level obtained by any organisation in the defense industry for this technology.

Raytheon is the prime contractor for both domestic and international Patriot Air and Missile Defense Systems and system integrator for Patriot Advanced Capability-3 missiles. The Patriot system is used by 12 nations around the globe.

Mitsubishi to Launch tiny SiC Power Factor Correction Module

Reduces power consumption and size of small motors for home appliances

Mitsubishi Electric has launched a transfer-moulded super-mini dual in-line package power factor correction (DIPPFC) module incorporating silicon carbide transistors and diodes, which is expected to help reduce the power consumption and size of home appliances.



SiC contributes to lower power consumption and compact size. Features of the module include: power loss reduction of about 45 percent compared to silicon products; a SiC schottky barrier diode (SBD) to reduce recovery current power consumption and electromagnetic interference noise; SiC MOSFET achieves maximum 40kHz high-frequency switching and contributes to downsizing of peripheral components, such as reactors and heat sinks; power factor correction (PFC) and driving IC contribute to downsizing by reducing mounting surface area and simplifying wiring.

Mitsubishi Electric commercialised its first DIPIPM transfer-moulded intelligent power module in 1997 and over the years has contributed greatly to miniaturization and energy-savings in inverter systems. The technology has gained increased importance because annual power consumption has become an important index of energy savings in consumer appliances, such as air conditioners.

Development of this DIPPFC module has been partially supported by Japan's New Energy and Industrial Technology Development Organization (NEDO).

GE leads US Consortium to develop next generation SiC materials and processes

New York Power Electronics Manufacturing Consortium to invest over $500 million in the next five years

New York State will partner with over 100 private companies, led by General Electric, in an American venture to develop next generation of SIC materials and processes, Governor Andrew Cuomo announced yesterday. Called the New York Power Electronics Manufacturing Consortium (NY-PEMC), the venture will invest over $500 million in the next five years.

The enterprise will be managed through the newly merged SUNY College of Nanoscale Science and Engineering (CNSE)/SUNY Institute of Technology (SUNYIT) campus based in Albany. GE will be a lead partner in the fab, housed at the CNSE Nano Tech complex (pictured above), which will develop and produce low cost, high performance 6in silicon carbide (SiC) wafers.

All NY-PEMC partner companies will have access to state-of-the-art 6in SiC tools and a baseline process flow, contributed by GE, where they can make their own enhancements in preparation for high volume, cost effective manufacturing. University researchers from around the state will also participate in the program. The idea is to use the state's nanotech facility to attract researchers and private companies to create a high-tech cluster in New York state.

"This partnership will create thousands of new jobs in Upstate New York, tapping into our highly trained workforce and existing centres of high tech research and development," said Cuomo. "With commitment from our partners, we are advancing

New York's capability to compete in the international marketplace and make this state the place to develop and manufacture high tech materials. This investment and partnership today will utilise the workforce of tomorrow, creating jobs and increasing long-term investments in New York State."

The partnership is enabled by the START-UP NY tax free initiative, in addition to $135 million in New York State funds provided to CNSE for the establishment of the NY-PEMC facilities, which will attract $365 million in private funds and know-how to support personnel, equipment and process flow, tool installation, facilities and materials for a total five-year investment of $500 million.

EPC Introduces A4WP Compliant Wireless Power Transfer Demo Kit

GaN FET evaluation kit for 6.78MHz, 35W wireless power transfer systems

Efficient Power Conversion Corporation (EPC) has announced the availability of a complete demonstration wireless power transfer kit. The 40V (EPC9111) or 100V (EPC9112) wireless kits comprise a source (or amplifier) board, a Class 3 A4WP compliant source (or transmit) coil, and a Category 3 A4WP compliant device (or receiving) board including coil

The system is capable of delivering up to 35W into a DC load while operating at 6.78MHz (the lowest ISM band). The kit simplifies the evaluation process of using eGaN FETs for wireless power transfer. The EPC9111 and EPC9112 utilise the high frequency switching capability of EPC gallium nitride transistors to facilitate wireless power systems with greater than 75 percent efficiency.

Wireless energy transfer systems need high efficiency, low profile, robustness to changing operating conditions and, in some cases, low weight. This means designs should be efficient and able to operate at high switching speeds without a bulky heatsink. Furthermore the design must be able to operate over a wide range of coupling and load variations. The fast switching capability of eGaN FETs, says EPC, is ideal for highly resonant power transfer applications.

The popularity of highly resonant wireless power transfer is increasing rapidly, particularly for applications targeting portable device charging. The end applications are varied and evolving quickly from mobile device charging, to life-extending medical implementations, to safety-critical hazardous environments.

The source board is a A4WP compliant, Zero Voltage Switching (ZVS), Class-D amplifier featuring either the 40V EPC2014 (EPC9111) or the 100 V EPC2007 (EPC9112) eGaN FET. It is configured in an optional half-bridge topology (for single-ended configuration) or default full-bridge topology (for differential configuration), and include the gate driver(s) and oscillator that ensure operation of the system at 6.78MHz. These amplifier boards are available separately as EPC9506 and EPC9507 for evaluation in existing customer systems.

The source coil, as well as the device coil, are Rezence (A4WP) compliant and have been pre-tuned to operate at 6.78MHz. The device board includes a high frequency Schottky diode based full-bridge rectifier and output filter to deliver a filtered unregulated DC voltage. The device board comes equipped with two LED's, one to indicate the power is being received and a second LED, which indicates that the output voltage has reached the maximum and is above 37 V.The device board can also be configured as a half-bridge rectifier that allows for double output voltage operation.

GaN-Based amplifiers behind World Cup 4k Ultra HDTV uplink

Advantech's SapphireBlu amplifiers help transmit the most viewed sporting event of the year

Advantech Wireless, a Canadian manufacturer of satellite, rf equipment and microwave systems, has revealed that 4k Ultra HDTV transmissions of the recent World Cup football tournament in Brazil were powered with the help of its SapphireBlu series of GaN-based high power amplifiers.

These Ku-Band GaN amplifiers were combined with the company's 13m A-Line Antenna in a major DTH Uplink system, allowing millions of viewers in Latin America and Brazil to follow the event.

"This powerful technology offers unprecedented ground power, linearity and cost savings," stated David Gelerman, CEO at Advantech Wireless. "For the first time, we are able to experience worldwide tournaments and fast moving sporting events produced in 4K Ultra HD. It is an incredible experience that brings the world together and makes us appreciate how close we are. We are very proud of being part of this worldwide achievement and contributed to the successful transmission of the biggest sport event of the year."

Awarded Teleport Technology of the year 2014 by the World Teleport Association and 'Vision Award' as Most Innovative Product of the Year 2013, the SapphireBlu Series of GaN based HPA systems are designed to offer very high linear power. This technology is so powerful, says the company, that it's possible with them to saturate all transponders of the modern satellite with a single 13m antenna and a single amplifier per polarisation.

National Research Council of Canada announces GaN design kit

Software gives access to NRC's GaN electronics fabrication service

The National Research Council of Canada (NRC) is now offering the second version of its gallium nitride GaN500v2 Design Kit software. Combined with Canada's only foundry for GaN electronics, the kit will enable industry and academics to create revolutionary technologies and device designs, according to the NRC.

The NRC provides complete fabrication processing from 3in GaN on SiC wafers through to characterisation and wafer dicing. Devices are fabricated with 0.5 micron gate length. Partners can choose full wafer runs (one customer's designs only) or shared wafer runs, which consolidate demand on three or more fabrication runs per year. The latter service is offered in partnership with CMC Microsystems.

The GaN500v2 Design Kit includes both a design manual and a physical design kit, based on Agilent's ADS CAD tool. The design manual includes the process description and design rules for all supported devices for the GaN technology and the related foundry services available through the Canadian Photonics Fabrication Centre of the NRC of Canada. The technology is appropriate for, but not limited to, RF and microwave devices.

The minimum ADS CAD bundle required for running the kit includes the ADS core and layout module. The design kit is compatible with ADS 2014 and earlier.

Compound Semiconductors to be worth $104.55 Billion in 2020

Market expected to grow at 12.63 percent CAGR from 2014 to 2020

According to a new report published by MarketsandMarkets, the compound semiconductor market is expected to grow at a CAGR of 12.63 percent from 2014 to 2020, reaching $104.55 billion in 2020.

The compound semiconductor market includes materials such as III-V, II-VI, IV-IV groups of compound semiconductors, and sapphire. Beneficial features such as direct gap, wide range of band gaps, higher electron mobility, and low power consumption, mean compound

semiconductors are finding wide application in LEDs; high speed and high power devices; lasers; sensors; and IR-visible-UVs.

The report ‹*Compound Semiconductor Market by Type (III-V, II-VI, IV-IV, sapphire), Deposition Technology (CVD, MBE, HVPE, Ammonothermal, MOVPE, LPE, ALD), Product (Power, Opto-electronic), Application, and Geography-2013-2020*'› covers the overall compound semiconductor market segmented into five major segments: compound semiconductor types, deposition technology, products, application, and geography.

MarketsandMarkets is a global market research and consulting company based in the US.

Macom Expands GaN Portfolio with 90W Avionics Power Module

Fully-matched, two-stage GaN module provides true surface mount solution

Macom has announced the newest entry in its portfolio of GaN in plastic power module products. Optimised for pulsed avionics applications in the 960 to 1215MHz band, Macom's new two-stage, fully matched GaN surface mount power module scales to peak pulse power levels of 100W in a 14 x 24 mm package size.

Under pulsed conditions, these modules deliver output power greater than 90W, with 30dB typical associated power gain and 60 percent typical power added efficiency. They support 50V operation and up to 3ms pulse width/duration for improved signal flexibility.

Delivering benefits in size, weight and power while enabling high volume manufacturing efficiency, Macom's new GaN power modules feature a Land Grid Array (LGA) pattern for enhanced thermal flow and true SMT assembly and do not require copper coining or complicated thermal management techniques on the system PCB.

Equipment and Materials

MELCO begins production with new Aixtron MOCVD tool

Tool to be used for GaN-on-Si PAs for mobile communication basestations

Mitsubishi Electric Corporation (MELCO) has begun operations with Aixtron's AIX 2800G4 HT Planetary Reactor system. The 11x4-inch wafer configuration tool will be used mainly for the development and volume production of high efficiency GaN-on-Si power amplifiers for mobile communication base stations.

MELCO's decision to buy the G4 for production of high efficiency power amplifiers is based on the positive experience with Aixtron's previous G3 MOCVD tool generation. As the Planetary Reactor provides system flexibility and a maximum production yield through superior material uniformity combined with a low wafer bow, the company looks forward to using it in volume production.

Frank Wischmeyer, vice president power electronics of Aixtron, says: "Gallium Nitride-on-Silicon technology is becoming the technology of choice for manufacturers of power electronics as it offers high performance and cost effective manufacturing processes on 4in, 6in and 200 mm Silicon. We are very pleased to enable MELCO to produce devices like monolithic high-efficiency power amplifiers or discrete HEMTs."

GaN-based components enable higher power densities at higher frequencies with potential applications that include satellite communication and radar, in addition to mobile phone network base stations.

Mitsubishi Electric Corporation (MELCO) is a Japanese multinational electronics and electrical equipment manufacturing company headquartered in Tokyo. Established in 1921, it is one of the core companies of the Mitsubishi Group generating revenues of $37,94bn in 2013.

ClassOne's new Electroplater gets first customer

Solstice system goes to Washington Nanofabrication Facility

ClassOne Technology has sold its first production unit of the new Solstice electroplating systems, launched at SEMICON, to the Washington Nanofabrication Facility (WNF) at the University of Washington, USA.

The WNF is a national user centre that is a part of the National Nanotechnology Infrastructure Network (NNIN). It is a full service micro and nanotechnology user facility, providing 15,000 sq ft of laboratories, cleanrooms, and user spaces focused on enabling basic and applied research, advanced R&D and prototype production.

Founded last year, ClassOne Technology produces wet processing tools specifically aimed at the needs of cost-conscious smaller-substrate users in emerging technologies such as MEMS, LEDs, power devices, RF communications, interposers, photonics and microfluidics.

To date, ClassOne has announced two Solstice models: The semi-automated Solstice LT features 1 or 2 chambers for development and pilot lines and starts at $350k. The fully-automated, cassette-to-cassette Solstice S8 provides up to eight process chambers, throughputs up to 75 wph and starts at $1M - which is less than half the cost of equivalent 300mm tools from the large manufacturers.

"The Solstice LT was exactly what we've been looking for," said Michael Khbeis, associate director of the WNF. "It's a very flexible development tool with the capabilities we need to serve our customers and perform a range of advanced processes - Through Silicon Via (TSV) plating and MEMS are particularly important to us. Plus, the LT price was within our budget, so we made our purchase commitment right there at the show."

Japanese lab creates new GaN substrate

SCAM substrate better than sapphire for crystal defects

Fukuda Crystal Laboratory, based in Sendai, Japan, has created 2inch-diameter samples of $ScAlMgO_4$ (scandium aluminum magnesium oxide) crystal, also known as SCAM. The idea is to replace sapphire in GaN-based LEDs and laser diodes by reducing crystal defects for GaN-based semiconductors grown on it. As a result, it is expected to boost brightness of GaN-based LEDs.

A research group led by Takashi Matsuoka, professor at the Institute for Materials Research at Tohoku University (also in Sendai), formed an LED structure by using the prototype crystal as a base for stacking GaN-based semiconductor layers, the crystal did indeed improve the crystal structure of the GaN.

1.8 percent lattice mismatch

The lattice mismatch between SCAM and GaN is as small as 1.8 percent, and SCAM reduces the appearance of crystal defects called dislocations. Though SCAM crystals are difficult to make, Fukuda Crystal Laboratory created 2inch high-quality SCAM crystals using the Czochralski (CZ) method. It improved crystal quality by modifying the CZ furnace structure and the conditions for crystal growth.

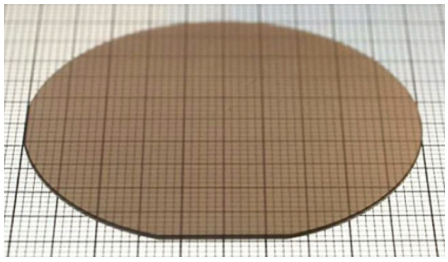
When the prototype SCAM crystal was cleaved and its C surface examined by X-ray diffraction, the full width at half maximum (FWHM) scatter was 12.9 seconds - equivalent to that produced by a perfect crystal of Si.

Fukuda Crystal Laboratory formed the wafers simply by cleaving an ingot of SCAM crystal without resorting to cutting or polishing, reducing the potential cost of wafer fabrication. When a GaN thin film was grown on the cleaved surface of the SCAM crystal using metal-organic chemical vapor deposition at a temperature of 1040degC, a low-dislocation crystal having a mirror surface was formed. The company considers this as a major achievement.

Fukuda Crystal Laboratory plans to increase the diameter of the SCAM crystals as well as commercialise the process. Specifically, it intends to release a 2 inch -diameter SCAM substrate by the spring of 2015.

Ammono announces new p-type GaN substrates

Substrate offers new potential for device architectures



Ammono, a company that focuses on research, development and manufacturing of compound semiconductor materials, will presenting a new p-type GaN bulk substrate material (Ammono-GaN) at the International Workshop on Nitride Semiconductors (IWN2014) in Wroclaw, Poland on August 25th.

Typically, dedicated donor doping can increase GaN conductivity, providing electrons as majority charge carriers (n-type). Successful and efficient p-type doping of GaN was always a difficult technological task, because of high activation energy of typical acceptors. Up untill today only thin layers of p-type GaN could be obtained by epitaxial methods or ion implantation.

