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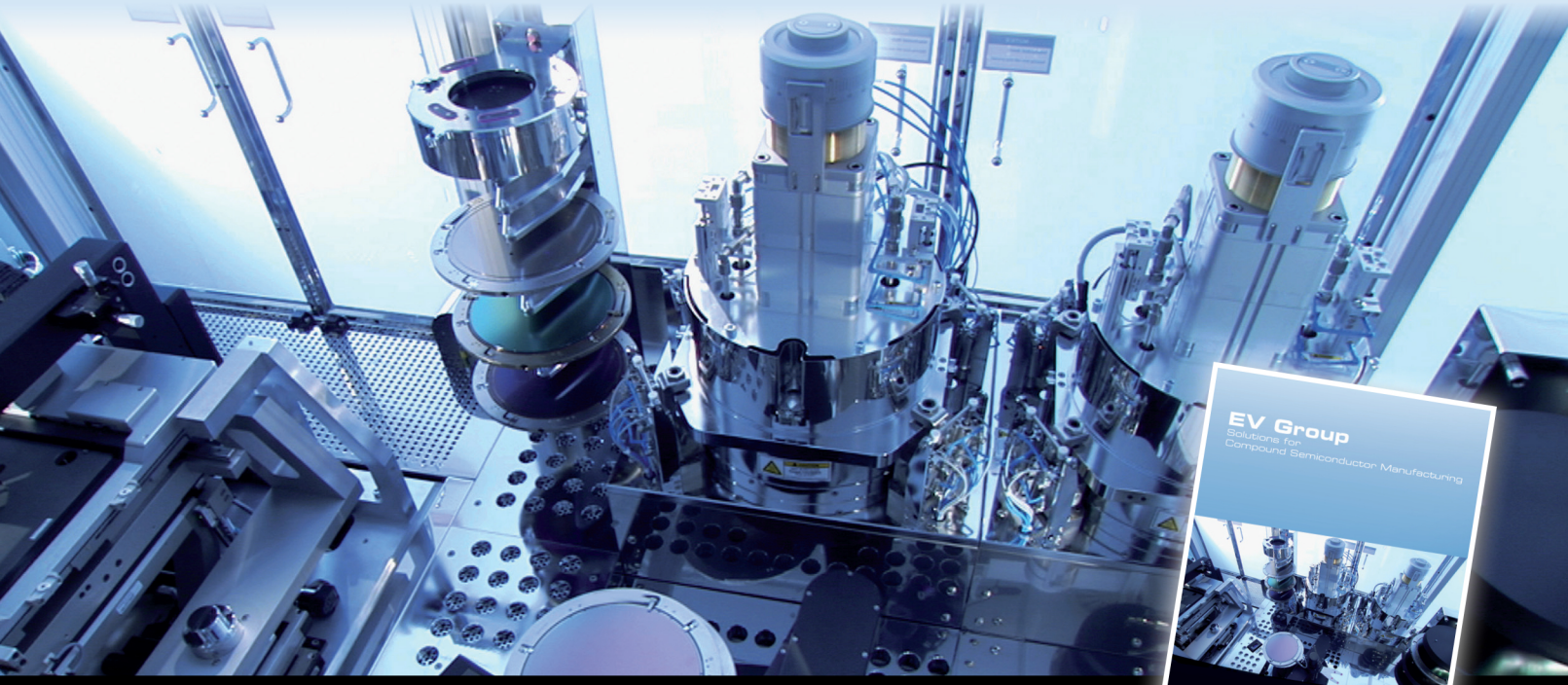


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# semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

Vol. 10 • Issue 3 • April/May 2015

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## III-Vs on Si for 7nm CMOS?

## Developments in nitrides on silicon

Philips sells major stake in Lumileds • Aixtron acquires PlasmaSi

News from OFC • Hanergy plant for Alta's flexible GaAs PV cells

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*Veeco's New TurboDisc EPIK700 GaN MOCVD System*

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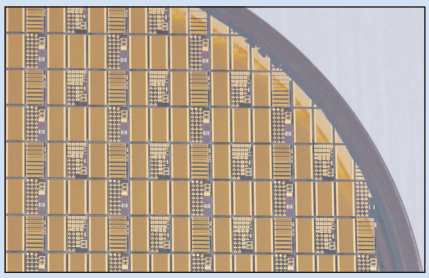
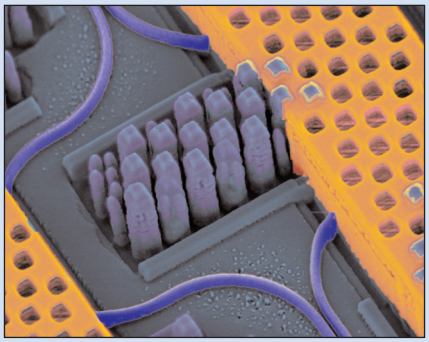
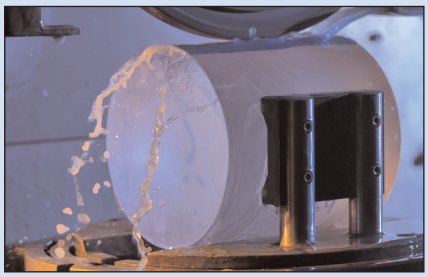


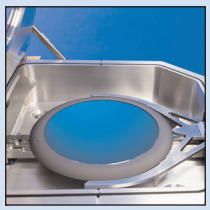
**p15** The HiPoSwitch project has completed with the development of fast, efficient normally-off GaN-on-Si power transistors.



**p58** IBM, which has integrate silicon photonic chips with a processor in the same package, avoiding the need for transceiver assemblies.



**p68** Sapphire core fabrication at Rubicon, which discusses how larger diameters and patterned substrates are impacting LED manufacturing.



Cover: Veeco's chief technology officer and its senior director, MOCVD Technology discuss how systems with single-wafer chambers can address the transition of gallium nitride on silicon power devices from R&D to volume production. . **p84**

# editorial

## GaN-on-silicon power electronics adds to LED MOCVD revival

In this issue we focus on developments in III-V-on-silicon technology, which is showing increasing promise for both microelectronics and optoelectronics.

On pages 88–91, we report on February's IEEE International Solid-State Circuits Conference (ISSCC) in San Francisco, covering the topic of high-mobility channels for moving beyond silicon in CMOS transistors. Specifically, significant changes (including Ge PMOS and InGaAs NMOS) are seemingly converging on the 7nm technology node when, reports suggest, Intel plans to move away from silicon transistors, starting around 2018 (following Intel's existing 14nm technology then 10nm, in 2016–17).

In the meantime, nitrides on silicon are showing increasing viability as an economic alternative to silicon for power semiconductor electronic devices. The three-year European Union-funded HiPoSwitch ('High Power Switch') project was completed recently after developing prototype fast, high-efficiency GaN-on-Si enhancement-mode (normally-off) power transistors (page 15). Meanwhile, more commercial GaN-on-Si products are being presented at events such as PCIM (Power Conversion Intelligent Motion) Europe 2015 in Nuremberg, Germany (19–21 May). There, for example, Belgium-based III-nitride epitaxial material supplier EpiGaN is demonstrating its range of GaN-on-Si epiwafers meeting industrial specifications for high-electron-mobility transistor devices operating at 650V (page 16). In addition, California's Efficient Power Conversion (EPC) has launched 60V and 100V e-mode GaN-on-Si power field-effect transistors for power management applications that are "designed to compete on price while outperforming silicon". As the price barrier to widespread adoption falls. EPC reckons such new products demonstrate that GaN transistors can displace silicon MOSFETs and "drive the industry back onto the Moore's Law growth curve".