In the ammonothermal process the incorporation of acceptor during the growth results in a larger hole concentration and p-type conductivity, without generation of structural defects.

According to the company, the dislocation density in p-type Ammono-GaN remains the same as the dislocation density of n-type Ammono-GaN substrates, being below $5x10^4$ cm^{-2}. Carrier (free hole) concentration in this material is at the level of 10^{16} cm^{-3}, while electrical resistivity is 10-100Ω*cm.

In the area, where many solutions are already patented, the introduction of such a new substrate offers new potential for device architectures. It is expected that laser diodes, LEDs, high power transistors and high frequency transistors may gain many benefits by using this new material.

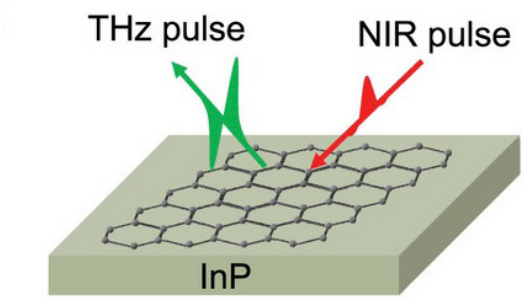
Indium Phosphide substrate test reveals purity of graphene

Rice, Osaka scientists use terahertz waves to spot contaminants

The environment around graphene, including defects in the substrate on which it is placed as well as gas molecules that surround it, can substantially influence its electronic performance. Because it is easy to accidently introduce such impurities, it would be useful to detect and identify out-of-place molecules.

Researchers at Rice and Osaka universities have now found a simple way to do this using terahertz spectroscopy and InP as a substrate for the

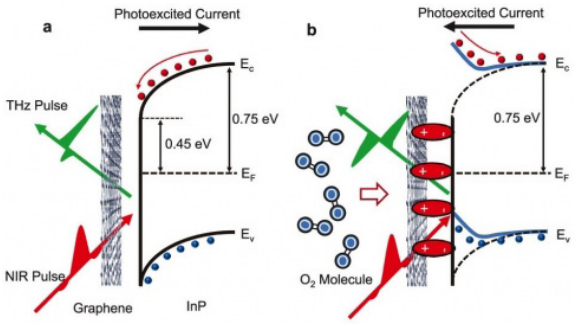
graphene. Their research was published this week by*Nature's* open-access online journal *Scientific Reports*.



Their contactless technique involves hitting the combined material with femtosecond pulses from a near-infrared laser. The pulses excite the indium phosphide so that it emits terahertz radiation back through the graphene. Imperfections as small as a stray oxygen molecule on the graphene can then be picked up by a spectrometer.

"The change in the terahertz signal due to adsorption of molecules is remarkable," said Junichiro Kono, one of the researchers from Rice. "Not just the intensity but also the waveform of emitted terahertz radiation totally and dynamically changes in response to molecular adsorption and desorption. The next step is to explore the ultimate sensitivity of this unique technique for gas sensing."

The technique can measure both the locations of contaminating molecules and changes over time. «The laser gradually removes oxygen molecules from the graphene, changing its density, and we can see that,» Kono said.



Pictured above a), Band diagram for pristine graphene on InP. The photo excited current flows towards the substrate. (b), Band diagram for graphene on InP with adsorbed oxygen molecules between them. The charge transfer between graphene and oxygen creates dipoles, which modify the band bending. The photoexcited current now flows towards the surface.

The experiment involved growing pristine graphene via chemical vapour deposition and transferring it to an indium phosphide substrate. Laser pulses generated coherent bursts of terahertz radiation through a built-in surface electric field of the indium phosphide substrate that changed due to charge transfer between the graphene and the contaminating molecules. The terahertz wave, when visualised, reflected the change.

The researchers expect the finding to be important to manufacturers considering the use of graphene in electronic devices. "For any future device designs using graphene, we have to take into account the influence of the surroundings," said Kono. Graphene in a vacuum or sandwiched between noncontaminating layers would probably be stable, but exposure to air would contaminate it, he said.

The Rice and Osaka labs are continuing to collaborate on a project to measure the terahertz conductivity of graphene on various substrates, he said.

The National Science Foundation (NSF); the Japan Society for the Promotion of Science; the Ministry of Education, Culture, Sports, Science and Technology-Japan and the Murata Science Foundation supported the research. NanoJapan is funded by the NSF's Partnerships for International Research and Education program.

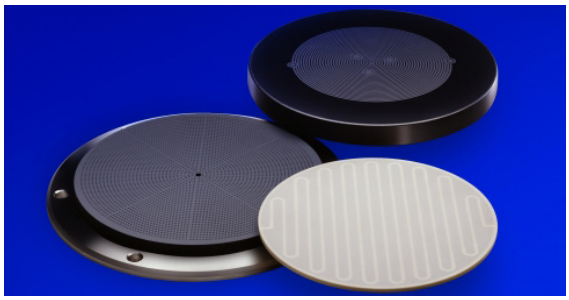
The paper *'Imaging molecular adsorption and desorption dynamics on graphene using terahertz emission spectroscopy'* by Y. Sono et al. appears in Nature Scientific Reports **4**, Article number: 6046

Replaceable, wear-resistant films extend Electrostatic Chuck life

Films available for CVD, PVD, etch and ion implant processes

Morgan Advanced Materials has introduced new solutions in sacrificial wear layers to extend the life of alumina or beryllia electrostatic chucks (ESCs)

for semiconductor, solar and LED applications. Applied as a final protective layer, the Diamonex technical hard-coats offer extended life benefits to new or refurbished ESCs.



These thin, wear-resistant films, made of diamond-like-carbon (DLC) and other nanocomposite materials, are adjusted to meet specific resistivity requirements of the ESC while protecting electronic layers and extending the overall life of the part. They have a broad range of chemical resistance, meet chamber process compatibility requirements, and can withstand high-temperature heated chuck applications.

The hard-coats can be applied to new or refurbished ESCs, even for ESCs originally designed without a sacrificial wear layer. The technical films are available for CVD, PVD, etch and ionimplant processes. The films feature mesa patterning for low defectivity and can be used in most high temperature processes.

US lab offers insights into new class of semiconductors

Hybrid perovskites are ‘best of both worlds’ for light harvesting

A paper published in *Nature Photonics* by researchers at the University of Notre Dame in Indiana, describes their investigations into the fundamental optical properties of a new class of semiconducting materials known as organic-inorganic ‹hybrid› perovskites. They conclude that the materials offer the best compromise between cost and performance for light harvesting.

‹Perovskites› refers to the structural order these materials adopt upon drying and assembling in the solid state. In solid-state thin film solar cells, hybrid perovskites have recently shown light-to-electricity conversion efficiencies approaching 20 percent, rivaling that of commercial solar cells based on polycrystalline silicon. More importantly, these materials are easy and cheap to process using coating and or printing in contrast to solar technologies that typically require high purity materials, especially for silicon solar cells, and high-temperature processing.

However, the scientific community does not yet fully know how these unique materials interact with light on a fundamental level.

In this study, Joseph Manser under the direction of Prashant Kamat, present new insights into the excited-state properties of hybrid methylammonium lead iodide (CH3NH3PbI3) thin films through a technique known as ‹transient absorption pump-probe spectroscopy› . This approach was used to examine the events that occur trillions of a second after light absorption in the hybrid methylammonium lead iodide. They analysed both the relaxation pathway and spectral broadening in photoexcited hybrid methylammonium lead iodide and found that the excited state is primarily composed of separate and distinct electrons and holes known as free carriers.

«The fact that these separated species are present intrinsically in photoexcited hybrid methylammonium lead iodide provides a vital insight into the basic operation of perovskite solar cells,» Manser said. «Since the electron and hole are equal and opposite in charge, they often exist in a bound or unseparated form known as an ‹exciton.› Most next-generation photovoltaics based on low-temperature, solution-processable materials are unable to perform the function of separating these bound species without intimate contact with another material that can extract one of the charges.» This separation process siphons energy within

the light-absorbing layer and restricts the device architecture to one of highly interfacial surface area. As a result, the overall effectiveness of the solar cell is reduced. «However, from our study, we now know that the photoexcited charges in hybrid perovskites exist in an inherently unbound state, thereby eliminating the additional energy loss associated with interfacial change separation,» Manser said. «These results indicate that hybrid perovskites represent a ‹best of both worlds› scenario, and have the potential to mitigate the compromise between low-cost and high-performance in light-harvesting devices.»

Although the research was on the fundamental optical and electronic properties of hybrid perovskites, it does have direct implications for device applications. Understanding how these materials behave under irradiation is necessary if they are to be fully optimised in light-harvesting assemblies.

Manser and Kamat›s research was supported by the Department of Energy›s Office of Basic Energy Science.

The paper ‹*Band filling with free charge carriers in organometal halide perovskites*› by J Manser et al, appears in Nature Photonics (2014) doi:10.1038/nphoton.2014.171

AXT Appoints Gary Fischer as CFO

Silicon Valley veteran to help grow global operations

AXT, the Californian manufacturer of compound semiconductor substrates, has appointed Gary L. Fischer as vice president and chief financial office. Fischer will have responsibility for AXT's global finance and accounting organisation and will report to chief executive officer, Morris Young.

"Gary brings to the table a wealth of public-company experience in finance, strategic planning, global operations and investor relations," said Young. "He has years of executive-level leadership, building technology businesses from early-stage to sustainable long-term profitability and revenue growth. This will be tremendously beneficial to AXT as we seek to increase our footprint in the global marketplace, leveraging our diversified portfolio of products as well as our key competitive differentiators."

Fischer is a Silicon Valley veteran, with experience working in Asia and Europe. In 1993, he joined ISSI, a leader in advanced memory solutions, as chief financial officer. He took the company public in 1995 and later became its president and chief operating officer. In 2005, Fischer joined eRide, a fabless semiconductor company that develops both GPS devices and software for location-based services. The company was acquired in 2009.

Fischer continued with eRide as a consultant into 2014 and expanded his consulting practice to assist a number of growth companies on a variety of finance and M&A projects.

Mitsubishi launches wafer bonding services

Machines can bond different kind of materials at room temperature

Mitsubishi Heavy Industries (MHI) has launched wafer bonding services performed using its in-house developed wafer bonding machines, which are capable of bonding different kind of materials at room temperature.

Until now the company has offered trial services of this kind to businesses and other potential

users considering the machine's adoption; now those same services have been expanded to include businesses and research institutes with no immediate plans to acquire the machine.

In launching the new services, MHI aims to boost recognition of the effectiveness of room-temperature wafer bonding, a technology originating in Japan, as a means toward expanding machine sales; it also looks to develop bonding services into a new area of business.

Quantum dot market to reach $5 billion by 2020

Solar power and displays driving demand

The global quantum dot market produced a revenue of $316 million in 2013 and is expected to grow to around $5 billion by 2020 at a CAGR of nearly 30 percent, according to a new research report by Allied Analytics LLP.

Refinement of manufacturing technologies and mass production will mean that volume consumption will grow faster at 116.5 percent during the same period to reach 72 ton in 2020, says the report 'Quantum Dot (QD) Market - Global Analysis, Growth, Trends, Opportunities, Size, Share and Forecast through 2020.'

Drivers for growth include efficient conversion of solar energy into power and rising use of volume-driven display devices. Additionally, the technology is more efficient than conventional technologies.

"The QD display market is set to grow exponentially as many companies such as Sony Corporation, LG Display etc. are getting into alliance with QD technology providers to commercialise QD displays, especially TV sets," note analysts Shreyas Naidu and Priyanka Gotsurve.

However, some factors such as high cost of technology and slow adoption due to extended research are serving as the restraints for the market growth. Although, mass manufacturing and bulk purchasing will quickly negate the cost constraints. The further penetration of the technology in newer applications such as security & defence, food, and packaging will provide the essential future growth thrust to the market.

North America has the highest revenue share due to early adoption. The region is expected to grow consistently and attain revenue of $1.92 billion by 2020. However, Asia-Pacific is expected to have the highest CAGR of 30.4 percent for the analysis period 2013-2020.

The report is available from researchandmarkets.com

Agilent's measurement business starts trading as Keysight Technologies

Separation expected to complete in NovemberAgilent Technologies' electronic measurement business has begun operating under the new name of Keysight Technologies. It will remain a wholly owned subsidiary of Agilent until early November 2014 when the separation is expected to be completed.

"As we launch our new company, we are mindful of our rich heritage as part of Agilent and prior to that, Hewlett-Packard," said Ron Nersesian, Keysight president and CEO. "We are also mindful of our responsibility and commitment to our stakeholders including customers, our shareholders and our employees. We look forward to the many opportunities ahead that will allow us to focus solely on electronic measurement and showcase the leading-edge technologies that our customers have come to expect."

Keysight's separation from Agilent was announced in September 2013. The new company provides electronic measurement instruments and systems and related software, software design tools

and services used in the design, development, manufacture, installation, deployment and operation of electronic equipment.

Vishay Orders Aixtron MOCVD system for LED production

Plan to rapidly expand GaAs-based infrared LED portfolio

Vishay Semiconductor GmbH has acquired an MOCVD system from Aixtron to expand its infrared LED production capacities. The company aims to substantially extend its product portfolio in this area. The system was delivered to Vishay at the end of March.

"We opted for Aixtron's planetary reactor, as it deposits high-quality layers and offers very high production stability, long operating times, and high throughput rates. Not only that, Aixtron will support us with process expertise, thus enabling us to rapidly and efficiently expand our gallium arsenide-based infrared LED production," commented Heinz Nather, senior vice president or Vishay's Opto division.

"We are delighted to have convinced Vishay Semiconductor, one of the world's leading producers of semiconductors and power electronics, with our range of technologies and services," remarked Frank Schulte, Vice President of Aixtron Europe. "We have great expectations of our ongoing cooperation with Vishay."

Vishay Semiconductor GmbH forms part of Vishay Intertechnology, Inc, based in Malvern, Pennsylvania, USA, one of the world's largest manufacturers of discrete semiconductor elements (diodes, rectifiers, transistors, optoelectronic components, integrated circuits) and passive electronics components (resistors, capacitors, inductors, sensors, transformers).

Riber signs agreement with Annealsys

Addition of innovative thin-film deposition techniques part of diversification strategy

Riber has signed a distribution agreement with Annealsys, a company specialising in innovative vapour phase chemical deposition processes (CVD and ALD) for a wide range of applications, from semiconductors to solar cells, LEDs and microsystems..

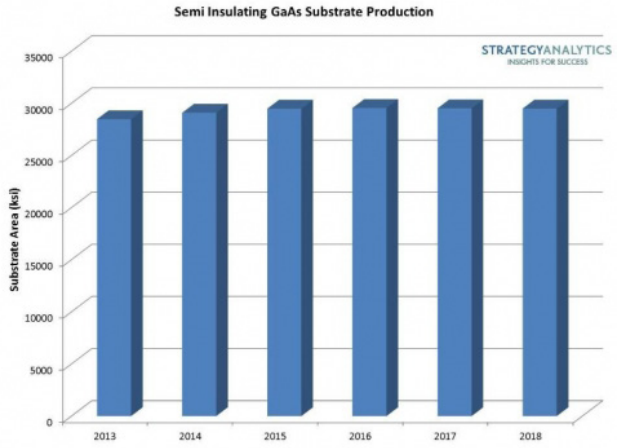
Annealsys' equipment is aimed primarily at research laboratories and universities, and industrial operators producing small batches. Founded in 2004 and based in Montpellier, France, Annealsys has built up unique CVD and ALD expertise, particularly for the integration of direct liquid injection vapourisers, making it possible to implement a wide variety of chemical precursors and develop processes for growing new materials.

Initially, the partnership will focus on CVD and ALD products and the American and Asian regions. Annealsys is looking to accelerate its sales growth internationally while for Riber it is an opportunity to further diversify into other thin-film deposition techniques.

GaAs Substrate Market Sees Further Revenue drop in 2013

Report predicts challenging times for substrate makers

Despite strong growth in the GaAs device market, GaAs bulk substrate manufacturers saw both production and revenues decline for the second straight year, according to a recently released Strategy Analytics' report.



The report '*Semi-Insulating GaAs Bulk Substrate Markets: 2013-2018"* forecasts that new mobile architectures, competing technologies and flattening

GaAs device growth rates will result in further declines in the total available market (TAM) for GaAs bulk substrates.

It concludes that demand for semi-insulating GaAs bulk substrates declined by nearly 2 percent in 2013. The volume decline and increasing price erosion caused revenues to decline by 8 percent. As a result, bulk substrate demand will grow with a CAAGR of less than 1 percent through 2018. With price erosion returning to historical levels, the slow growth of substrate production will drop revenues to $160 million in 2018.

Eric Higham, Strategy Analytics' service director for advanced semiconductor applications commented: «There will be challenging times ahead for GaAs substrate manufacturers. «The emergence of CMOS PAs and multi-mode, multi-band GaAs PAs will both act to slow growth and reduce revenue.»

Asif Anwar, director in the firm's strategic technologies practice added: «The good news is that prior disruptions in the GaAs bulk substrate supply chain appear to have been addressed, but this means a return to historical price erosion rates that will pull revenues down.»

Meller Optics introduces custom Sapphire wafer Carriers

Carriers more durable than quartz and impervious to polishing abrasives and solvents

Meller Optics, of Rhode Island, USA, has introduced custom fabricated sapphire wafer carriers for thinning semiconductors. The carriers are more durable than quartz and are impervious to polishing abrasives and solvents, says the company.

Meller sapphire wafer carriers feature Moh 9 hardness and superior strength due to off-axis crystal growth; permitting their custom fabrication as thin as 0.018in in 2 to 6in diameter sizes. Suited for the uniform thinning of semiconductor materials such as GaAs, they can be custom perforated for vacuum hold-down or de-lamination and can withstand repeated use.

The carriers provide part-to-part uniformity with ± 1.2µm thickness and parallelism to 10 arc-sec, depending upon size. Second only to diamond in terms of hardness, they are chip-, chemical-, and scratch-resistant and can be supplied with reference flats and laser markings.

Meller Sapphire Wafer Carriers are priced according to size, configuration, and quantity; with four to six weeks typical delivery.

Leading European lab orders Riber MBE system

Third sale of new compound semiconductor research system

Riber is announcing a third order for its Compact 21 DZ molecular beam epitaxy (MBE) system, which is designed for fundamental research on compound semiconductors. The machine will enable a leading European laboratory to increase its development capabilities for designing III-V semiconductor devices.

After two machines sold during the first half of 2014, this new purchase order confirms the commercial success of the new Compact 21 DZ system since its launch onto the market at the end of 2013, says Riber.

The Compact 21 DZ system is aimed at compound semiconductor research particularly structures based on III-V, II-VI, GaN materials, graphene, and oxides. It is well suited for the development of emerging technologies, such as UV LEDs or high-performance solar cells. Compact and flexible, it is designed to meet the needs of users looking to minimise their fixed costs, according to the company.

Agnitron To Ship 1500degC Reactor Upgrade for MOCVD System

Reactor offers economical growth capability for nitride-based materials and silicon carbide

Agnitron Technology is shipping its latest high

temperature reactor upgrade for the Veeco MOCVD D-series Legacy System platform. The single two or three inch wafer, vertical quartz tube reactor upgrade will be fitted to a D180 system at the Korean Photonics Technology Institute (Kopti) in Gwangju, Seoul, South Korea.

According to the company, the High Temperature Radio-Frequency (HT-RF) reactor upgrade provides an economical high temperature growth capability to researchers seeking high quality aluminum nitride (AlN) epitaxial films, which are grown at process temperatures above 1400degC. Additionally, the HT-RF reactor excels at growth of all nitride based materials and is also suitable for silicon carbide.

Ross Miller, director of Agnitron technology development commented: "Ultra-low gas flows of the HT-RF reactor translate to hydride gas consumption 15 percent that of a D180 reactor making this a very capable yet economical choice for researchers." Miller added that Atomic Layer Deposition style switching manifolds are available as an option for supporting Migration Enhanced Epitaxy growth techniques.

Currently the HT-RF reactor is offered as a standalone upgrade for the Veeco Legacy D125 and D180 Nitride MOCVD platforms as well as in the form of an Agnitron original design complete MOCVD system known as Agilis. The Agilis system provides all the process capabilities of the HT-RF reactor but in a compact cabinet with all new electronics and digital hardware communication protocols.

An identical HT-RF reactor upgrade is currently in operation at Agnitron's facility for growth of AlN as part of the power electronics research program funded by the US Department of Energy.

CyberOptics extends APS line to GaAs, LED and 150mm fabs

Airborne particle sensor technology now available in multiple form factors

To meet demand for airborne particle measurement in GaAs, LED and 150mm semiconductor fabs, CyberOptics Corporation has announced an extension to its WaferSense Airborne Particle Sensor (APS) line this week at SEMICON West, San Francisco.

With APS technology, equipment engineers can wirelessly monitor, identify and troubleshoot airborne particles in real-time within semiconductor process equipment and automated material handling systems. According to the company, customers have experienced up to 88 percent time savings, up to 95 percent reduction in costs, and up to 20 times the throughput with half the manpower resource requirements using the WaferSense APS relative to legacy surface scan wafer methods.

CyberOptics' WaferSense measurement portfolio including the Auto Leveling System (ALS), the Auto Gapping System (AGS), the Auto Vibration System (AVS), the Auto Teaching System (ATS) and the Airborne Particle Sensor (APS) are available now in 150mm, 200mm, 300mm and 450mm wafer sizes.

Veeco Expands Compound Semiconductor R&D Portfolio with Agnitron Technology

Partnership allows universities and institutions to obtain low cost MOCVD systems for materials R&D applications

Veeco Instruments has formed a strategic partnership with Agnitron Technology, a focused compound semiconductor research and development company specialising in the refurbishment and upgrade of Veeco legacy MOCVD equipment.

The partnership will allow universities and institutions to obtain low cost, reliable MOCVD systems for materials research and development applications. Additionally, Veeco R&D MOCVD system users will be able to upgrade to Agnitron's innovative Imperium software platform and have access to Agnitron's technical support team.

"Veeco's technology has served the compound semiconductor R&D and mass production markets for decades," said William J Miller, executive VP of Veeco process equipment. "We are taking the next step to expand our R&D reach with Agnitron's combined MOCVD refurbishment capabilities

and differentiated software solutions. Together, we are launching compelling product offerings to a customer base that we know extremely well - leading research universities and labs around the world."

Imperium control software is available as an upgrade on Veeco's legacy Discovery and Explorer Series MOCVD systems, providing increased functionality, productivity, and support from the legacy EpiView software. As a Veeco Certified Partner, Agnitron will leverage Veeco's worldwide sales and service to expand their reach beyond the North American market.

"Partnering with a compound semiconductor equipment leader like Veeco allows us to meet the increasing worldwide demand for highly capable, low cost MOCVD solutions in the R&D space," said Andrei Osinsky, president and CEO, Agnitron Technology. "Veeco's customer connectivity will open doors to new markets in need of complete turn-key MOCVD solutions that are available with matched system components based on specific system and process needs."

New Solstice Plating Tool Targets Smaller substrate Users

Plater cuts costs for emerging technologies

ClassOne Technology has announced its new Solstice line of electroplating tools. Described as 'advanced plating for the rest of us', Solstice is designed specifically for the smaller-substrate users in emerging technologies such as MEMs, LEDs, power devices, RF communications, interposers, photonics and microfluidics. According to the company Solstice is priced at that's less than half of equivalent 300mm tools from the large manufacturers.

"For too long, the bigger equipment companies have focused on building ever-smaller devices on ever-larger substrates," said Kevin Witt, ClassOne's VP of technology. "They've been serving the market segment that buys expensive high-end tools - but they've left the cost-conscious 100 to 200mm people behind. Up till now, the smaller-substrate users either had to buy used equipment or pay top dollar to get the big manufacturers to build them a 200mm or smaller plating tool." According to Byron Exarcos, president of ClassOne, Solstice is the first automated plating tool that can deliver advanced performance on smaller substrates at affordable prices.

The new Solstice comes in two models: The fully-automated, cassette-to-cassette Solstice S8 provides up to eight process chambers for throughputs up to 75 wph, with system prices starting at $1 million. The semi-automated Solstice LT features 1 or 2 chambers for development and pilot lines, with systems starting at $350k. So, emerging technology users now have an affordable, scalable path from wet bench to volume production and higher ROI.

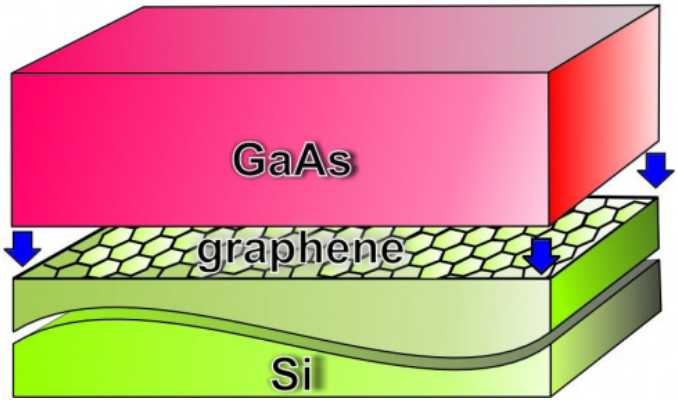
The plating equipment enables multiple types of metal deposition with chemical pre-wet, etch, rinse and drying processes, all on a single-wafer, highly-reliable, automated system - and all driven by the long-proven Solaris controller on a Windows 7 platform.

Novel Devices

US researchers show new way of growing III-V layers on Si

Ultra smooth GaAs films deposited on Si using graphene buffers

UC Los Angeles (UCLA) researchers, in collaboration with colleagues at UC Irvine and UC Riverside, have come up with a new way of depositing smooth GaAs films on silicon substrates using graphene buffer layers in between.



According to the researchers, the compatibility of their growth technique with current silicon planar CMOS technology presents an important step towards integrating electronics and photonics on the same chip. Applications such as photonic networks on chip, optical transceivers, free-space laser communications, and microwave photonics could benefit.

Led by Kang L Wang, the Raytheon Professor of Electrical Engineering at UCLA and the study's principal investigator, the group showed that ultra-smooth and epitaxial GaAs thin films can be deposited successfully on a growth-assisting graphene layer, which functions as a lattice-mismatch/thermal-expansion-coefficient-relieving layer.

The approach involves depositing hetero-layered GaAs by molecular beam epitaxy on graphene/silicon at growth temperatures ranging from 350 to 600degC under a constant arsenic flux.

The low energy of the graphene surface and the GaAs/graphene interface is overcome through an optimised growth technique, which includes initiating the growth with a Ga prelayer at room temperature. This increases the wettability of the graphene surface, facilitating the nucleation process.

In addition to the effect of Ga prelayer, the growth rate was observed to have a significant effect on the surface morphology of GaAs. It turns out that a lower growth rate of GaAs yields a smoother surface. In this way, the researchers obtained an atomically smooth low-temperature GaAs nucleation layer.

A few experimental investigations have already been reported on the growth of GaAs nanowires on Si using graphene. Nanowire on graphene, according to the researchers, is technologically easier to realise than smooth GaAs on graphene. Nevertheless, successful operation of nanowire-based devices is impeded by carrier loss mechanisms, surface-state induced band bending, Fermi level pinning, poor ohmic contacts, and uncontrolled incorporation of n- and p-type dopants. These issues result in poor optoelectronic performance. In effect, nanowire-based devices have still has not turned out to be an alternative to its counterpart, smooth thin-film based devices.

The results, published in *Advanced Functional Materials*, suggest the UCLA technique can be applied to other light-emitting III-V semiconductors such as InP and GaSb on silicon.

The team has overcome several material-related challenges in this work. Most significantly, while conventional direct heteroepitaxial deposition of GaAs on silicon requires the growth of 1 μm thick GaAs to realise a certain material quality, the UCLA-led group's growth technique demonstrated that the same quality can be obtained by depositing only 25nm of GaAs on top of silicon.

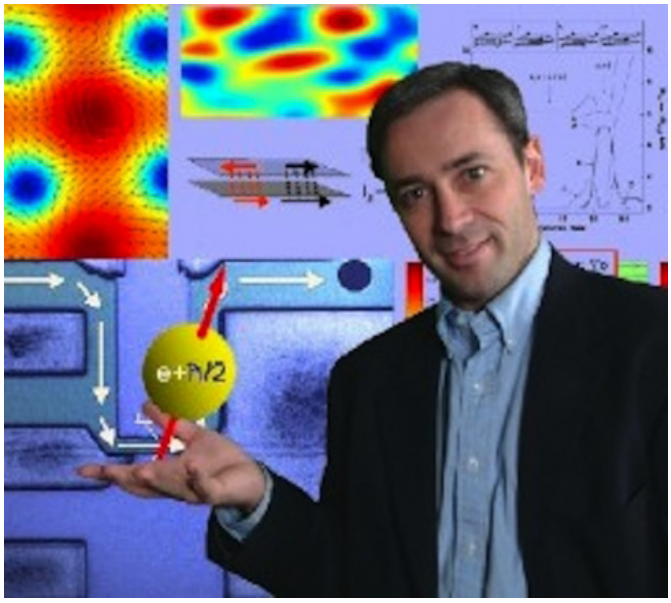
This work is financially supported by the King Abdulaziz City for Science and Technology (KACST), Saudi Arabia and California Center of Excellence on Green Technology. This work also uses the Extreme Science and Engineering Discovery Environment (XSEDE), which is supported by National Science Foundation.

'Towards van der Waals epitaxial growth of GaAs on Si using a graphene buffer layer' by Yazeed Alaskar et al, appeared in Adv. Funct. Mater. (2014);

http://dx.doi.org/10.1002/adfm.201400960

GaAs forms basis of tunable spintronics

Researchers show precise control of spin using inter-valley transitions



An international team of scientists has for the first time developed an efficient electrically tunable spin-charge converter made of the common semiconductor material GaAs. Comparable efficiencies have only been observed in platinum before.

Spin-charge converters transform electric into magnetic signals and vice versa. As such they are important in the emerging field of spintronics, which is a way of making circuits based on the charge of electrons and their spin (the rotation of the electron around its own axis) and spin-related magnetism. Spin generates a magnetic field like a small magnet. In some materials, electron spins spontaneously align their direction, leading to ferromagnetism. Additionally, 'spin-up' or 'spin-down directions can be used to represent two states - 0 and 1 - the basis of digital technology.

The work of Jairo Sinova (pictured above) and colleagues from the Johannes Gutenberg University Mainz in collaboration with researchers from the UK, Prague, and Japan shows that it is possible to precisely control spin using electric fields rather than magnetic ones - crucial for making use of electron spin for information transmission and storage. The results were published in the journal Nature Materials.

Spin-Hall Effect

The spin Hall effect is the key to generating, detecting and using spin currents. The effect appears when an electric field drives electrons through a semiconductor plate. Taking a look at the classical Hall-effect, the interaction of moving electrons and an external magnetic field forces the electrons to move to one side of the plate, perpendicular to their original direction. This leads to the so-called Hall voltage between both sides of the plate.