This is backed up by market research firm IHS, which forecasts that gallium nitride and silicon carbide power devices will achieve price and performance parity with silicon MOSFETs, IGBTs or rectifiers in 2020, and that the SiC and GaN power semiconductor market will grow 17-fold to $2.5bn in 2023 (page 83).

This growth potential is being tapped by MOCVD reactor makers such as Veeco, which on pages 84–85 discusses how systems with single-wafer chambers can address the transition of GaN-on-Si power devices from R&D to volume production.

This medium-term prospect promises to supplement the near-term revival in the GaN MOCVD system market to 220 reactors in 2015, forecasts IHS, driven by "aggressive expansion plans" of Chinese LED makers (with the three largest taking 27% of all installations) — see page 82. Indeed, on pages 80–81, SEMI forecasts that China will comprise half of all LED epi & chip equipment spending in 2015–2016, as the country grows at double the global rate, from 35% to almost 40% of worldwide LED epi capacity in 2016.

Longer term, European researchers have developed a low-temperature plasma-assisted molecular beam epitaxy (PAMBE) process for the direct growth on silicon of indium gallium nitride compositions spanning the whole range from GaN to InN (pages 86–87). This could open the way to a wider range of wavelengths and applications such as solar cells, say the researchers.

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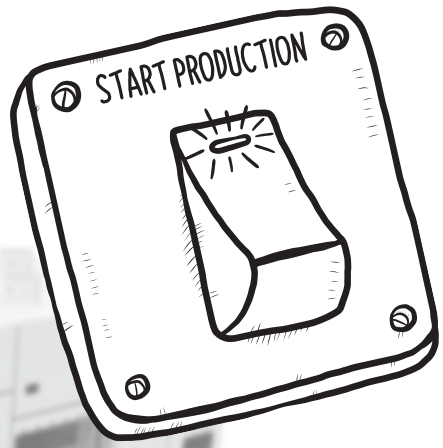

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# Market for LED lamps in general lighting in USA to grow at 22.4% CAGR from $1.22bn to $3.36bn in 2019

The market value of LED lamps installed for general lighting in the USA (including indoor & outdoor accent and functional lighting for residential, commercial and government areas) reached $1.22bn in 2014 and will grow strongly at average annual growth rate of 22.4% to $3.36bn in 2019, according to a market forecast and analysis report by ElectroniCast Consultants.

The consumption value is forecast to increase with strongly rising quantity growth slightly offset by declining average prices.

The market study breaks out the forecast by eight major lamp types: parabolic aluminized reflector (PAR), general service (A-Type), decorative, multi-faceted reflector (MR)-compatible, tube and strips/tape, street-lights, high-bay, and other/ miscellaneous LED lighting. Some lamp categories, in turn, have multiple sub-categories, determined by physical size and Watt equivalents of the lamp.

ElectroniCast quantifies the LED tape by the meter price/quantity, and over 15 million meters are expected for installation in 2015 in the USA. LED strips have LEDs on a flexible printed-circuit board, and the super thin profile and narrow width make them suitable for a multitude of purposes where fluorescent or halogen lights would be too bulky and consume too much power.

Several cities in the USA have already installed LED street-lights. "The installed value of LED-based lamps used in street lighting in the United Sates is forecast at $728m in 2019," says Stephen Montgomery, principal analyst — LED Practice at ElectroniCast. "The Government sector leads in terms of consumption value in the LED-based street-lamp product category. In 2014, the Government sector held 80% of the total LED streetlight lamp market in the USA," he notes.

**www.electronicast.com**

# US LED lighting market to reach $5.2bn in 2015, driven by declining LED prices & supportive government initiatives

The US LED lighting market should grow to $5.2bn in 2015, driven by continuously declining LED prices (due to decreasing production) cost coupled with US government initiatives such as the Energy Policy Act of 2005 and increasing consumer inclination towards the adoption of green technologies, according to the report 'United States LED Lighting Market Forecast & Opportunities, 2020' by TechSci Research.

Driven by continuing innovation over the last decade, LED technology has made huge inroads into general lighting applications due to it being highly energy efficient, cost effective and environment friendly. The USA witnessed the launch of LED lighting products in early stages of technology development, and over the last five years the LED lighting market has witnessed phenomenal growth and is gradually moving towards maturity. General lighting, backlighting and automotive segments are the major applications. Presently, the general lighting segment dominates the LED lighting market and is expected to account for most demand by 2020.

"Continuing innovation in LED lighting technology, along with recovering construction and automobile industry and favorable government initiatives to promote the use of LED technology, are expected to positively influence the US LED lighting market over the next five years," says research director Karan Chechi. "In addition, the ban on use of incandescent lamps and sharply declining LED prices are expected to further boost the demand for LED lighting products in the country," Chechi adds.

**Continuing innovation in LED lighting technology, along with recovering construction and automobile industry and favorable government initiatives to promote the use of LED technology, are expected to positively influence the US LED lighting market over the next five years**

"The market is also expected to witness increasing consolidation in the coming years," Chechi notes. Cree, Philips, GE and Osram Sylvania are major players in the US LED lighting market and are expected to see further increases in their respective market shares during the forecast period as a result of their wide-ranging product portfolio and highly competitive product pricing strategies, concludes the report.

**www.techsciresearch.com/3311**

# LED value moving down supply chain, from chip level to module and system level

In 2015, companies are not relying on more technical breakthroughs, except at the LED module level, where integration remains an important issue. "However, there is still overcapacity," cautions Pars Mukish, business unit manager, LED, OLED and Sapphire at market research firm Yole Développement. "This is causing many changes in the supply chain, first at the chip level, then at the module/system level." One example is Royal Philips' spin-off (announced in July 2014) of its LED business, which grew from its acquisition of Lumileds in 2005.

The LED industry's complexity results from numerous technical issues, its many players, and a multitude of lighting applications. Its promise is due to especially large volume lighting opportunities, stresses Yole in its latest reports. The market research firm foresees a global business reaching almost $516m at the system level by 2016 (according to the 'LED in road and street lighting report' of July 2013 from Yole Développement & Luxfit).

Today, LED technology's average penetration rate is 10–20%, depending on geographic area. Each country has its own policy and has set up different measures to aid LED implementation. For example, in Japan, penetration has reached 30% due to government involvement.