For the spin-Hall effect, electron-spins are generated by irradiating the sample with circularly polarised light. The electron spins are then parallel or anti-parallel, and their direction is perpendicular to the plate and the direction of movement. The moving electron spins are now forced to one or the other side of the plate, depending on the spin orientation. The driving force behind this is 'spin-orbit coupling', a relativistic electromagnetic effect which influences moving electron spins. This leads to the separation of both spin orientations.

To make practical use of this effect, it is essential to get a highly efficient spin separation. Up to now, platinum has been the most efficient spin-charge converter material, as it is a heavy metal, and the spin-orbit coupling of heavy metals is known to be especially strong due to the large amount of protons (positive charge) in their core.

Use of Inter-Valley Transitions

Sinova and his colleagues have shown that GaAs can be an as efficient spin-charge converter as platinum, even at room temperature, which is important for practical applications. Moreover, the physicists have demonstrated for the first time that the efficiency can be tuned continuously by varying the electric field that drives the electrons.

The reason for this lies in the existence of 'valleys' in the conduction band of the semiconductor material. One can think of the conduction band and its valleys as of a motor highway with different lanes, each one requiring a certain minimum velocity. Applying a higher electric field enables a transition from one lane to the other.

Since the spin-orbit coupling is different in each lane, a transition also affects the strength of the spin-hall effect. By varying the electric field, the scientists can distribute the electron spins on the different lanes, thus varying the efficiency of their spin-charge converter.

By taking into account the valleys in the conduction band, Sinova and his colleagues open up new ways to find and engineer highly efficient materials for spintronics. Especially, since current semiconductor growth technologies are capable of engineering the energy levels of the valleys and the strength of spin-orbit coupling, e.g. by substituting Ga or As with other materials like Aluminum.

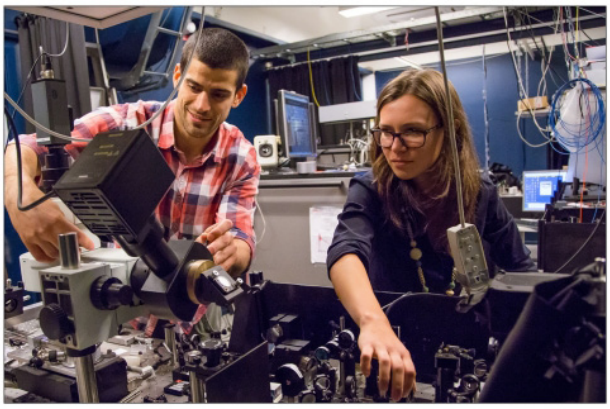
'Electric control of the spin Hall effect by intervalley transitions' by N. Okamoto et al appears in *Nature Materials*, 2014; DOI: 10.1038/nmat4059

Quantum dots used to make a single-photon cannon

Researchers report control of photons with a 98.4 percent success rate

One of the most promising technologies for future quantum circuits are photonic circuits based on light (photons). Making such circuits, however, requires finding a way to create a stream of single photons and control their direction.

Now Scientists at the Niels Bohr Institute have succeeded in doing this - a breakthrough they published last month in *Physical Review Letters*.

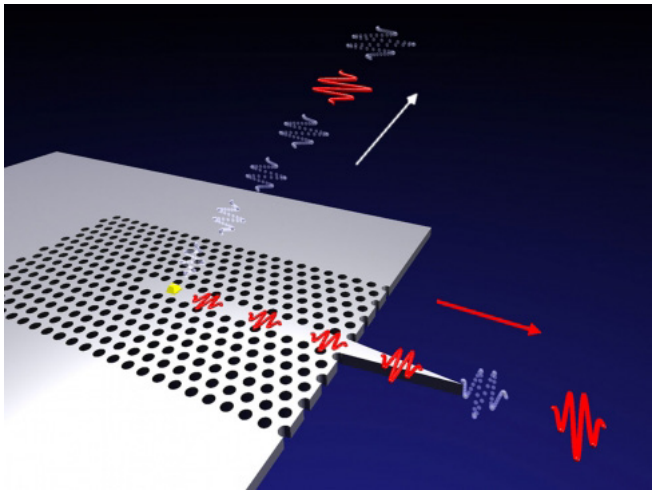


Above: Postdoc Immo Söllner and PhD-student Marta Arcari have been the driving force in the work with the experiment here at the quantum photonics lab at the Niels Bohr Institute.

Photons and electrons behave very differently at the quantum level. Electrons are so-called fermions and can easily flow individually, while photons are bosons that prefer to clump together. But because information for quantum communication based on photonics lies in the individual photon, it is necessary to be able to send them one at a time.

"So you need to emit the photons from a fermionic system and we do this by creating an extremely strong interaction between light and matter," explains Peter Lodahl, Professor and head of the research group Quantum Photonics at the Niels Bohr Institute at the University of Copenhagen.

The researchers have developed a kind of single-photon cannon integrated on an optical chip. The optical chip consists of an extremely small photonic crystal that is 10 microns wide and 160 nanometers thick. Embedded in the centre of the chip is a quantum dot light source (illustrated below with the yellow symbol).



"What we then do is shine laser light on the quantum dot, where there are atoms with electrons in orbit around the nucleus. The laser light excites the electrons, which then jump from one orbit to another and thereby emit one photon at a time. Normally, light is scattered in all directions, but we have designed the photonic chip so that all of the photons are sent through only one channel," explains Søren Stobbe, Associate Professor of the Quantum Photonic research group at the Niels Bohr Institute.

Peter Lodahl and Søren Stobbe explain that it not only works, but also that it is extremely effective.

"We can control the photons and send them in the direction we want with a 98.4 percent success rate. This is ultimate control over the interaction between matter and light and has amazing potential. Such a single-photon cannon has long been sought after in the research field and opens up fascinating new opportunities for fundamental experiments and new technologies," they explain.

The two researchers are in the process of patenting several parts of their work, with a specific goal of developing a prototype high-efficiency single-photon source, which could be used for encryption or for calculations of complex quantum mechanical problems and in general, is an essential building block for future quantum technologies. It is expected that the future's quantum technology will lead to new ways to code unbreakable information and to carry out complex parallel calculations.

'*Probing Electric and Magnetic Vacuum Fluctuations with Quantum Dots'* by P. Tighineanu et al appears in Phys. Rev. Lett. **113**, 043601

Direct wafer bonding yields large-scale InGaAs-on-insulator transistors

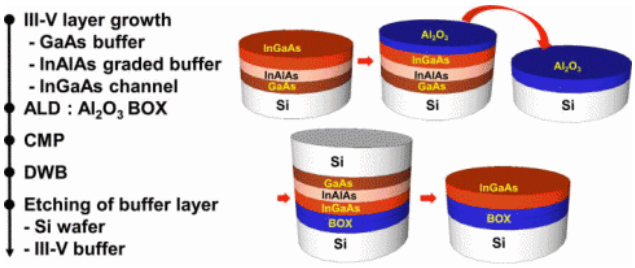
InGaAs grown on a Si donor wafer uses III-V buffer layer

Heterogeneous integration of III-V devices on Si wafers has been explored at length as a way of merging electrical and photonic applications. But existing methodologies have drawbacks such as inferior device quality or high cost in comparison with the current Si-based technology.

A team of researchers from the University of Tokyo and the companies JST-CREST and IntelliEPI has recently demonstrated InGaAs-on-insulator (OI) fabrication from an InGaAs layer grown on a Si donor wafer with a III-V buffer layer instead of growth on a InP donor wafer.

They report that the InGaAs-OI transistors exhibited high electron mobility of 1700 cm^2/V s and uniform distribution of the leakage current, indicating high layer quality with low defect density.

Their paper in *Applied Physics Letters* explains how the technology allowed them to yield large wafer size scalability of III-V-OI layers up to the Si wafer size of 300mm with a high film quality and low cost. They confirmed the high film quality using Raman and photoluminescence spectra.



Shown above is the process flow of InGaAs-OI wafers by the DWB technique developed in this study. InGaAs/InxAl1xAs/GaAs layers were epitaxially grown on Si substrates. After Al_2O_3 deposition as a BOX layer, CMP was carried out for surface smoothing for Al_2O_3/III-V/Si wafer and wafers were bonded to each other. Subsequent wet etching thinned the top Si and the III-V buffer layers, resulting in the formation of InGaAs-OI on Si substrates.

Heterogeneous integration of III-V compound semiconductors on Si wafers is a key issue for high-performance electrical as well as optical device applications. According to the researchers, In-based III-V compound semiconductors are most preferred channel materials of n-channel transistors for future CMOS circuits due to their high electron injection velocity to replace current Si-based channels facing their physical limitations.

'Direct wafer bonding technology for large-scale InGaAs-on-insulator transistors' by SangHyeon Kim et al appears in Appl. Phys. Lett. **105**, 043504 (2014); http://dx.doi.org/10.1063/1.4891493

US researchers claim competitor for graphene

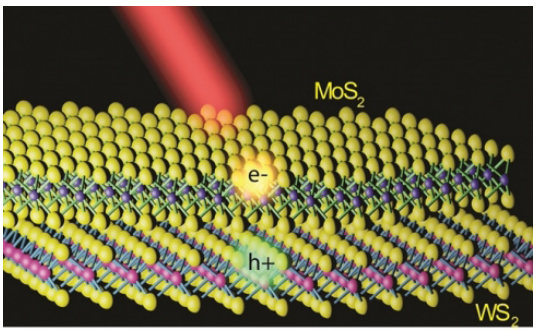
Demonstration of ultrafast charge transfer in photo-excited 2D semiconductors

A new class of materials is emerging made up of heterostructures held together by weak Van der Waals forces. In these materials, quantum coupling between stacked atomically thin 2D layers, including graphene, hexagonal-boron nitride and transition-metal dichalcogenides (MX2), give rise to

fascinating new phenomena.

Now an international team of researchers led by a scientist with the US Department of Energy (DOE's) Lawrence Berkeley National Laboratory has reported the first experimental observation of ultrafast charge transfer in photo-excited MX2 materials, in this case MoS_2/WS_2. The recorded charge transfer time was under 50 femtoseconds, comparable to the fastest times recorded for organic photovoltaics.

MX2 materials (comprising consist of a single layer of transition metal atoms, such as molybdenum or tungsten, sandwiched between two layers of chalcogen atoms, such as sulphur), are particularly exciting for novel optoelectronic and photovoltaic applications because 2D MX2 monolayers can have an optical bandgap in the near-infrared to visible range and exhibit extremely strong light-matter interactions. Theory predicts that many stacked MX2 heterostructures form type II semiconductor heterojunctions that facilitate efficient electron-hole separation for light detection and harvesting.



Pictured above is an illustration of the Berkeley Laboratory's MoS2/WS2 heterostructure. It shows a MoS2 monolayer on top of a WS2 monolayer. Electrons and holes created by light are shown to separate into different layers.

"We've demonstrated, for the first time, efficient charge transfer in MX2 heterostructures through combined photoluminescence mapping and transient absorption measurements," says Feng Wang, a condensed matter physicist with Berkeley Lab's Materials Sciences Division and the University of California (UC) Berkeley's Physics Department. "Our study suggests that MX2 heterostructures, with their remarkable electrical and optical properties and the rapid development of large-area synthesis, hold great promise for future photonic and optoelectronic applications."

Wang is the corresponding author of a paper in *Nature Nanotechnology* describing this research. The paper is titled *‹Ultrafast charge transfer in atomically thin MoS2/WS2 heterostructures›*. Co-authors are Xiaoping Hong, Jonghwan Kim, Su-Fei Shi, Yu Zhang, Chenhao Jin, Yinghui Sun, Sefaattin Tongay, Junqiao Wu and Yanfeng Zhang.

"Combining different MX2 layers together allows one to control their physical properties," says Wang, who is also an investigator with the Kavli Energy NanoSciences Institute (Kavli-ENSI). "For example, the combination of MoS2 and WS2 forms a type-II semiconductor that enables fast charge separation. The separation of photoexcited electrons and holes is essential for driving an electrical current in a photodetector or solar cell."

"MX2 semiconductors have extremely strong optical absorption properties and compared with organic photovoltaic materials, have a crystalline structure and better electrical transport properties," Wang says. "Factor in a femtosecond charge transfer rate and MX2 semiconductors provide an ideal way to spatially separate electrons and holes for electrical collection and utilisation."

Wang and his colleagues are studying the microscopic origins of charge transfer in MX2 heterostructures and the variation in charge transfer rates between different MX2 materials. "We're also interested in controlling the charge transfer process with external electrical fields as a means of utilising MX2 heterostructures in photovoltaic devices," Wang says.

This research was supported by an Early Career Research Award from the DOE Office of Science through UC Berkeley, and by funding agencies in China through the Peking University in Beijing.

University of Washington makes 2D semiconductor junctions

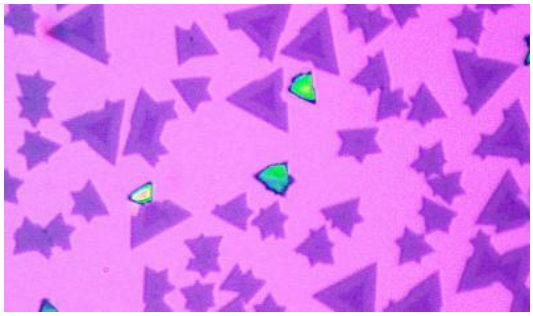
Scalable technique would suit mass-production

University of Washington (UW) researchers have demonstrated connecting two single-layer semiconductor materials to form a heterojunction using monolayers of molybdenum diselenide and

tungsten diselenide. The research was published online this week in *Nature Materials.*

“Heterojunctions are fundamental elements of electronic and photonic devices,” said senior author Xiaodong Xu, a UW assistant professor of materials science and engineering and of physics. “Our experimental demonstration of such junctions between 2D materials should enable new kinds of transistors, LEDs, nanolasers, and solar cells to be developed for highly integrated electronic and optical circuits within a single atomic plane.”

Collaborators from the electron microscopy centre at the University of Warwick, UK found that all the atoms in both materials formed a single honeycomb lattice structure, without any distortions or discontinuities. This provides the strongest possible link between two single-layer materials, necessary for flexible devices. Within the same family of materials it is feasible that researchers could bond other pairs together in the same way.



As seen under an optical microscope, the heterostructures have a triangular shape. The two different monolayer semiconductors can be recognised through their different colours.

The researchers created the junctions in a small furnace at the UW. First, they inserted a powder mixture of the two materials into a chamber heated to 900degC. Hydrogen gas was then passed through the chamber and the evaporated atoms from one of the materials were carried toward a cooler region of the tube and deposited as single-layer crystals in the shape of triangles.

After a while, evaporated atoms from the second material then attached to the edges of the triangle to create a seamless semiconducting heterojunction.

“This is a scalable technique,” said Sanfeng Wu, a UW doctoral student in physics and one of the lead authors. “Because the materials have different properties, they evaporate and separate at different times automatically. The second material forms around the first triangle that just previously formed. That’s why these lattices are so beautifully connected.”

With a larger furnace, it would be possible to mass-produce sheets of these semiconductor heterostructures, the researchers said. On a small scale, it takes about five minutes to grow the crystals, with up to two hours of heating and cooling time.

“We are very excited about the new science and engineering opportunities provided by these novel structures,” said senior author David Cobden, a UW professor of physics. “In the future, combinations of two-dimensional materials may be integrated together in this way to form all kinds of interesting electronic structures such as in-plane quantum wells and quantum wires, superlattices, fully functioning transistors, and even complete electronic circuits.”

The researchers have already demonstrated that the junction interacts with light much more strongly than the rest of the monolayer, which is encouraging for optoelectric and photonic applications like solar cells.

Hong Kong team integrates on-chip light source with III-nitride electronics

Approach holds promise for synchronous RF/optical comms and more...

Integrating III-nitride-based light-emitting and electronic control devices would help make more compact optoelectronics systems such as on-chip lighting control, synchronous RF/optical communications, and opto-couplers for power conversion. But attempts to grow LED and HEMT structures on the same substrate have been hampered by the incompatibility of their optimised growth temperatures and by the complexity of integrated devices with different active layers.

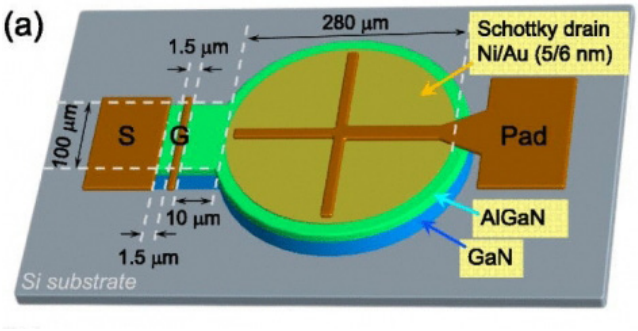
Now a team from Hong Kong University of Science and Technology has reported producing GaN band-edge ultraviolet emission at 3.4eV at room

temperature, at a small forward bias larger than -2V, from a simple metal-AlGaN/GaN Schottky diode. Their findings were published in Applied Physics Letters **105** (2014).

Schottky-drain electrode in an AlGaN/GaN HEMT

The researchers' goal was to produce electroluminescence (EL) at room temperature from metal-AlGaN/GaN Schottky diodes on a conventional doping-free III-nitride heterostructure suitable for HEMTs. (EL was first discovered in a metal-SiC structure in 1907. EL emissions from Schottky diodes on Si, II-VI, and III-V semiconductor have also been reported by research groups over the last 30 years).

By employing a semi-transparent Schottky-drain electrode in an AlGaN/GaN HEMT, the team succeeded in building a UV high electron mobility light-emitting transistor (HEM-LET) in a relatively straightforward manner. Figure **a)** below presents the schematic device structure of the device demonstrated in this work.



The team used an AlGaN/GaN heterostructure consisting of a 21nm Al 0.25Ga 0.75 N barrier and 3.8µm GaN buffer, grown by MOCVD on a 4inch p-type S (111) substrate. The heterostructure contained a 2DEG channel of density $10^{13}/cm^{-2}$ and mobility $2080cm^2/V^{-1}s^{-1}$ at room temperature.

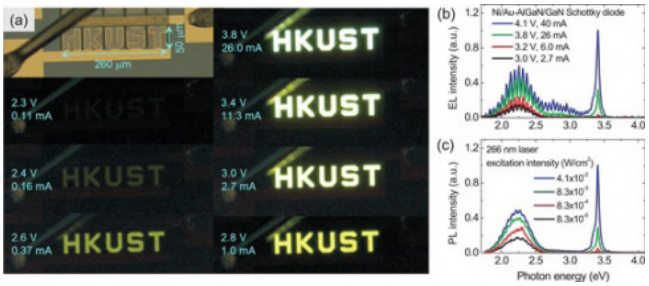
They defined the ohmic contacts using photolithography and formed them with Ti/Al/Ni/Au metallisation annealed at 850degC for 30s in N 2 ambience. Remote plasma pretreatment in an atomic-layer-deposition (ALD) machine was used to remove the residual native oxide and nitridise the surface. The passivation and surface protection layer was an AlN/SiN x (4/50nm) stack.

After the Schottky area was defined with photolithography, the SiN x was dry etched by a low-power plasma process and the AlN thin film removed by dilute alkaline solution. Then the semitransparent Schottky metal Ni/Au (5/6 nm) was deposited using an e-beam evaporator. A high electron mobility light-emitting transistor (HEM-LET) with ohmic source and semitransparent Schottky drain was made simultaneously.

Ni/Au (20/200 nm) was used as the gate metal and a SiN x/AlO (15/8 nm) stack insulator used as the gate dielectric for the HEM-LET, in order to single out the Schottky drain. Finally, the device was annealed at 400degC for 10 minutes in N2 ambience.

EL emission at room temperature

The team measured the current- voltage characteristics, and the EL and photoluminescence (PL) spectra. (A 266nm laser was used to excite the AlGaN/GaN heterostructure for the PL measurement).



With semi-transparent Ni/Au (5/6 nm) Schottky metal, the team reported clearly seeing EL emission from the Ni/Au-Al 0.25Ga 0.75 N/GaN Schottky diode at room temperature when the forward bias is higher than 2.2V. The EL intensity becomes stronger at a higher bias.

They found that the EL spectra consisted of not only yellow and blue luminescence but also a narrow GaN band-edge UV component at 3.4eV, similar to the PL spectra of the AlGaN/GaN heterostructure as shown in graph c) above.

Both the EL and PL spectra are from the GaN layer; no emission from the thin AlGaN barrier layer was detected. The yellow/blue is due to radiative transition of electronics from conduction band of a shallow donor to a deep acceptor in the GaN layer. Its relative intensity, compared with GaN band-edge UV emissions decreased with increasing bias/current or laser excitation intensity in both the LE and PL spectra

The team also experimented with another Schottky

metal, Pt/Au and found similar results concluding this is a general property of metal-AlGaN/GaN Schottky diodes.

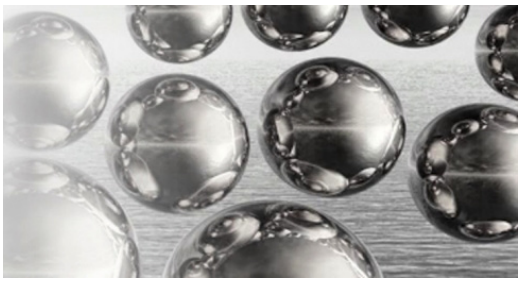
From these results, the researchers think it would be possible to realise synchronous radio-frequency/ optical communications using an AlGaN/GaN HEMLET, and an all-on-chip opto-coupler for III-nitride power electronics.

They also suggest that the metal-AlGaN/GaN light-emitting Schottky diode provides an alternative for micro-display with unique advantages. The back electrode is served by a high-mobility 2DEG channel, and the pixel is defined by the top Schottky contact, eliminating th mesa etching process and current spreading design and allowing for a higher resolution and smaller pixel size.

'P-doping-free III-nitride high electron mobility light-emitting diodes and transistors' by Baikui Li et al, appears i Appl. Phys. Lett. **105**, 032105 (2014); http://dx.doi.org/10.1063/1.4890238

Quantum Materials buys Bayer's Quantum Dot Patents

Deal protects IP for automated QD manufacturing



Quantum Materials Corporation (QMC)) has bought five sets of patent families from Bayer Technology Services GmbH, the major innovation driver for Bayer AG of Leverkusen, Germany.

"We acquired these patents to not only expand our technology portfolio in heavy metal-free and QDSC production, but also to protect the advances we have made to date in the volume manufacturing of nanoparticles, including quantum dots," said Stephen Squires, Quantum Materials' CEO and president. "Bayer is a research pioneer in the nanotech and QD fields and these early filings were awarded with broad claims. It will be very difficult for competitors to produce materials in volume similar to ours without breaching our patents."

The patents provide broad IP protection for advances Quantum Materials has achieved in economical high-volume quantum dot (QD) manufacturing. In addition, the Bayer patents cover volume production technology for heavy metal-free (HMF) quantum dots and nano-particles; increasing quantum yields for HMF quantum dots; and hybrid organic quantum dot solar cell (QDSC) production as well as a surface modification process for increased efficiency of high performance solar cells and printed electronics. The patent families were acquired through a cash purchase agreement and financial details will remain private.

The quantum dot-related patents extend Quantum Materials' ability to synthesise numerous heavy metal-free organic periodic table groups in addition to its own inorganic Group II-VI composites. The company intends to incorporate each patent into its advanced production processes, including high yield InP/ZnS nanocrystals, a heavily researched QD in high demand in optoelectronics.

The solar-related patents describe the fundamental design of quantum dot solar cells and processes for optimising quantum dots for solar and other printed electronics applications. The solar patents enhance Quantum Material's licensed patent on printing OLED and QD solar cells and other printed electronic devices by gravure or high-speed roll-to-roll.

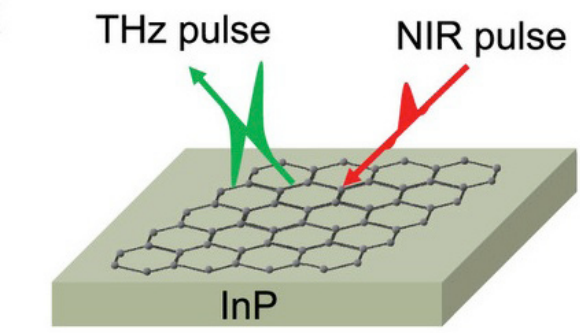
"Bayer Technology Services has been successfully working in the field of nanotechnology for more than 30 years . We are very happy that Quantum Materials is also using our patents to invest into new markets Bayer is not focusing on," adds Guenter Bachlechner, head of technology development and senior vice president of Bayer Technology Services .

Indium Phosphide substrate test reveals purity of graphene

Rice, Osaka scientists use terahertz waves to spot contaminants

The environment around graphene, including defects in the substrate on which it is placed as well as gas molecules that surround it, can substantially influence its electronic performance. Because it is easy to accidently introduce such impurities, it would be useful to detect and identify out-of-place molecules.

Researchers at Rice and Osaka universities have now found a simple way to do this using terahertz spectroscopy and InP as a substrate for the graphene. Their research was published by *Nature›s* open-access online journal *Scientific Reports*.

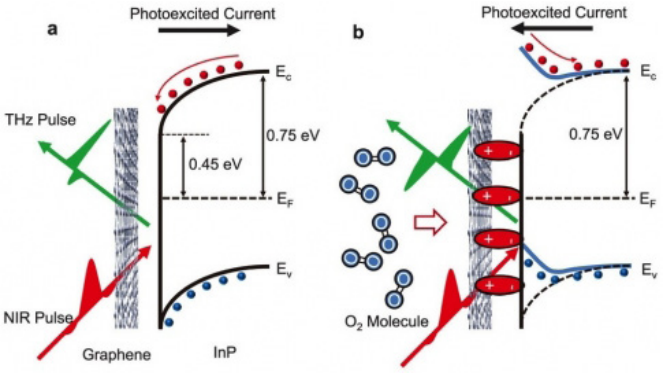


Their contactless technique involves hitting the combined material with femtosecond pulses from a near-infrared laser. The pulses excite the indium phosphide so that it emits terahertz radiation back through the graphene. Imperfections as small as a stray oxygen molecule on the graphene can then be picked up by a spectrometer.

"The change in the terahertz signal due to adsorption of molecules is remarkable," said Junichiro Kono, one of the researchers from Rice. "Not just the intensity but also the waveform of emitted terahertz radiation totally and dynamically changes in response to molecular adsorption and desorption. The next step is to explore the ultimate sensitivity of this unique technique for gas sensing."

The technique can measure both the locations of contaminating molecules and changes over time.

«The laser gradually removes oxygen molecules from the graphene, changing its density, and we can see that,» Kono said.



Pictured above a), Band diagram for pristine graphene on InP. The photo excited current flows towards the substrate. (b), Band diagram for graphene on InP with adsorbed oxygen molecules between them. The charge transfer between graphene and oxygen creates dipoles, which modify the band bending. The photoexcited current now flows towards the surface.

The experiment involved growing pristine graphene via chemical vapour deposition and transferring it to an indium phosphide substrate. Laser pulses generated coherent bursts of terahertz radiation through a built-in surface electric field of the indium phosphide substrate that changed due to charge transfer between the graphene and the contaminating molecules. The terahertz wave, when visualised, reflected the change.

The researchers expect the finding to be important to manufacturers considering the use of graphene in electronic devices. "For any future device designs using graphene, we have to take into account the influence of the surroundings," said Kono. Graphene in a vacuum or sandwiched between noncontaminating layers would probably be stable, but exposure to air would contaminate it, he said.

The Rice and Osaka labs are continuing to collaborate on a project to measure the terahertz conductivity of graphene on various substrates, he said.

The National Science Foundation (NSF); the Japan Society for the Promotion of Science; the Ministry of Education, Culture, Sports, Science and Technology-Japan and the Murata Science Foundation supported the research. NanoJapan is funded by the NSF's Partnerships for International

Research and Education program.

The paper *'Imaging molecular adsorption and desorption dynamics on graphene using terahertz emission spectroscopy'* by Y. Sono et al. appears in Nature Scientific Reports **4**, Article number: 6046

Scientists at the State Key Laboratory of Molecular Engineering of Polymers, at Fudan University, Shanghai have made perovskite (a calcium titanium oxide mineral) solar cells with a flexible fibre structure, opening up the possibility of weaving them into textiles.

The technique, detailed in the journal *Angewandte Chemie*, involved continuously winding an aligned multiwalled carbon nanotube sheet electrode onto a fibre electrode. Photoactive perovskite materials were incorporated inbetween them through a solution process.

The fibre-shaped perovskite solar cell exhibits an energy conversion efficiency of 3.3 percent, which remained stable on bending. The perovskite solar cell fibres may be woven into electronic textiles for large-scale application by well-developed textile technologies, according to the researchers, making them potentially useable in wearable and portable electronic devices.

Full details can be found in the paper *'Integrating Perovskite Solar Cells into a Flexible Fiber'* by L. Qiu et al (2014), Angew. Chem. Int. Ed.. doi: 10.1002/anie.201404973

3M reveals new quantum dot display material

Protective plastic promises greener grass for longer...

Quantum dots could bring brighter, more vibrant colour to TVs, tablets, phones and other displays, according to Eric Nelson from the company 3M, talking this week at the 248th National Meeting & Exposition of the American Chemical Society (ACS).

Nelson was describing a new technology developed by his company quantum dot enhancement film (QDEF) that makes liquid crystal display (LCD) screens more richly coloured.

"Green grass just pops out at you from these displays," says Nelson, who helped create the plastic films that hold the quantum dots in a screen. "We believe this is the most efficient way to get to a high-colour display."

The QDs (made for 3M by Nanosys in this case) produce specific colours of light based on how big they are. In 3M QDEF displays, the LCD's white backlight is replaced with a blue one, and a sheet of plastic embedded with QDs that produce red and green light is placed over it. The display combines these three colours to produce all the colors the viewer sees.

One drawback of the dots is that they break down quickly when exposed to water and oxygen in the air. To address this challenge, Nelson helped create the plastic sheathing that protects them. They sandwiched the QDs between two polymer films, with the QDs embedded in an epoxy glue. "The polymer/quantum dot sandwich looks like a piece of plastic film," says Nelson. Coatings on the film provide further protection and enhance the viewing experience.

Because the QDEF displays need less light, says Nelson, they consume less electricity and help device batteries last longer than other high-colour solutions. He says 3M's tests have shown that the dots' heavy metals — many of which are already found in today's electronics — are entirely sealed inside the film. That means they won't leach out during the products' lifetime or as they languish in landfills if the displays aren't recycled.

3M hopes QDEF technology will compete well with more costly displays like those that use organic light-emitting diodes (OLEDs). Nelson explains that OLEDs produce similarly brilliant colors to the QDEF displays, but they use individual lights to

make different colors. The drawback to OLEDs is that they are much more costly to manufacture.