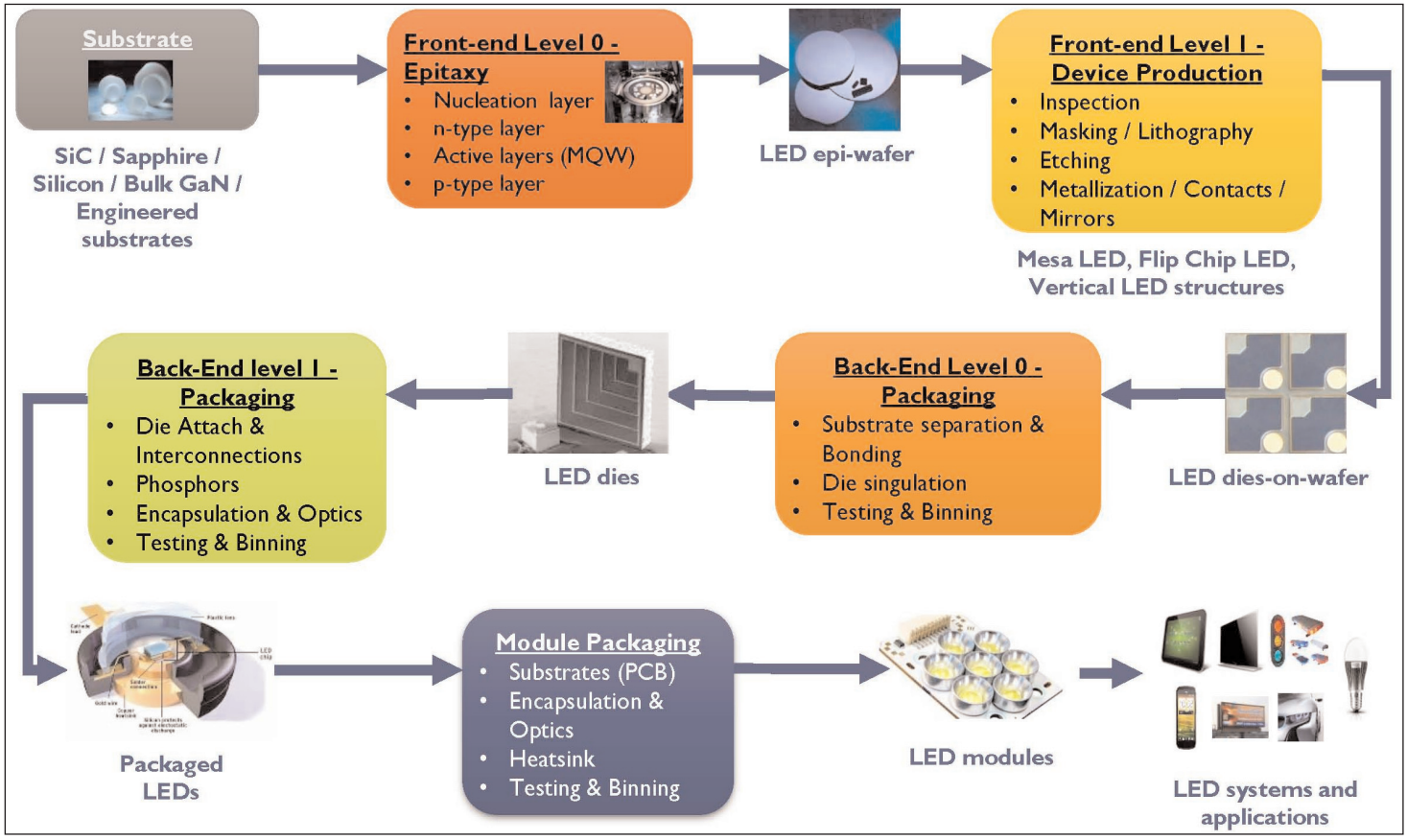
Governmental measures are clearly welcome, as the public still considers the technology to be expensive. "Even though we saw a real breakthrough for LED technology from 2006 to 2014, upfront LED costs are still high compared to existing technologies," notes Mukish.

"Today, the real growth is in external lighting applications where LED technology is partially implemented," he continues. "Commercial and industrial lighting players are also considering LED technology, but today implementation is still developing."

In 2015, technical issues are different to previous years, since they are mainly located at the LED module level, says Yole. LED market leaders are therefore developing answers to packaging and integration needs. In last September's report 'LED Packaging Technology and Market trends', Yole detailed the positive impact of advanced packaging technologies on LED manufacturing, especially LED packaging materials.

"In 2015, we clearly see the value moving later in the supply chain," Mukish says. "It was initially at the LED chip level, but we have identified strong investments at the module and system level to develop smart solutions in terms of packaging technologies and functionalities." Yole is hence focusing its 2015 activities on analyzing new technologies at the LED module level, investigating the impact on the supply chain and determining the strategies of key players (in a report on LED modules, related technologies and equipment, out in mid-2015).

**www.yole.fr**



# Anadigics expands small-cell wireless infrastructure power amplifier family for Band 8 WCDMA/LTE

Anadigics Inc of Warren, NJ, USA has introduced the AWB7229 small-cell power amplifier (PA), optimized for efficiency, linearity, output power and thermal characteristics in WCDMA, HSPA, LTE FDD and TD-LTE small-cell base-stations operating at Band 8 (925–960MHz) frequencies. Manufacturers can leverage this performance to develop infrastructure solutions that consume less power, offer higher throughput, and provide greater coverage and range, says the firm.

"The rapid increase in wireless data consumption places tremendous pressure on existing wireless infrastructure," says Charles Armour, senior director of business development for Wireless Infrastructure Products. "With the industry's broadest portfolio of high-performance power amplifiers for small-cell applications, Anadigics is enabling the newest generation of high throughput, reliable, and compact base stations, including picocells, enterprise-class femtocells, and high-performance customer premises equipment (CPE). These solutions provide an economical and pragmatic path to expand broadband network capacity and are gaining momentum with service providers."

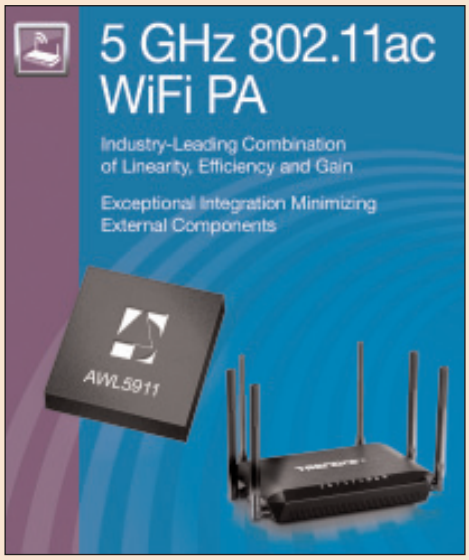
Anadigics' family of small-cell wireless infrastructure PAs leverages the firm's InGaP-Plus technology and design architectures. The AWB7229 delivers 13% efficiency to minimize power requirements. With linearity of –47dBc ACPR (adjacent channel power ratio) @ +27dBm linear output power and 29dB gain for ½-Watt linear output power applications, it is optimized to provide high-throughput data rates with a wide coverage area.

The AWB7229 power amplifier is available in the same compact, low-profile 7mm x 7mm x 1.3mm surface-mount package used across the entire AWB71XX and AWB72XX product lines, allowing the same PCB layout to be used for different bands and power levels. The AWB7229 also offers an integrated +4.5V bias, eliminating the need for complicated external bias circuitry, which simplifies design and system integration and reduces PCB space requirements.

## WiFi infrastructure amplifier powers TRENDnet's new router

Anadigics is shipping its AWL5911 802.11ac WiFi power amplifier (PA) in volume for use in TRENDnet's new AC3200 TEW-828DRU tri-band wireless router. Showcased at January's 2015 International Consumer Electronics Show (CES) in Las Vegas, the high-performance router features all gigabit Ethernet ports, USB 3.0 and USB 2.0 ports, and six separate antennas to support ultra-performance 802.11ac connectivity.

"WiFi routers and access points are a critical part of the connectivity infrastructure both inside and outside the home," says Alex Miller, product marketing manager for WiFi Products at Anadigics. "As the total number of connected devices increases, it's essential for a WiFi network to maintain a rich overall user experience," he adds. Operating at 4900–5900MHz, the AWL5911 provides what is claimed to be exceptional linearity, output power and gain to help TRENDnet's AC3200 tri-band router deliver high-throughput connectivity at extended ranges even in crowded WiFi network situations.




**Anadigics' AWL5911 802.11ac WiFi power amplifier**

The AC3200 TEW-828DRU router uses six AWL5911 amplifiers in each unit to drive high power in the 5GHz band to each of six antennas. The simultaneous operation of multiple transmit chains puts tremendous emphasis on power amplifier operating efficiency, ensuring good system thermal management without expensive heat sinking.

Anadigics' family of 802.11ac WiFi power amplifiers for infrastructure applications leverages the firm's patented InGaP-Plus technology and unique design architectures. The AWL5911 power amplifier in particular delivers 33dB of linear power gain and 1.8% EVM at +22dBm output power with what is claimed to be best-in-class power efficiency to provide improved thermal operation. It also features an internal digital PA-enable interface that eliminates the need for an external buffer amplifier, as well as a high-precision integrated detector that facilitates accurate power control over varying load conditions (3:1 VSWR) as well as extending the dynamic range. In addition, the compact 4mm x 4mm x 0.8mm QFN package includes RF ports internally matched to 50Ω and DC blocked in order to reduce PCB space requirements.

**www.anadigics.com**

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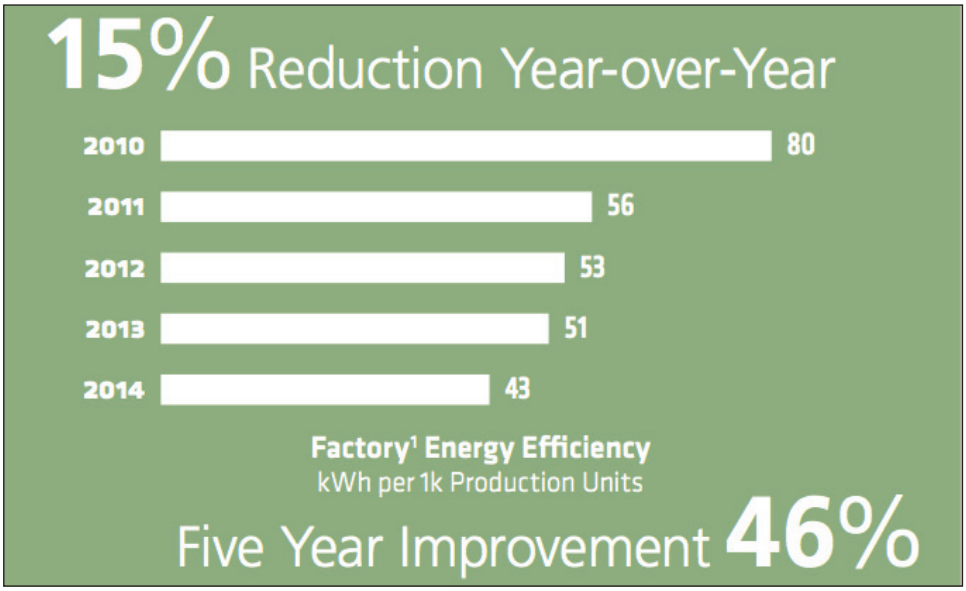
# Skyworks reduces year-on-year energy usage by 15%

Skyworks Solutions Inc of Woburn, MA, USA (which makes analog and mixed-signal semiconductors) has released its 2014 Sustainability Report, a voluntary non-financial public document that addresses the firm's commitment to sustainable business practices. The report highlights annual efficiency improvements and provides an overview of Skyworks' initiatives in multiple areas, from its environmental efforts and labor practices, to its health & safety programs, ethics policies and stewardship activities.

Skyworks says that in 2014 it continued its trend of manufacturing products with fewer natural resources, reducing hazardous materials and increasing energy efficiency. The firm also took further steps to ensure its materials continue to be sourced responsibly, expanded its employee programs promoting health, fitness and safety, and completed a global employee survey to find ways to make Skyworks a better place to work.




"Our goal is to develop and manufacture connectivity solutions through sustainable business practices, reducing our impact on the global environment," says Bruce J. Freyman, executive VP of worldwide operations. "We look forward to leveraging our systems and processes to ensure continuous improvement."

**www.skyworksinc.com**

# Cavendish Kinetics adopts STATS ChipPAC's wafer-level technology for RF MEMS antenna tuners

Singapore-based STATS ChipPAC Ltd (a provider of semiconductor packaging design, assembly, test and distribution services) says that Cavendish Kinetics of San Jose, CA, USA (which supplies RF MEMS antenna tuning solutions for LTE smartphones, handheld and wearable devices) has adopted its wafer-level packaging technology to deliver its SmarTune RF MEMS tuners in the smallest possible form factor, as a 2mm$^2$ chip-scale package. SmarTune devices feature a MIPI RFFE interface, have been shipping in volume since 2014, and are qualified beyond 100 billion cycles.

Cavendish says that LTE smartphone original equipment manufacturers (OEMs) are rapidly adopting antenna tuning solutions to be able to provide the required signal strength across the large number of LTE spectrum bands used globally. The firm claims that its SmarTune RF MEMS tuners outperform traditional RF silicon-on-insulator (SOI) switch-based antenna tuning solutions by 2–3dB, resulting in much higher data rates (up to 2x) and improved battery life (up to 40%). Its RF MEMS tuner shipments are ramping aggressively and can now be found in six different smartphone models across China, Europe and North America, with many additional designs in development.

"Our RF MEMS tuners present demanding packaging requirements, including the need to deliver the smallest possible form factor in a process that protects the integrity of our hermetically sealed MEMS structure," says Cavendish's executive VP of operations Atul Shingal. "STATS ChipPAC's wafer-level packaging platform provided advantages in package size, performance and scalability, and a proven, cost-effective manufacturing process that supports our accelerating volume production," he adds.

STATS ChipPAC provides a platform of wafer-level technology, from fan-in wafer-level packaging (FIWLP) to highly integrated fan-out wafer-level packaging (FOWLP) solutions known as embedded wafer-level ball grid array (eWLB). Cavendish and STATS ChipPAC are jointly working to utilize the inherent benefits of wafer-level packaging technology to drive further RF antenna tuning innovations for the smartphone market.

"In future products, we will be able to provide Cavendish Kinetics with options for greater functional integration and silicon partitioning capabilities that are only feasible with our industry-leading fan-out eWLB technology," says STATS ChipPAC's VP & chief marketing officer Dr Rajendra Pendse.

**www.cavendish-kinetics.com**

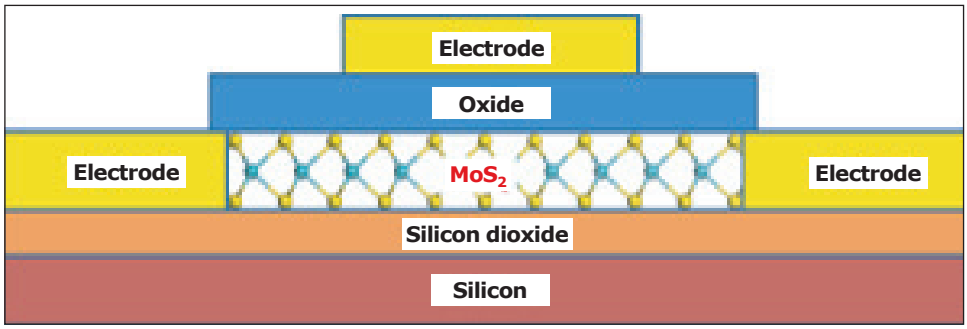
# Singapore's A*STAR develops simple, one-step method for creating high-quality 2D materials

## Magnetron sputtering of wafer-scale monolayer molybdenum disulfide could enable industrial-scale production

Shijie Wang at Singapore's A*STAR (Agency of Science, Technology and Research) Institute of Materials Research and Engineering (IMRE) and his collaborators have developed a technique for creating large areas of atom-thin two-dimensional (2D) semiconductor molybdenum disulfide for use in electronic devices (Tao J et al, 'Growth of wafer-scale $MoS_2$ monolayer by magnetron sputtering', Nanoscale 7, 2497–2503 (2015)).

Molybdenum disulfide belongs to the transition-metal dichalcogenide family of materials, which have two chalcogenide atoms (such as sulfur, selenium or tellurium) for every transition-metal atom (e.g. molybdenum and tungsten). These materials and their wide range of electrical properties provide an excellent platform material system for versatile electronics, but creating high-quality material over areas large enough for industrial-scale production is difficult.