Although QDEF displays are more expensive than conventional low-color LCDs, Nelson says the cost will come down as the technology becomes more widespread and as manufacturing costs come down with increased production scale. Several devices featuring QDEF are already on the market, and more are on the way.

The next graphene?

$1.7m US research grant to focus on new 2D materials

A team of engineering researchers from California has been awarded a $1.7 million grant from the US National Science Foundation (NSF) to characterise, analyse and synthesise a new class of ultra-thin film materials that could improve the performance of personal electronics, optoelectronic devices and energy conversion systems.

The potential of layering two-dimensional materials into novel heterostructures held together by weak van der Waals interactions is attracting increasing attention. Graphene has already been well studied but dozens of these one-atom- or one-molecule-thick crystals are known including monolayers of MoS2, hexagonal boron nitride, WSe2, graphane, fluorographene, mica and silicene. Researchers at Vienna University of Technology, for instance, recently reported developing a new compound semiconductor structure combining tungsten diselenide with molybdenum disulphide to create a ‘designer’ optoelectronic material.

The Californian team is led by Alexander Balandin, University of California, who is founding chair of the materials science and engineering program at UC Riverside’s Bourns College of Engineering. (A group led by Balandin at UC Riverside previously discovered the unusually high thermal conductivity of graphene.)

Other members of the team are Roger Lake, a UC Riverside professor, Alexander Khitun, a UC Riverside research professor, and Tina Salguero, an assistant professor at the University of Georgia.

This project will investigate novel electrical, optical, and thermal phenomena in such materials and heterostructures. The research is expected to produce new material synthesis techniques and enable practical applications of ultra-thin film materials in electronic switches, optical detectors, low-power information processing and direct energy conversion.

Each member of the NSF-funded team will cover different aspects of the research and application of the van der Walls materials. Balandin will conduct materials characterization, fabrication and experimental testing of nanodevices, Lake will perform the first principal theoretical analysis and computer simulation of the properties of new materials and devices. Khitun will design circuits and systems based on two-dimensional materials and atomic heterostructures. Salguero will synthesize new materials using chemical approaches.

The NSF funding was awarded via the Emerging Frontiers in Research and Innovation (EFRI-2014) program called Two-Dimensional Atomic-layer Research and Engineering (2-DARE).

Australian researchers pioneer graphene process using epitaxial SiC

Technique scalable to 300mm wafers

Researchers at Griffith University in Australia are successfully fabricating graphene from silicon carbide on silicon wafers using a process they say is scalable to 300mm mass production wafers.

Dr Francesca Iacopi’s team are using the Australian National Fabrication Facility’s (ANFF) Silicon Carbide Epitaxial reactor located at the Queensland Micro and Nanotechnology Centre at Griffith. They have combined the production of low cost silicon carbide wafers (made through the deposition of a

high quality SiC layer onto low cost Si wafers), with the ability to pattern and etch this material using a plasma and finally to use novel low-temperature technology to synthesise graphene on only the required pattern.

The researchers say that the combination of a crystalline SiC core with a surface graphene coating is ideal for sensing devices. The exceptional mechanical properties of SiC (which is the second hardest material after diamonds) can be further enhanced by graphene, resulting in excellent fracture strength. Additionally, graphene offers a wealth of surface chemistry approaches for targeting specific ions and molecules.

Earlier this year, the team produced SiC micro-resonators by replacing the traditional metals with a one molecule thick, transparent, highly conductive graphene layer. This work was detailed in a paper called *'Microresonators with Q-factors over a million from highly stressed epitaxial silicon carbide on silicon' by A.R Kermany et al i*n Applied Physics Letters **104**, 081901 (2014).

Quantum dot market to reach $5 billion by 2020

Solar power and displays driving demand

The global quantum dot market produced a revenue of $316 million in 2013 and is expected to grow to around $5 billion by 2020 at a CAGR of nearly 30 percent, according to a new research report by Allied Analytics LLP.

Refinement of manufacturing technologies and mass production will mean that volume consumption will grow faster at 116.5 percent during the same period to reach 72 ton in 2020, says the report 'Quantum Dot (QD) Market - Global Analysis, Growth, Trends, Opportunities, Size, Share and Forecast through 2020.'

Drivers for growth include efficient conversion of solar energy into power and rising use of volume-driven display devices. Additionally, the technology is more efficient than conventional technologies.

"The QD display market is set to grow exponentially as many companies such as Sony Corporation, LG Display etc. are getting into alliance with QD technology providers to commercialise QD displays, especially TV sets," note analysts Shreyas Naidu and Priyanka Gotsurve.

However, some factors such as high cost of technology and slow adoption due to extended research are serving as the restraints for the market growth. Although, mass manufacturing and bulk purchasing will quickly negate the cost constraints. The further penetration of the technology in newer applications such as security & defence, food, and packaging will provide the essential future growth thrust to the market.

North America has the highest revenue share due to early adoption. The region is expected to grow consistently and attain revenue of $1.92 billion by 2020. However, Asia-Pacific is expected to have the highest CAGR of 30.4 percent for the analysis period 2013-2020.

The report is available from researchandmarkets.com

QMC achieves 95 percent yield on automated Quantum Dot system

Mass production system suits large quantum product rollouts, claims company

Quantum Materials Corp (QMC) has announced it is achieving around 95 percent Quantum Yield (QY) for green Tetrapod Quantum Dots (TQD) manufactured by its automated mass production system.

The Full-Width Half-Maximum (FWHM) achieved was 36nm with tunable emission from 530 to 550nm. Potential clients are currently evaluating these TQDs.

QMC says its ability to achieve economies of scale with automated production offers supply security and dependable cost forecasting in joint ventures planning very large quantum dot product rollouts.

The company previously stated that capacity could be expanded sufficient to support the entire display industry converted to quantum dot 4K and 8K displays. According to market researcher IHS, demand for QD-LCD displays is projected to jump to 87.3 million units by 2020 as QD prices decrease and a reliable and uniform quantum dot supply is assured for large production runs.

In solar photovoltaics, Solterra Renewable Technologies, a QMC wholly owned subsidiary, calculates that one Solterra Quantum Dot Solar Cells (QDSC) Plant can be scaled up to produce 1000 Megawatts per year of printed solar cells using its own dedicated production of QMC quantum dots.

A Solterra QDSC facility would rely on low CAPEX for both the QD production as well as low startup costs for the solar cell equipment, says the company. Combined automated production of QD and QDSC allow a cost goal of under 12c per kWh, the present estimated residential electricity rate in the US.

Solterra's goal is to establish regional or national QDSC plants entirely by the private sector, without federal subsidies, and a cost goal of under 12c per kWh.

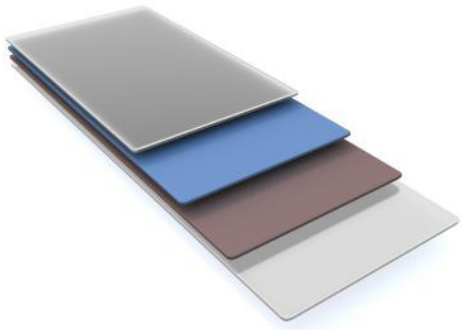
Sheets of stapled semiconductors could make ultra thin solar cells

Researchers combine tungsten diselenide with molybdenum disulphide to create 'designer' optoelectronic material

Researchers at the Vienna University of Technology have used two ultra-thin layers to create a new semiconductor structure suited for photovoltaic energy conversion.

Several months ago, Marco Furchi, Thomas Mueller, and Andreas Pospischil (pictured l-r) produced an ultra-thin layer of the photoactive crystal tungsten diselenide. Now, they have combined this semiconductor with another layer made of molybdenum disulphide, creating a material that shows potential for a new kind of solar cell technology, they say, that is extremely thin, semi-transparent, and flexible.

Two layers with different functions



Tungsten diselenide is a semiconductor which consists of three atomic layers. One layer of tungsten is sandwiched between two layers of selenium atoms. (The image shows the two semiconductor layers in the middle, connected to electrodes on either side).

When light shines on a photoactive material single electrons are removed from their original position. A positively charged hole remains, where the electron used to be. Both the electron and the hole can move freely in the material, but they only contribute to the electrical current when they are kept apart so that they cannot recombine.

To prevent recombination of electrons and holes, metallic electrodes can be used, through which the charge is sucked away - or a second material

is added. “The holes move inside the tungsten diselenide layer, the electrons, on the other hand, migrate into the molybednium disulphide”, says Mueller. Thus, recombination is suppressed.

This is only possible if the energies of the electrons in both layers are tuned exactly the right way. In the experiment, this can be done using electrostatic fields. Florian Libisch and Joachim Burgdörfer (TU Vienna) provided computer simulations to calculate how the energy of the electrons changes in both materials and which voltage leads to an optimum yield of electrical power.

Tightly packed layers

“One of the greatest challenges was to stack the two materials, creating an atomically flat structure”, says Thomas Mueller. “If there are any molecules between the two layers, so that there is no direct contact, the solar cell will not work.” Eventually, this feat was accomplished by heating both layers in vacuum and stacking it in ambient atmosphere. Water between the two layers was removed by heating the layer structure once again.

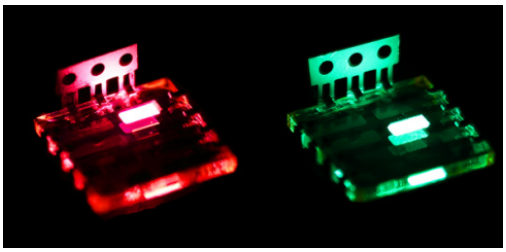
Part of the incoming light passes right through the material. The rest is absorbed and converted into electric energy. The material could be used for glass fronts, letting most of the light in, but still creating electricity. As it only consists of a few atomic layers, it is extremely light weight (300 square meters weigh only one gram), and very flexible. Now the team is working on stacking more than two layers - this will reduce transparency, but increase the electrical power.

2D materials

Ultra-thin 2D materials, which consist only of one or a few atomic layers are a hot topic. Research on such materials started with graphene, which is made of a single layer of carbon atoms. Mueller and his team applied their knowledge gained in handling, analysing and improving ultra-thin layers of graphene to other ultra-thin materials to do this work. The team was the first to combine two different ultra-thin semiconductor layers and study their optoelectronic properties.

Perovskite semiconductor shows promise for low cost LEDs

Material can be easily tuned to emit light in a variety of colours, say researchers



A hybrid form of perovskite - the same type of material which has recently been found to make highly efficient solar cells - has been used to make low-cost, easily manufactured LEDs, potentially opening up a wide range of applications such as flexible colour displays.

This class of semiconducting perovskites have generated excitement in the solar cell field over the past several years, after Henry Snaith’s group at Oxford University found them to be remarkably efficient at converting light to electricity. In two years, perovskite-based solar cells have reached efficiencies of nearly 20 percent, a level which took conventional silicon-based solar cells 20 years to reach.

Now, researchers from the University of Cambridge, University of Oxford and the Ludwig-Maximilians-Universität in Munich have demonstrated a new application for perovskite materials, using them to make high-brightness LEDs. The results are published in the journal *Nature Nanotechnology*.

Perovskite is a general term used to describe a group of materials that have a distinctive crystal structure of cuboid and diamond shapes. They have long been of interest for their superconducting and ferroelectric properties. But in the past several years, their efficiency at converting light into electrical energy has opened up a wide range of potential applications.

The perovskites that were used to make the LEDs are known as organometal halide perovskites, and contain a mixture of lead, carbon-based ions and halogen ions known as halides. These materials dissolve well in common solvents, and assemble to form perovskite crystals when dried, making them

cheap and simple to make.

"These organometal halide perovskites are remarkable semiconductors," said Zhi-Kuang Tan, a PhD student at the University of Cambridge's Cavendish Laboratory and the paper's lead author. "We have designed the diode structure to confine electrical charges into a very thin layer of the perovskite, which sets up conditions for the electron-hole capture process to produce light emission."

Spin-coating

The perovskite LEDs are made using a simple and scalable process in which a perovskite solution is prepared and spin-coated onto the substrate. This process does not require high temperature heating steps or a high vacuum, and is therefore cheap to manufacture in a large scale. In contrast, conventional methods for manufacturing LEDs make the cost prohibitive for many large-area display applications.

"The big surprise to the semiconductor community is to find that such simple process methods still produce very clean semiconductor properties, without the need for the complex purification procedures required for traditional semiconductors such as silicon," said Richard Friend of the Cavendish Laboratory, who has led this programme in Cambridge.

"It's remarkable that this material can be easily tuned to emit light in a variety of colours, which makes it extremely useful for colour displays, lighting and optical communication applications," said Tan. "This technology could provide a lot of value to the ever growing flat-panel display industry."

The team is now looking to increase the efficiency of the LEDs and to use them for diode lasers, which are used in a range of scientific, medical and industrial applications, such as materials processing and medical equipment. The first commercially-available LED based on perovskite could be available within five years.

Imec demonstrates 28Gb/s photonics platform

III-V laser integration still in the laboratory

Imec has reached some key development milestones for its silicon photonics platform (iSiPP25G) by extending the performance towards 28Gb/s and beyond.

At wafer-scale, it has demonstrated a ring-based wavelength division multiplexing (WDM) filter with a thermo-optic tuning efficiency better than 1nm/mW per channel; a thermally tunable 28Gb/s ring modulator with an efficiency of 260pm/mW; and a high-speed germanium photodetector achieving an average responsitivity of 0.85A/W, and opto-electrical bandwidth of 50GHz with dark currents at -1.0V below 50nA.

Silicon photonics holds the promise of converging electronics and photonics, but a key component still missing within such a platform is a low-cost high-performance laser. IMEC is considering adding III-V lasers to the platform in the future by hybrid approaches such as flip-chip bonding. It is also exploring adding monolithically integrated lasers using InP-nanowires lasers and colloidal quantum dots.

Last year, researchers from IMEC and the University of Ghent presented the first room-temperature operation of an ultra-short InP nanowire laser that is epitaxially grown on an exactly [001] oriented silicon substrate. In May 2014, the team gave a paper at the International Conference on Indium Phosphide and Related Materials(IPRM) showing an improvement of the device with ultra low threshold performance.

'An Ultra-Short InP Nanowire Laser Monolithic Integrated on (001) Silicon Substrate', by Z. Wang et al was presented at IEEE summer topicals 2013.

'InP Nanowire lasers Epitaxially Grwnn on (001) Silicon 'V- groove' templates', by B. Tian et al was presented at the International Conference on Indium Phosphide and Related Materials(IPRM) 2014.

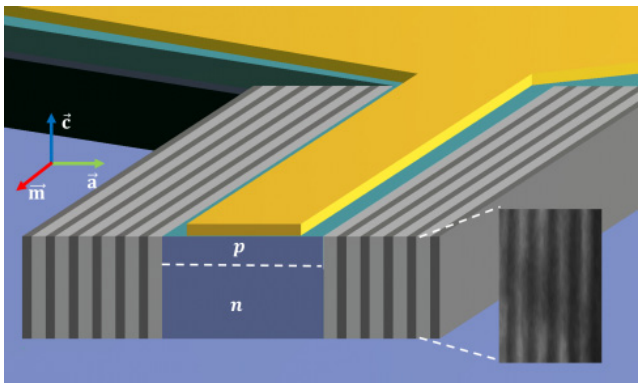
US researchers develop room temperature Polariton Laser

Device could be future optical replacement for on-chip wires

Scientists from the University of Michigan and Intel Corporation in the US have demonstrated what appears to be the first electrically powered, room-temperature polariton laser. The device, based on a GaN-based microcavity diode, could advance efforts to replace on-chip wire connections with lasers, leading to smaller and more powerful electronics, say the researchers.

A polariton is a quasiparticle that results from a coupling between a photon and an electron-hole pair (an "exciton") in a semiconductor material. In 1996, researchers realised that-under certain conditions-polaritons will condense into a single quantum state, from which they will spontaneously emit coherent, monochromatic light. In contrast to stimulated lasing, the polariton emitters do not need to be constantly pumped up into excited states (so-called population inversion). As a consequence, polariton lasers begin lasing at a relatively low threshold power.

Experimental realisations of polariton lasers have so far required either low temperatures or a pump laser to create the initial polaritons. Described in the journal *Physical Review Letters*, the room temperature polariton laser produced a beam of UV laser light at a threshold current density of 169 A/cm^2, which is almost a factor of 100 less than for conventional GaN-based lasers.



The device consists of a thin strip of gallium nitride, sandwiched between stacks of metal oxide mirrors. *(In the diagram above, the mirrors are represented by the grey bars. The yellow is the electrode through which the researchers stimulate the laser. The purple is the gallium nitride semiconductor).* When electric current enters such a microcavity, it can generate polaritons. But unlike previous designs in which electricity passed through or around the high-resistance mirrors, the team injects current orthogonally to the microcavity's emitting direction, thus avoiding overheating the device and destroying the lasing.

'Room Temperature Electrically Injected Polariton Laser' by P Bhattacharya et al, Phys. Rev. Lett. 112, 236802 (2014)

Scientists embed nearly perfect InAs crystals into nanowires

Research takes another step towards future multifunctional nanoelectronic devices

Scientists at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), the Vienna University of Technology and the Maria Curie-Skodowska University Lublin have for the first time successfully embedded nearly perfect indium arsenide semiconductor crystals into a silicon nanowire.

Silicon 'hetero-nanowires' integrated with III-V segments is considered a highly promising candidates for future high-speed and multifunctional nanoelectronic devices. However one of the major obstacles for in building such structures has been the numerous defects caused by crystal lattice mismatch at these dimensions.

In this case, the researchers used ion beam synthesis and heat treatment with xenon flash-lamps, two technologies in which the Ion Beam Center of the HZDR has held experience for many years. They initially needed to introduce a determined number of atoms precisely into the wires using ion implantation. They then carried out the flash-lamp annealing of the silicon wires in their liquid-phase within twenty milliseconds. "A silicon oxide shell, measuring merely fifteen-nanometers-thick, maintains the form of the liquid nanowire," explains HZDR scientist Slawomir Prucnal, "while the implanted atoms form the indium-arsenide

crystals."

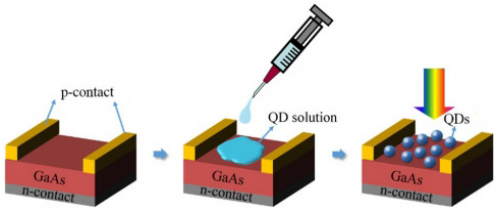
Wolfgang Skorupa, head of the research group adds: "The atoms diffuse in the liquid-silicon-phase so rapidly that within milliseconds they form flawless mono-crystals delineated from their surroundings with nearly perfect interfaces." In the next step, the scientists want to implement different compound semiconductors into silicon nanowires and also optimise the size and distribution of the crystals.

The results are published in the journal Nano Research: *'III-V semiconductor nanocrystal formation in silicon nanowires via liquid-phase epitaxy'* by S. Prucnal et al, DOI: 10.1007/s12274-014-0536-6

Quantum dots boost conversion efficiency of GaAs Solar cells

Dots act as luminescent downshifters

A team of scientists from Taiwan has shown that adding CdS or CdSe quantum dots (QDs) to GaAs solar cells could increase their efficiency by nearly 25 percent. The results were reported in *Nature* last week.



GaAs-based single-junction solar cells already hold the photovoltaic world record for the highest power conversion efficiency (PCE) at 28.8 percent. Boosting conversion efficiency in GaAs solar cells further requires reducing surface reflection and using the full solar spectrum, especially in the ultraviolet (UV) range.

High-energy photons can be easily absorbed at short distances, but the generated electron-hole pairs are close to the semiconductor surface, where recombination loss is strong. One way of solving this is to find a way to transform high-energy photons into lower-energy photons in process called luminescent downshifting.

Organic dyes have previously been used as downshifters but dye molecules have poor photon stability and narrow absorption spectrum bands. The researchers from National Chiao Tung University and the Industrial Technology Research Institute, in Hsinchu, Taiwan, used various QDs as the downshifting agents. The resultant hybrid design offers antireflective features to boost photon harvesting at long wavelengths while enhancing the collection of photogenerated carriers in the ultraviolet region.

They measured and analysed several photovoltaic parameters, including short-circuit current density, open circuit voltage, and external quantum efficiency to investigate the performance of the hybrid device. The results, they say, showed that quantum dots effectively enhanced overall power conversion efficiency by as high as 24.65 percent compared with traditional GaAs-based devices. Further analysis of the quantum efficiency response showed that the luminescent downshifting effect can be as much as 6.6 percent of the entire enhancement of photogenerated current.

This is a brief overview of *'A Highly Efficient Hybrid GaAs Solar Cell Based on Colloidal-Quantum-Dot-Sensitization'* by Hau-Vei Han et al, Nature Scientific Reports **4**, Article number: 5734 doi:10.1038/srep05734

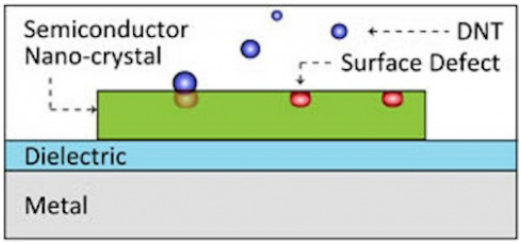
Laser sensor could lead way to handheld bomb-detectors

Tiny plasmon-based sensor detects minute traces of explosives in the air

A team at University of California, Berkeley led by Xiang Zhang, professor of mechanical engineering, has shown that a plasmon laser sensor can be used to detect minute concentrations of explosives in the air, including a hard-to-detect plastic explosive called PETN popular among terrorists. The results were published in the journal *Nature Nanotechnology*.

Plasmon lasers work by coupling electromagnetic waves with the electrons that oscillate at the surface of metals to squeeze light into nanoscale spaces far past its natural diffraction limit of half a wavelength. The UC Berkeley plasmon laser is based on a

cadmium suphide semiconductor square measuring around 50nm thick and 1000nm long, placed on a silver surface and separated by a 8nm gap of magnesium fluoride. The most intense electric fields of the device reside in the magnesium fluoride gap.



In designing the sensor device, the researchers took advantage of the chemical makeup of many explosives, particularly nitro-compounds such as DNT and its more well-known relative, TNT. Their unstable nitro groups are characteristically electron deficient, which increases the interaction of the molecules with natural surface defects on the semiconductor. The sensor works by detecting the increased intensity in the light signal that occurs as a result of this interaction.

The engineers put the sensor to the test with various explosives - 2,4-dinitrotoluene (DNT), ammonium nitrate and nitrobenzene - and found that the device successfully detected the airborne chemicals at concentrations of 0.67 parts per billion, 0.4 parts per billion and 7.2 parts per million, respectively. One part per billion would be akin to a blade of grass on a football field. These results, which are much more sensitive than those published to date for other optical sensors, were published in the advanced online publication of the journal Nature Nanotechnology.

The researchers hope that their plasmon laser sensor could detect pentaerythritol tetranitrate, or PETN, a plastic explosive favoured by terrorists because small amounts of it pack a powerful punch and it escapes x-ray machines when not connected to a detonator. It is the explosive found in Richard Reid's shoe bomb in 2001 and Umar Farouk Abdulmtallab's underwear bomb in 2009. PETN has more nitro functional groups and is more electron deficient than the DNT we detected in our experiments, so the sensitivity of their device should be even higher than with DNT, say the researchers.

"The ability to magnify such a small trace of an explosive to create a detectable signal is a major development in plasmonsensor technology, which is one of the most powerful tools we have today, " said Zhang.

The sensor device builds upon earlier work on plasmon lasers by Zhang's lab that uses reflectors to bounce the surface plasmons back and forth inside the sensor (similar to the way sound waves are reflected across the room in a whispering gallery) and using the optical gain from the semiconductor to amplify the light energy.

Zhang said the amplified sensor creates a much stronger signal than the passive plasmon sensors currently available, which work by detecting shifts in the wavelength of light. "The difference in intensity is similar to going from a light bulb for a table lamp to a laser pointer," he said. "We create a sharper signal, which makes it easier to detect even smaller changes for tiny traces of explosives in the air."

Co-lead author Ren-Min Ma, an assistant professor of physics at Peking University who did this work when he was a postdoctoral researcher in Zhang's lab, said: "Our technology could lead to a bomb-detecting chip for a handheld device that can detect the tiny-trace vapour in the air of the explosive's small molecules."

The sensor also could be developed into an alarm for unexploded land mines that otherwise are difficult to detect, the researchers said.

The US Air Force Office of Scientific Research Multidisciplinary University Research Initiative program helped support this work.

'Explosives detection in a lasing plasmon nanocavity' by Ren-Min Ma et al, appears in Nature Nanotechnology (2014), doi:10.1038/nnano.2014.135

Scientists create identical quantum dots and place them with pinpoint precision

Research opens the door to quantum dot architectures completely free of uncontrolled variations

The ambitious goal of creating quantum dots with digital fidelity by eliminating variations in their size, shape and arrangement has remained elusive.

Such perfect reproducibility is important as it opens the door to quantum dot architectures free of uncontrolled variations, which is necessary for technologies ranging from nanophotonics to quantum information processing.

Now scientists from Paul-Drude-Institute for Solid-State Physics in Berlin, NTT Basic Research Laboratories, Japan; and the Naval Research Laboratory (NRL), USA have managed to create quantum dots with identical, deterministic sizes, according to a recent report in *Nature Nanotechnology*.

Quantum dots are often called artificial atoms because, like real atoms, they confine electrons to quantised states with discrete energies. But real atoms are identical, whereas most quantum dots comprise hundreds or thousands of atoms, with variations in size and shape and, consequently, unavoidable variability in their wavefunctions and energies.

Creating atomically precise quantum dots requires every atom of the quantum dot to be placed in a precisely specified location without error, and multiple dots to be arranged in exactly defined configurations without variation. The researchers achieved this goal using a scanning tunnelling microscope (STM) to manipulate the atoms and an atomically precise surface template to define a lattice of allowed atomic positions.

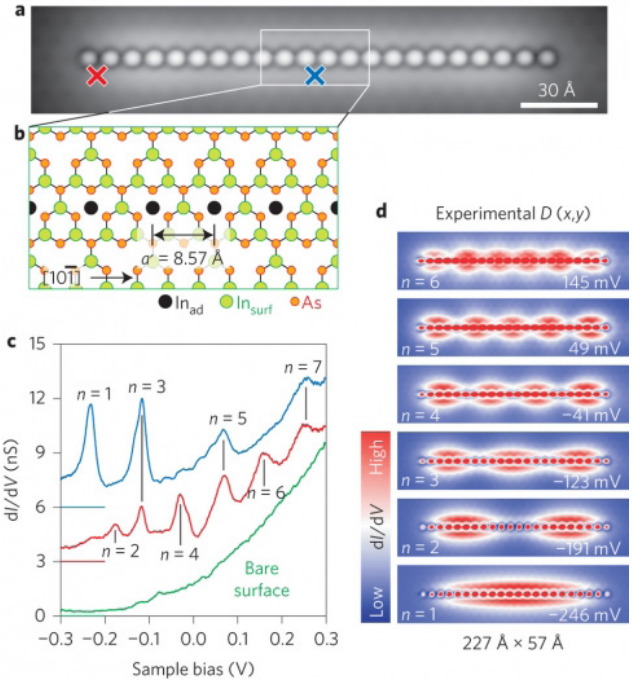
The template was the surface of an InAs crystal, which has a regular pattern of indium vacancies and a low concentration of native indium adatoms adsorbed above the vacancy sites. The adatoms are ionized +1 donors and can be moved with the STM tip by vertical atom manipulation. The team assembled quantum dots consisting of linear chains of N = 6 to 25 indium atoms.

Because the indium atoms are strictly confined to the regular lattice of vacancy sites, every quantum dot with N atoms is essentially identical, with no intrinsic variation in size, shape, or position. This means that quantum dot "molecules" consisting of several coupled chains will reflect the same invariance.

Steve Erwin, a physicist at NRL and the team's theorist, pointed out that "this greatly simplifies the task of creating, protecting, and controlling degenerate states in quantum dot molecules, which is an important prerequisite for many technologies." In quantum computing, for example, qubits with doubly degenerate ground states offer protection against environmental decoherence.

By combining the invariance of quantum dot molecules with the intrinsic symmetry of the InAs vacancy lattice, the team say they have created degenerate states that are surprisingly resistant to environmental perturbations by defects.

The reproducibility and high fidelity offered by these quantum dots makes them excellent candidates for studying fundamental physics. Looking forward, the team also anticipates that the elimination of uncontrolled variations in quantum dot architectures will offer many benefits to a broad range of future quantum dot technologies from nanophotonics to quantum information processing.



Figures a,b, c and d above show the quantized states of a digital quantum dot in which electrons are confined by a chain of ionized indium adatoms. Picture a, is a topographic STM image (0.1 nA, _0.3 V) of a chain of indium adatoms assembled on InAs(111)A. Twenty-two indium atoms were placed on adjacent indium-vacancy sites of the (2 x 2)-reconstructed surface. b, shows the atomic structure of the image section indicated in a. The surface consists of indium (green) and arsenic (orange) atoms, and the chain is formed by In adatoms (black circles) adsorbed above vacancy sites. c, shows the differential conductance (dI/dV)

spectra (red and blue) recorded at the off-chain tip positions indicated in a, revealing quantized electron states with quantum numbers n = 1-7. The reference spectrum of pristine InAs(111) A (green) reveals that the Fermi level is pinned in the conduction band due to intrinsic electron accumulation at the surface. d, Spatial DOS maps D(x,y) obtained by constant-height dI/dV scanning at the bias voltages corresponding to the resonances in c. Quantized states for n = 1-6, each with n lobes and n- 1 nodes, are clearly revealed.

This work is described in Nature Nanotechnology **9**, 505-508 (2014) *'Quantum dots with single-atom precision'* by Stefan Folsch et al.

doi:10.1038/nnano.2014.129

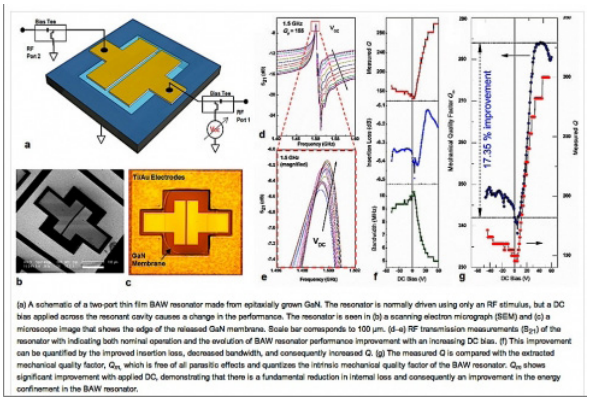
Research on GaN-based resonators gives new insights into Phonon-Electron Interactions

Studies suggest possibility of new class of acousto-electrically amplified resonant devices

Piezoelectric semiconductors (PS), such as ZnO, GaN and CdS, rely on interactions between electronic and mechanical domains. But when used to make real world devices such as resonators, these interactions are lossy and have limited conversion efficiency.