"Mechanical exfoliation methods for obtaining 2D materials have limited usefulness in commercial applications, and all previous chemical methods are incompatible for integration with device fabrication," says Wang. "Our technique is a one-step process that can grow good-quality monolayer films, or few layers of $MoS_2$ films, at wafer scale on various substrates using magnetron sputtering."




**Transistors made of films of 2D $MoS_2$ could be integrated with other silicon electronics devices. © 2015 A*STAR IMRE**

The team fired a beam of argon ions at a molybdenum target in a vacuum chamber, ejecting molybdenum atoms from the surface where they reacted with a nearby sulfur vapor. These atoms then assembled onto a heated substrate of either sapphire or silicon. The team found that they could grow monolayer, bilayer, trilayer or thicker samples by altering the power of the argon-ion beam or the deposition time.

The material quality was confirmed using common characterization tools including Raman spectroscopy, atomic force microscopy (AFM), x-ray photoelectron spectroscopy (XPS) and transmission electron microscopy (TEM). The electrical properties of the $MoS_2$ films were also demonstrated by creating a working transistor.

"Our next step in this work will focus on the application of this technique to synthesize other two-dimensional materials and integrate them with different materials for various device applications," says Wang.

**www.imre.a-star.edu.sg**

# Microsemi completes acquisition of Vitesse

Microsemi Corp of Aliso Viejo, CA, USA (which designs and makes analog and RF devices, mixed-signal integrated circuits and subsystems for communications, defense & security, aerospace and industrial markets) says that its subsidiary LLIU100 Acquisition Corp has merged into Vitesse Semiconductor Corp of Camarillo, CA, completing its acquisition of Vitesse (announced on 31 March).

Each outstanding share of Vitesse has been converted into the right to receive $5.28 per share in cash — the same price paid in the tender offer. Vitesse shares have ceased trading on Nasdaq.

Vitesse designs semiconductors, application software and integrated turnkey systems solutions for carrier, enterprise and Internet of Things (IoT) networks. Products enable the fastest-growing network infrastructure markets including mobile access/IP edge, Cloud access, and industrial-IoT networking.

As well as silicon-based products, Microsemi provides RF, microwave and millimetre-wave products including high-reliability diodes, power transistors, limiters, detectors, switches, low-noise amplifiers, power amplifiers and integrated multi-function modules based on silicon carbide, silicon germanium, gallium arsenide, gallium nitride and indium phosphide.

Microsemi expect the acquisition of Vitesse to be accretive to earnings per share (EPS) in its first full quarter (to 27 September). It also foresees about $20m of cost-savings-related synergies on an annual basis, driving $0.16–0.20 of EPS accretion in its first full fiscal year (to end-September 2016).

**www.vitesse.com**

# Rohm presents third-generation SiC trench MOSFETs

At PCIM (Power Conversion Intelligent Motion) Europe 2015 in Nuremberg, Germany (19–21 May), Rohm Semiconductor is presenting its latest power management product designs, including 1200V and 650V silicon carbide MOSFETs based on a trench gate structure, while the firm is also developing SiC MOSFETs with a breakdown voltage of 1700V.

Compared to conventional planar MOSFETs, the trench MOSFETs reach about half the on-resistance over the whole temperature range, while the stability of the gate oxide film and of the body diode remains as high as those of Rohm's second-generation SiC MOSFETs.

Also, the reverse recovery behaviour has been drastically reduced. In principle, there is no tail current during switching, resulting in faster operation and 30% less switching loss. The result is higher reliability and increased current-carrying capacity at a reduced cell density and minimum conductivity while maintaining a compact format, says the firm.

Rohm says that the MOSFETs are suitable for use in switch-mode power supplies (SMPS), renewable energy inverters/converters, EV/HV (electric/hybrid vehicle) inverters and chargers.

**www.rohm.com/web/global/sic-mosfet**
**www.mesago.de/en/PCIM/home.htm**

# ON Semiconductor demos GaN HEMT-based two-stage converter

At PCIM (Power Conversion Intelligent Motion) Europe 2015 in Nuremberg, Germany (19–21 May), ON Semiconductor of Phoenix, AZ, USA (which supplies silicon-based power and signal management, logic, discrete and custom devices for energy-efficient electronics) is showcasing its latest advances in power management technology, including developments involving gallium nitride (GaN). Featured demonstrations include:

A two-stage converter demonstrating the latest high-efficiency results obtainable with GaN high-electron-mobility transistors (HEMTs). The 240W supply achieves 95% peak efficiency using the NCP1397 LLC controller, NCP1654 power factor correction (PFC) controller, and TPH3202PS or NTP8G202N GaN transistor switching devices. The board uses GaN HEMTs in both the PFC stage and in the primary side of the LLC stage.

Also, at the Exhibitor Forum presenters Chris Rexer and Jason McDonald are talking about 'Advanced Silicon and GaN Power Technologies from ON Semiconductor for next generation applications in the Medium to High Voltage Range'.

In addition, in the Poster Dialogue Sessions, ON Semiconductor technical experts are giving the following presentations:

- 'Development of 650V Cascode GaN Technology' by Charlie Liu;
- '1 kW LLC Resonant Converter with HV GaN Switches' by Adam Vasicek.

**www.onsemi.com**
**www.mesago.de/en/PCIM/home.htm**

# Digi-Key distributing Global Power Technologies' silicon carbide products worldwide

As part of its growth strategy to reach a broader set of customers, Global Power Technologies Group (GPTG) has announced an exclusive global distribution agreement with Digi-Key Electronics of Thief River Falls, MN, USA, a provider of both prototype/design and production quantities of electronic components. "We're proud to announce an exclusive partnership with Digi-Key as part of our global growth strategy to reach a broader set of customers"

As a full-service silicon carbide (SiC) manufacturer for the commercial power market, GPTG produces 100mm and 150mm epitaxial wafers, SiC discrete diodes, SiC discrete mosfets, SiC modules and sub-systems for multiple market sectors.

Digi-Key is an online source for purchasing electronic components, featuring local websites, 24x7 technical support and multi-lingual customer service. As part of the agreement, GPTG's product line will be extended to Digi-Key's global customer base of 550,000 design engineers.

"Increasing demand for our low-cost semiconductors has influenced our decision to align with a highly respected global distributor," says Michael DiGangi director of business development at Global Power Technologies Group. "Having proven their success with design engineers around the world, Digi-Key is a great fit for our product line," he believes.

GPTG is a vertically integrated company and, under this structure, it expects SiC technology to be fully and economically deployed to meet market demand from industry segments that are seeking improvements in power system efficiency. SiC product cost are hence expected to reach silicon price points in the near future.

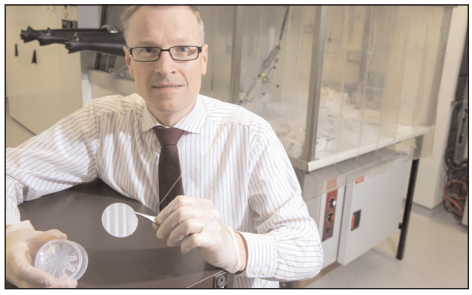
**www.gptechgroup.com**
**www.digikey.com**

# Nano-GaN Power Electronic Devices project aims to save 25% of power lost in energy conversion

## Tyndall, Illinois Institute and Queens Belfast granted €1m via US–Ireland R&D Partnership

Funded by Science Foundation Ireland (SFI), Invest Northern Ireland (InvestNI) and the US National Science Foundation (NSF) government agencies through the US–Ireland R&D Partnership program, over €1m has been awarded for the project 'Nano-GaN Power Electronic Devices'.