Now recent work on GaN-based bulk acoustic standing wave (BAW) resonators by Vikrant Gokhale and Mina Rais-Zadeh at the University of Michigan, has shown that with the right design and material properties, it is possible to achieve low-loss in such devices with unprecedented ability to dynamically tune resonator Q.

The study, published in *Nature*, is claimed to be the first comprehensive investigation of phonon-electron interactions in piezoelectric semiconductor BAW resonators. The results indicate that it is possible to design such resonators with: a) minimum phonon-electron scattering loss under normal operation; b) reduced total energy loss via acousto-electric interaction; and c) acousto-electric gain that can overcome all other losses, effectively creating a highly frequency-selective acousto-electric resonant amplifier.



As well as showing that phonon-electron interactions can lead to acoustic gain of standing waves in PS-BAW resonators, the researchers say that they have presented, for the first time, a comprehensive model that explains the resulting enhanced mechanical Q of PS-BAW resonators under the acousto-electric effect.

The dynamics of acoustic waves (phonons) trapped in resonant cavities made of solid elastic materials have been studied extensively over the years. At resonant frequency, mechanical energy is confined in the form of standing waves in the cavity, which is the basis of BAW resonators. Ideal standing wave BAW resonators are lossless but the energy confinement in practical materials is not ideal due to a number of phonon-scattering processes. This attenuation limits the quality factor (Q).

Expressions for maximum Q-limits for scattering processes such as anharmonic phonon-phonon loss and thermoelastic damping (TED) are well known. A neglected scattering process is the phonon-electron interaction, which is significant in piezoelectric semiconductor materials such as ZnO, GaN and CdS that have both moderate-to-high doping concentrations and a mechanism facilitating strong electromechanical interactions. Similar to well-known lattice loss mechanisms such as the phonon-phonon loss, the phonon-electron scattering is dependent on the bulk material properties and is not design dependent.

Gokhale and Rais-Zade used thin-film GaN-based BAW resonators as test platforms for dynamic performance enhancement via acousto-electric amplification. The films were unintentionally doped (UID) bulk GaN. The researchers compared theoretical estimates with measured results

obtained using the GaN BAW resonators.

The results showed that, in effect, pumping electrical energy into the system can be used to offset the mechanical losses. This dynamic and reversible improvement in the Q of PS-BAW resonators can be distinctly observed on applying a DC electric field. The experimental work focused on GaN as it is a high-quality acoustic PS material predicted to be optimal for demonstrating acousto-electric amplification. Other PS materials (CdS, ZnO H-SiC, GaAs, InP, InGaAs, and AlAs41) could also be potentially used to achieve Q-amplified BAW resonators, say the researchers.

An important question arising from this work, say the researchers, is whether one can overcome all other sources of loss in a practical PS-BAW resonator and achieve frequency-selective resonant BAW amplifiers. To demonstrate this experimentally, they say, further investigation is necessary into PS-BAW resonators made with high-quality thin-film materials, such as GaN, CdS, or ZnO. Ideally, the resonators should be optimized for low reflection loss, operated under controlled pressure/temperature, and stimulated with continuous wave or pulsed DC excitation. This would enable exhaustive investigation into acousto-electric interactions in PS materials and encourage the design of a new class of high-performance acousto-electrically amplified resonant devices.

This is a very brief summary of the paper P*honon-Electron Interactions in Piezoelectric Semiconductor Bulk Acoustic Wave Resonators by* Vikrant J. Gokhale and Mina Rais-Zadeh. from Nature Scientific Reports **4**, Article number: 5617 doi:10.1038/srep05617

Quantum dots to combat piracy

3D printing technology embeds quantum dots to produce unique security signature

Quantum Materials Corporation, based in Texas USA, has acquired a technology to embed quantum dots into 3D-printed objects as a kind of security signature. QMC hopes that this 3D-printing/additive manufacturing approach, developed at Virginia Tech in the US, will be a way of protecting 3D printed objects from being copied.

QMC is known for making tetrapod-shaped quantum dots (QD) for medical, display, solar energy and lighting applications. Compared to their spherical cousins, tetrapod QDs offer advantages such as higher brightness, more colours, the use of less active material, better stability and longer lifetime.

By using tetrapod quantum dots with specific structural characteristics, or dual emission tetrapods that can emit two different colours, the company says it can further increase the security measures inherent in the Virginia Tech process.

“The remarkable number of variations of semiconductor nanomaterials properties QMC can manufacture, coupled with Virginia Tech’s anticounterfeiting process design, combine to offer corporations extreme flexibility in designing physical cryptography systems to thwart counterfeiters,” said David Doderer, QMC’s VP for research and development.

IBM Announces $3 Billion Research Initiative To Tackle Chip Grand Challenges

Scientists and engineers start to work on a post-silicon future

IBM today announced it is investing $3 billion over the next five years in two research programs to push the limits of chip technology needed to meet the emerging demands of cloud computing and Big Data systems.

One program will be aimed at ‘7 nanometer and beyond’ silicon technology to address the challenges threatening current semiconductor scaling techniques. The second will focus on alternative technologies for post-silicon era chips using new materials and circuit architectures, including III-V technologies, silicon photonics, carbon nanotubes, low power transistors, graphene, quantum computing, and neurosynaptic computing.

The research teams, who will focus on providing orders of magnitude improvement in system level performance and energy efficient computing, will

comprise IBM scientists and engineers from Albany and Yorktown, New York; Almaden, California; and Europe.

“Scaling to 7nm and below is a terrific challenge, calling for deep physics competencies in processing nano materials affinities and characteristics. IBM is one of a very few companies who has repeatedly demonstrated this level of science and engineering expertise,” said Richard Doherty, technology research director, The Envisioneering Group.

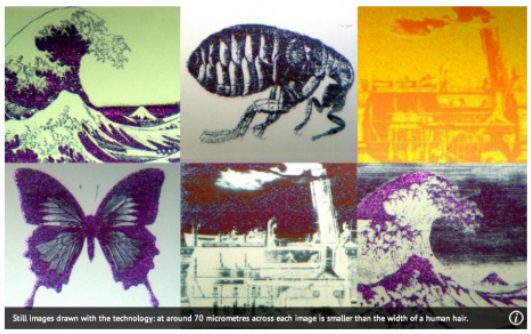
Beyond 7 nanometers, the challenges dramatically increase, requiring a new kind of material to power systems of the future, and new computing platforms to solve problems that are unsolvable or difficult to solve today, says the company.

British researchers create building blocks for new high-resolution display technology

Phase-change film ‘sandwich’ shows potential for thin, flexible nano-pixel displays

A team led by scientists at Oxford University has shown the possibility of combining optical and electrical control in ultrathin phase-change films to create pixels just a few hundred nanometers across. They think their research, published in this week’s *Nature*, could pave the way for extremely high-resolution and low-energy thin, flexible displays for applications such as ‘smart’ glasses, synthetic retinas, and foldable screens.

Phase-change materials (materials that can change from an amorphous to a crystalline state) such as the alloy germanium antimony tellurium (GST) have for years been used in optical storage media such as rewritable DVDs. More recently, such materials have been investigated as candidates for the next generation of electrically operated non-volatile memories. In this latest study, the researchers found that by sandwiching a seven nanometer thick layer of GST between two layers of a transparent electrode made from indium tin oxide (ITO) they could use a tiny current to ‘draw’ images within the sandwich ‘stack’. The layers of the GST sandwich are created using a sputtering technique where a target is bombarded with high-energy particles so that atoms from the target are deposited onto another material as a thin film.



Initially still images were created using an atomic force microscope but the team went on to demonstrate that such tiny ‘stacks’ can be turned into prototype pixel-like devices. These ‘nano-pixels’ - just 300 by 300 nanometres in size - can be electrically switched ‘on and off’ at will, creating the coloured dots that would form the building blocks of an extremely high-resolution display technology.

Whilst the work is still in its early stages, the Oxford team has filed a patent on the discovery with the help of Isis Innovation, Oxford University’s technology commercialisation company. Isis is now discussing the displays with companies who are interested in assessing the technology, and with investors.

“We didn’t set out to invent a new kind of display,” said Harish Bhaskaran of Oxford University’s Department of Materials, who led the research. “We were exploring the relationship between the electrical and optical properties of phase change materials and then had the idea of creating this GST ‘sandwich. We found that not only were we able to create images in the stack but, to our surprise, thinner layers of GST actually gave us better contrast. We also discovered that altering the size of the bottom electrode layer enabled us to change the colour of the image.’

He added: “Because the layers that make up our devices can be deposited as thin films they can be incorporated into very thin flexible materials - we have already demonstrated that the technique works on flexible Mylar sheets around 200 nanometres thick.”

Peiman Hosseini of Oxford University’s Department of Materials, first author of the paper, said: “One of the advantages of our design is that, unlike most

conventional LCD screens, there would be no need to constantly refresh all pixels, you would only have to refresh those pixels that actually change. This means that any display based on this technology would have extremely low energy consumption."

The research suggests that flexible paper-thin displays based on the technology could have the capacity to switch between a power-saving 'colour e-reader mode', and a backlit display capable of showing video. Such displays could be created using cheap materials and, because they would be solid-state, promise to be reliable and easy to manufacture.

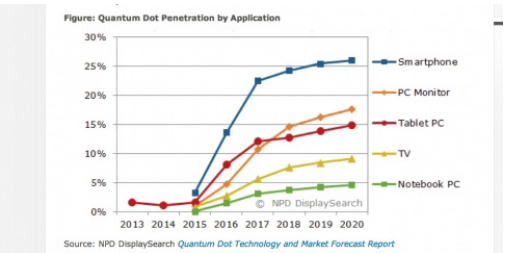
David Wright of the Department of Engineering at the University of Exeter, co-author of the paper, said: "Along with many other researchers around the world we have been looking into the use of these GST materials for memory applications for many years, but no one before thought of combining their electrical and optical functionality to provide entirely new kinds of non-volatile, high-resolution, electronic colour displays - so our work is a real breakthrough."

A report of the research, entitled *‹An optoelectronic framework enabled by low-dimensional phase change films›* by Hosseini et al is published in Nature **511**, 206-211 (10 July 2014) doi:10.1038/nature13487

Quantum Dot Display Technology set to enter mainstream markets

New report forecasts rising use of quantum dot displays for smartphones and tablet PCs

According to NPD DisplaySearch's latest market research on quantum dot displays, by 2015 3 percent of smartphone TFT LCDs will use quantum dots, growing to 26 percent in 2020. In tablet PCs, the figure will be nearly 2 percent in 2015, growing to 15 percent in 2020. For LCD TV, the company forecasts that less than 1 percent of LCD TV screens will use quantum dots in 2015, growing to 9 percent in 2020.



"Quantum dot solution prices remain high compared to other more entrenched technologies," said Yoonsung Chung, general manager, NPD DisplaySearch Korea. In 5in smartphone panels, the cost of panels using sheet-type on-surface quantum dots is 20 percent higher than typical TFT LCD smartphone panels. As the display size increases, so does the cost, with the premium for a 55 in TV panel estimated to be 35 percent.

Quantum dot provides a colour gamut exceeding the National Television System Committee (NTSC) colour specifications; typical TFT LCDs achieve only up to 75 percent of NTSC. However quantum dot technology has several problems, including reduced durability, higher cost, and restrictions on the use of cadmium and other heavy metals in household products.

"Display makers have shown interest in adopting quantum dot technology, but they have been concerned about heavy metals and higher prices," Chung noted. "Recently, however, the European Union has offered a temporary exemption for the use of cadmium-containing quantum dots in displays. Cadmium-free quantum dot materials have also become available, so display manufacturers are taking a fresh look."

NPD DisplaySearch' s *Quantum Dot Technology and Market Forecast Report* provides global market research on the benefits, challenges, makers and market drivers that affect the adoption of quantum dot technology.

Researchers show low temperature deposition of GaN for TFTs

Study demonstrates possibility of using GaN layers to make flexible transparent substrates

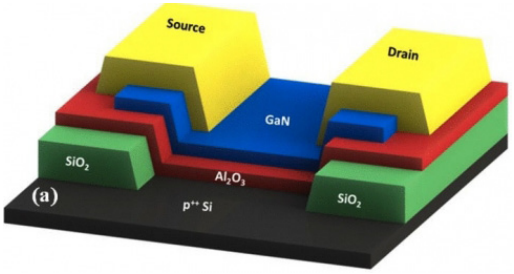
Researchers at the Bilkent University in Turkey have grown GaN thin film transistors (TFT) with a thermal budget below 250 degC. The study, they say, demonstrates the possibility of using low-temperature atomic layer deposition (ALD)-grown GaN layers to make stable flexible/transparent TFT devices.

TFTs, usually based on amorphous Si (a-Si), are the driving elements of liquid crystal display technology. However, due to low carrier mobility in a-Si, high fabrication thermal budget, and strong absorption of visible light, a-Si is not suitable for flexible and transparent electronics applications. Transparent metal oxides, in particular ZnO, have been proposed instead but stability remains an important problem.

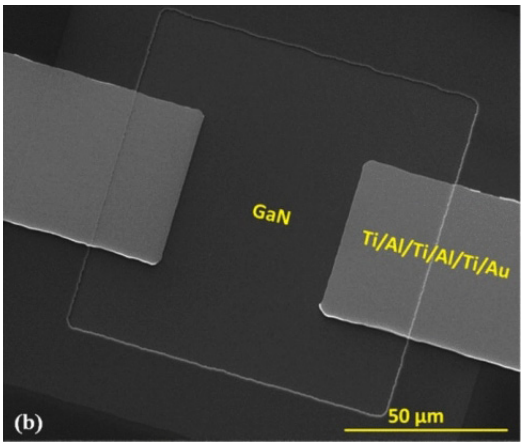
As a transparent semiconducting material with a band-gap of 3.4eV, GaN is another option for the active layer of TFTs, however the two main deposition techniques for the use of epitaxial GaN films require high deposition temperatures.

To use GaN in settings with limited thermal budget, such as back end of line (BEOL) and flexible substrates, low-temperature deposition of GaN is being pursued using various methods such as sputtering, pulsed laser deposition (PLD), and atomic layer deposition (ALD).

ALD offers the most uniform and conformal deposition even at sub-nanometer thickness levels, say the researchers. In their paper in Applied Physics Letters, the team at Bilkent describe the development of a hollow-cathode plasma-assisted atomic layer deposition (HCPA-ALD)-grown GaN based TFT with the lowest reported thermal budget so far, keeping the entire layer growth and device fabrication steps below 250degC.



A 3D picture of the proposed TFT is shown above (a) , and a scanning electron microscope (SEM) image of the top view of the device is shown below (b).



The researchers report that the deposited GaN thin film has a polycrystalline wurtzite structure with a crystallite size of 9.3nm using GIXRD and LPA, respectively. Elemental analysis of the films revealed the low amount of oxygen in HCPA-ALD based GaN thin films. Output characteristics of the TFTs are obtained which show that the fabricated devices exhibit *n*-type enhancement mode field effect transistor behavior with clear pinch-off and saturation characteristics. Transfer characteristics of the devices show that the fabricated transistors have on-to-off ratios of 2 x 10^3. Finally, the effect of the positive gate bias stress on threshold voltage of the devices is studied, and reasonable threshold voltage shifts for a device with a considerably thick gate insulator are obtained.

Reference: *Low temperature thin film transistors with hollow cathode plasma-assisted atomic layer deposition based GaN channels* by S. Bolat et al, Appl. Phys. Lett. 104, 243505 (2014); http://dx.doi.org/10.1063/1.4884061