Led by professor Peter Parbrook and Anne-Marie Kelleher at Ireland's Tyndall National Institute (in University College Cork), Dr Miryam Arredondo-Arechavala at Northern Ireland's Queens University Belfast, and professor John Shen at the USA's Illinois Institute of Technology, the project aims to improve the efficiency of converting electrical power by up to 25% which, it is reckoned, would represent a huge saving to the consumer and could substantially reduce global carbon emissions. This issue is of immense importance to the countries involved in the project, with Ireland in particular importing nearly 90% of its energy (leaving it very perceptible to changes in international markets).



**Tyndall's professor Peter Parbrook.**

Working with gallium nitride, the researchers will look to stabilize the material so it can be used to convert high voltages to more manageable levels, without the existing high energy losses. The new technology is expected to impact particularly the development of electric and hybrid electric vehicles (EV/HEV).

"This will be the first time nanostructures using gallium nitride will be used for power electronics," says Peter Parbrook, the Stokes Professor of Nitride Materials & Devices at Tyndall. "We will attempt to bend out the material's defects, making it more stable and hence more reliable in the conversion process," he adds. "It has the potential to produce significant energy-saving efficiencies that will benefit people in the home and at work."

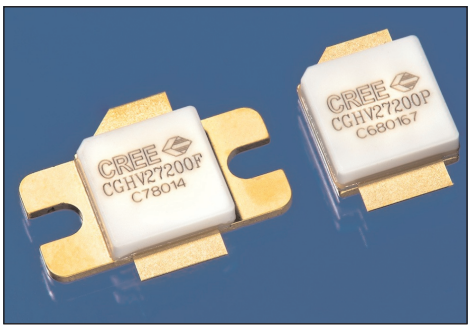
The Nano-GaN project will employ four new post-doctorate positions across the three partner research institutions.

**www.tyndall.ie**

# Cree unveils large-signal accuracy of GaN-on-SiC HEMTs

Cree Inc of Durham, NC, USA has released a new application note 'Load Pull Validation of Large Signal Cree GaN Field Effect Transistor (FET) Model' describing the accuracy of its large-signal models for RF power transistors, which allow RF design engineers to reduce power amplifier (PA) design iterations, design time, and development costs.

Cree says that its gallium nitride on silicon carbide (GaN-on-SiC) high-electron-mobility transistor (HEMT) devices are growing increasingly popular in applications including broadband amplifiers, cellular infrastructure, tactical & satellite communications and test instrumentation due to their high efficiency, high gain, and relatively simple matching characteristics. However, it is notoriously difficult to predict the large-signal performance of RF power devices like these due to self-heating and the complex dependence of nonlinearity component parameters on signal level, thermal effects, and ambient conditions. Consequently, design engineers must either develop hardware and conduct time-consuming and potentially inaccurate load-pull measurements or rely on the accuracy of large-signal models to evaluate such devices in their simulation environments.




**Cree's 100–200W GaN-on-SiC HEMTs.**

Cree says that, to put designers at ease and spare them the time and cost of conducting load-pull measurements, as well as the risk of generating defective data, it carefully compared measured and modeled data for its 100W and 200W GaN-on-SiC HEMTs. Verified using a standard load-pull system at optimal impedances over multiple frequencies, the results demonstrate the exceptional accuracy with which the firm's proprietary large-signal models represent actual device performance, it is claimed.

Further, in addition to providing RF design engineers with assurance and reducing design time and development costs related to load-pull measurements, Cree's highly accurate models also allow engineers to conduct in-depth 'what-if' analyses that can close layout links and enable faster design cycles and more first-pass design successes, the firm adds.

**www.cree.com/RF**

# GaN Systems signs distributor in Japan, Taiwan & China

GaN Systems Inc of Ottawa, Ontario, Canada, a fabless producer of gallium nitride (GaN)-based power switching transistors based on its proprietary Island Technology for power conversion and control applications, has signed an agreement with Tokyo-based electronics trading firm Value Integrated Technology Co Ltd (Vitec) to distribute its Island Technology high-power GaN devices to its customer base in Japan, Taiwan and China.

GaN Systems claims to be the first company to have developed and productized a comprehensive portfolio of gallium nitride enhancement-mode high-electron-mobility transistor (E-HEMT) power devices with current ratings from 7A to 220A, in both 650V and 100V. The firm's Island Technology die design — combined with the extremely low inductance and thermal efficiency of GaN*PX* packaging and Drive Assist technology — provides its GaN E-HEMTs with what is reckoned to be 40-fold improvement in switching and conduction performance over silicon MOSFETs and IGBTs.

**Vitec's VP semiconductor sales Akira Sasaki and GaN Systems' CEO Jim Witham.**

"Vitec has a strong presence in the consumer and enterprise segments and has links with major brand-name manufacturers," comments GaN Systems' CEO Jim Witham. "Demand for our GaN power switching transistors is growing very rapidly as manufacturers seek to design smaller, lighter and more power-efficient products in order to gain competitive edge. Multiple consumer and enterprise products designed with our GaN devices will be launched starting in 2015… Vitec and GaN Systems will expand this reach substantially," he adds.

"We are very excited about the growth of GaN E-HEMT power switch designs in consumer and enterprise applications," says Vitec's VP of marketing Osamu Komaki. "Additionally, Vitec is expanding into industrial and automotive markets, and GaN Systems has a very strong portfolio of higher-current GaN power switches for high-power applications in these sectors. GaN Systems' product portfolio also complements Vitec's existing businesses in solar inverter and infrastructure power," Komaki adds.

"Vitec's core businesses and customers complement our existing network in Asia, and Vitec also has excellent potential to expand across multiple market sectors," says Charles Bailley, GaN Systems' senior director, marketing & sales, Asia. "GaN Systems has many existing design wins with our GaN E-HEMTs, and we are looking forward to accelerating this growth further with Vitec."

**www.gansystems.com**

# EPC launches wide-pitch eGaN FETs enabling high current in small footprint

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, has introduced an eGaN FET designed with a wider-pitch connection layout. The first in a family of 'Relaxed Pitch' devices, the EPC2029 80V, 31A eGaN FET features a 1mm ball pitch. The wider pitch allows for placement of additional and larger vias under the device to enable high-current-carrying capability despite the extremely small 2.6mm x 4.6mm footprint.

Compared to a silicon power MOSFET with similar on-resistance, the EPC2029 is much smaller and has many times superior switching performance, it is claimed. The device is suitable for applications such as high-frequency DC–DC converters, synchronous rectification in DC/DC and AC/DC converters, motor drives, and class-D audio.

To simplify the evaluation process of this latest eGaN FET, the EPC9046 development board is available to support easy 'in circuit' performance evaluation. The board is a half-bridge topology with onboard gate drives, featuring the EPC2029. The board is 2" x 2" and contain two eGaN FETs using the Texas Instruments LM5113 gate driver, supply and bypass capacitors. It contains all critical components and is laid out for optimal switching performance with additional area to add buck output filter components. There are also various probe points to facilitate simple waveform measurement and efficiency calculation.

The EPC2029 power transistor is priced at $6.03 each (in 1000-unit quantities) and the EPC9046 development board is $137.75. Both are available from distributor Digi-Key Corp.

**http://digikey.com/Suppliers/us/Efficient-Power-Conversion.page**
**http://epc-co.com/epc/Products/eGaNFETs/EPC2029.aspx**
**http://epc-co.com/epc/Products/DemoBoards/EPC9046.aspx**

# HiPoSwitch project completed with development of fast, efficient normally-off GaN-on-Si power transistors

## Transistor measuring 4.5mm x 2.5mm optimized for switching 600V

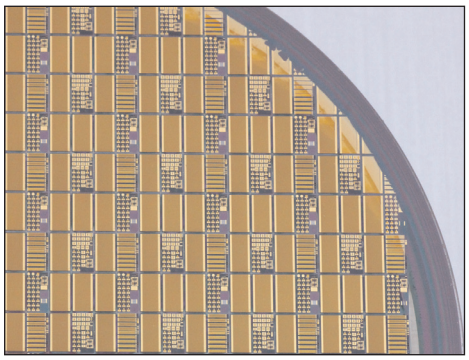
Lasting from September 2011 to end-August 2014 with a budget of €5.57m (including €3.58m of funding from the European Union), the recently completed three-year project HiPoSwitch ('High Power Switch') has developed prototype fast, high-efficiency power switches using gallium nitride (GaN) operating in enhancement-mode. Such transistors are essential for producing energy-efficient, compact and light-weight power converters that make electrical energy more usable. The market potential is reckoned to be enormous, since these converters are found in nearly every electronic device.

Power converters using GaN transistors have less than half the losses of existing technologies and make conversion efficiencies of over 98% practical. A great deal of primary energy consumption can be saved with their widespread use. "More than 3000 terawatt-hours of power are generated in Europe annually," says Joachim Würfl, head of both HiPoSwitch and the GaN Electronics business area at Berlin-based project coordinator Ferdinand-Braun-Institut, Leibniz-Institut fur Hoechstfrequenztechnik (FBH). "If you only converted a quarter of the electricity produced annually in Europe to a different level and increased the efficiency level by two percentage points, you can turn off at least two coalfired plants."

**From high-performance materials to mass-production techniques**

GaN possesses ideal physical properties for a semiconductor. "GaN components are therefore very efficient and very fast power switches. And this is because of their low on-state resistance with negligible losses," Würfl says. Higher switching frequencies also mean that passive elements of the power converter (i.e. the inductive coils and capacitors) can be considerably smaller in size (an improvement systems-wise).

GaN has already been used in microwave transistors for many years, and applied in thin layers mostly on silicon carbide (SiC) substrates. Over the last few years this technology has been further developed by FBH for 600V-rated power transistor switches. "This works well, but it is too expensive for mass markets," Würfl says. "As an alternative, the processes developed for SiC can be transferred to considerably more cost-effective but technologically more challenging silicon substrates."



**GaN on-silicon wafer.**

The advances made in the HiPoSwitch project fit with FBH's project partners. The eight European partners provided complementary competences spanning the value chain, from R&D (FBH; the Slovak Academy of Sciences, Institute of Electrical Engineering; Vienna University of Technology in Austria; and Italy's University of Padua) to industrial application (German deposition equipment maker Aixtron SE, Artesyn Austria GmbH & Co KG, Belgian epiwafer supplier EpiGaN and Infineon Technologies Austria AG).

FBH was so successful in optimizing the processing of GaN switching transistors on SiC and silicon that nearly ideal components became feasible, it is reckoned. Among others things, comprehensive investigations of drift and degradation effects carried out by University of Padua and Vienna University of Technology provided the foundation for this. The finished transistor chips were finally assembled into low-induction ThinPAK housings by Infineon in Malaysia. The single transistor measures only 4.5mm x 2.5mm and is optimized for switching 600V. It has an on-resistance of 75mΩ and handles a maximum of 120A. "We are the only ones in Europe who can manufacture these kinds of normally-off transistors at present," says Würfl.

EpiGaN — together with Aixtron — transitioned the epitaxy to silicon, so that manufacturing costs for the substrates are reduced by more than a factor of ten. At the same time, the wafer diameter is increased to 6" or even 8" (a necessary step towards cost-effective industrial production). Chip maker Infineon matched up the newly developed GaN technology with a silicon process line for industrial production of power semiconductors at its Austrian location in Villach.

Part of the project had a decidedly exploratory character, says Würfl, due to the new techniques and processes for implementing GaN power transistors. Together with colleagues at Vienna University of Technology and the Slovak Academy of Sciences, promising ideas for producing semiconductors were successfully tested, says FBH.

Positioned at the end of the value-added chain as a systems-level partner, Austria's Artesyn has developed a 3kW rectifier for telecoms applications including cellular base-stations. This unit converts line voltage to DC with an efficiency of 98%. A specialized switching topology was developed and implemented that is matched to the properties of the GaN switching transistors. Due to their broad usage, the market for such energy-saving power converters is enormous, it is reckoned, while their smaller size and weight also makes them attractive for aerospace applications.

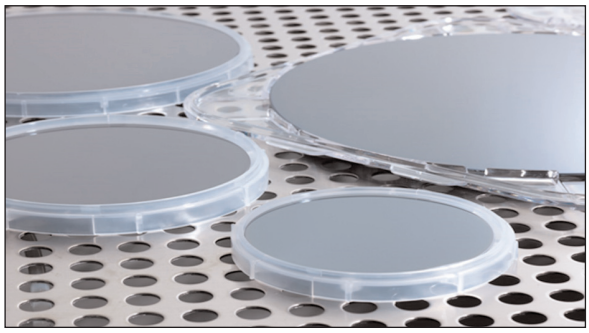
**www.fbhberlin.com**

# EpiGaN demos GaN-on-Si epiwafers at PCIM Europe

At PCIM Europe 2015 in Nuremberg, Germany (19–21 May), III-nitride epitaxial material supplier EpiGaN nv of Hasselt, near Antwerp, Belgium is demonstrating its product range of gallium nitride on silicon (GaN-on-Si) epiwafers that meet industrial specifications for high-electron-mobility transistor (HEMT) devices at 650V.

Incorporated in 2010, EpiGaN was founded by chief executive officer Dr Marianne Germain, chief technology officer Dr Joff Derluyn and chief operating officer Dr Stefan Degroote as a spin-off of nano-electronics research center Imec of Leuven, Belgium. The founders jointly developed GaN-on-Si technology on 6" and 8" wafers at Imec, part of which has been licensed to EpiGaN. In mid-2012, EpiGaN closed its first capital round of €4m, to allow it to start volume production of GaN-on-Si epi material.

The growing demand for electronic systems that offer high speed, high temperature and high power-handling capabilities has led the semiconductor industry to rethink the choice of device materials, says EpiGaN. Due to its unique characteristics such as lower on-resistance, higher breakdown voltage, higher operating temperature and higher switching frequencies, gallium nitride has become the preferred candidate for future power conversion systems, the firm adds.



**EpiGaN's GaN-on-silicon epiwafers.**

EpiGaN produces GaN-on-Si and GaN-on-SiC epiwafers for integrated device manufacturers (IDMs) to fabricate high-performance power switching systems (up to 600V) as well as RF power devices for millimeter-wave applications. EpiGaN has patented its GaN epiwafer technology to enable users to position themselves in new and rapidly growing market segments.

EpiGaN says that a competitive advantage of its GaN-on-Si (up to 200mm diameter) and GaN on SiC epiwafers — which are produced in metal-organic chemical vapor deposition (MOCVD) reactors — is that they are compatible with the existing standard Si-CMOS production infrastructure. IDMs can hence continue to utilize their investment in silicon processing lines.

This advantage arises from in-situ silicon nitride (SiN) layering — a key concept of EpiGaN's epiwafer technology — which provides what is claimed to be superior surface passivation and device reliability, and enables contamination-free processing. In-situ SiN structuring allows the use of pure AlN layers as a barrier material, with the resulting heterostructures having a sheet resistance below 250Ω/sq.

EpiGaN says that GaN technology is beginning to be introduced to numerous high-power applications such as industrial, consumer and server power supplies, as well as solar, AC drive and UPS (uninterruptible power supply) inverters, and hybrid and electric vehicles (HEVs).

GaN is also suited to RF applications such as cellular base-stations, radars and cable TV infrastructure in the networking, aerospace and defense industries, since it offers high breakdown strength, low noise figures and high linearity.

"Even best-in-class silicon devices are approaching their theoretical limits," says co-founder & CEO Marianne Germain. "We supply industry-leading GaN-on-Si and GaN-on-SiC epiwafers to the semiconductor industry to build the next generation of power switching and RF power systems, offering better power handling, higher conversion efficiency and lower volume and weight."

**www.epigan.com**

# MACOM showcases product and technology portfolio

At the Electronic Design Innovation Conference (EDI CON 2015) in the China National Convention Center, Beijing (14–16 April), M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) showcased a broad portfolio of new products for multi-market, aerospace, defense and networking applications.

Products on show included the following:

- the highest-power gallium nitride (GaN)-in-plastic-packaged power transistors;
- integrated GaN modules for L- and S-band frequencies;
- the highest-power E-band MMIC power amplifier;
- directional power detectors in ultra-small 1.5mm x 1.2mm plastic packages;
- high-power amplifiers for wireless backhaul;
- high-power switch family; and
- a broad catalog of 3000+ standard products.

In addition, MACOM staff presented a gallium nitride workshop on 'Commercialization of GaN for Cost-Effective Applications', as well as participating in two panel sessions covering the topics 'GaN' and '5G'.

**http://ediconchina.com**
**www.macom.com**

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# NI AWR showcases Design Environment software

At the Electronic Design Innovation Conference (EDI CON) in Beijing, China (14–16 April), NI AWR Corp of El Segundo, CA, USA showcased NI AWR Design Environment software in four 20-minute talks as well as one 40-minute workshop.

The NI AWR software presentations included the following:

- 'NI-AWR Integrated Framework for Radar Design';
- 'Implementation of a ZigBee Circuit Reference Design';
- 'Transceiver Module & Multi-Element Phased Array Design for 5G';
- 'Design Methodology for GaAs MMIC/Basestation PA';
- 'Resolving Cavity Resonance Effects in Microwave Circuits Workshop'.

Also, NI AWR software demonstrations at EDI CON included the following:

- 'NI AWR Design Environment V11 – What's New';
- 'Microwave Office for MMIC, RF PCB and Module Design';
- 'Visual System Simulator for Wireless Communications and Radar Systems'; and
- 'Analyst and AXIEM EM Technology for Interconnect Analysis'.

The NI AWR Design Environment software portfolio includes RF/microwave electronic design automation (EDA) tools such as Visual System Simulator for system design, Microwave Office/Analog Office for microwave/RF circuit design, and AXIEM and Analyst for electromagnetic analysis. NI AWR software tools can help design engineers to reduce development time and cost for components, circuits, systems and subsystems employed in wireless, high-speed wired, broadband, aerospace and defense, and electro-optical applications.

**http://ediconchina.com**
**www.ni.com/awr**

## NI AWR application note demos Design Environment load-pull simulation for designing wideband high-efficiency power amplifiers

NI AWR has announced an application note 'Using NI AWR Design Environment Load-Pull Simulation for the Designer of Wideband High-Efficiency PAs' that explores the design of power amplifiers leveraging load-pull technology within Design Environment software, specifically Microwave Office.

Using a Cree CGH40010F gallium nitride (GaN) high-electron-mobility transistor (HEMT) in a Class F PA at 2000MHz as the example circuit, the application note details how power-added efficiency (PAE) is maximized by optimizing source and load pull at the fundamental frequency, plus second and third harmonics.

Additionally, the ability of the load-pull technique to inspect transistor voltage and current waveforms helps users to gain confidence in their high-perform-

# Keysight showcases software, handheld RF/microwave products at WAMICON

Keysight Technologies Inc of Santa Rosa, CA, USA (which provides electronic measurement instruments and systems and related software used in the design, development, manufacture, installation, deployment and operation of electronic equipment) demonstrated new software and handheld RF/microwave capabilities at the 16th annual IEEE Wireless and Microwave Technology Conference (WAMICON 2015) in Cocoa Beach FL, USA (13–14 April).

As a gold sponsor of WAMICON, Keysight experts discussed everything from circuit-level modeling through system verification for general RF, microwave, millimeter-wave for 4G, emerging 5G communications and aerospace/defense.

Keysight experts will demonstrate:

**Software**

- ADS 2015, with its new capabilities and productivity improvements, including electro-thermal simulation, improved electromagnetic (EM) simulation, and IC and module/laminate design flow improvements (layout, DRC and LVS)
- EMPro, which now provides time- and frequency-domain 3D EM solvers in a full 3D modeling environment tightly integrated with ADS and Genesys.
- SystemVue system-level design and verification, with its new high-performance design personalities for wireless/4G/5G, radar/electronic warfare and next-generation verification

**Handheld RF/Microwave Tools**

- FieldFox, a combination spectrum analyzer, vector network, analyzer, power meter and independent continuous wave source with other RF/microwave functionalities – all contained in a rugged, lightweight package, with capabilities that make it ideal for RADAR, SATCOM, military and commercial communication systems.

Keysight experts also provided attendees with information on Keysight EEsof EDA University Educational Support Programs, explaining how these can enhance school curriculum and enrich the overall student learning experience.

**www.wamicon.org**
**www.keysight.com/find/eesof**

# IBM PDKs support RFIC interoperability between the latest Keysight ADS electronic design automation software and Cadence Virtuoso design platform

## Process design kit for silicon germanium 5PAe BiCMOS available; extension to RF silicon-on-insulator underway

IBM is offering specialty foundry clients a new set of interoperable process design kits (PDKs) for use with Keysight Technologies' Advanced Design System (ADS) EDA software and Cadence Design System's Virtuoso custom design platform, providing users access to a new silicon RFIC interoperability feature available in ADS 2015.01.

IBM says that its silicon-based specialty foundry technologies — RF CMOS, RF silicon-on-insulator (SOI), and silicon germanium (SiGe) — are optimized to help chip suppliers deliver differentiated RF front-end solutions in increasingly sophisticated devices. The challenges of high-frequency and large-signal design in such devices have increased the need for an interoperable co-design flow that exploits the best of both design platforms and that can help maximize designer productivity.

The ADS silicon RFIC interoperability feature simplifies this process by enabling users to edit and simulate schematic designs created by the Virtuoso environment in ADS, and vice versa. The same is true for layout where, for example, a user can open a Virtuoso IC layout cell view in ADS, instantiate the cell within a package or module, and then run an electromagnetic simulation on the complete design to validate its overall system performance.

"Currently, we provide separate Virtuoso and ADS PDKs to our foundry customers. With the new silicon RFIC interoperability, we will now have a single PDK that supports both platforms," says Ned Cahoon, Specialty Foundry business development executive at IBM. "The first interoperable PDK is now available for SiGe 5PAe, our 350nm SiGe BiCMOS process geared for power amplifiers, and work to extend this support to our most advanced RF SOI technologies is underway. Both technologies have gained significant industry traction for cellular and WiFi front-end module applications, and the new silicon RFIC interoperability feature can offer clients using these technologies additional design flexibility," he adds.

"Customers can now access ADS' dedicated RF design flow support based on a standard Virtuoso PDK," says Volker Blaschke, foundry program manager at Keysight EEsof EDA (which supplies electronic design automation software for microwave, RF, high-frequency, high-speed digital, RF system, electronic system level, circuit, 3D electromagnetic, physical design and device-modeling applications). "The new Silicon RFIC Interoperability is crucial for IC design and enables a true RFIC/package/board co-design flow. This interoperable flow increases designer productivity and flexibility, and reduces time-to-tape-out for silicon-based RF designs."

**www.ibm.com/us/en**
**www.keysight.com/find/eesof-ads2015.01**

# Solar-Tectic awarded patent for low-temperature thin-film deposition on low-cost substrates

The United States Patent and Trademark Office (USPTO) has issued Solar-Tectic LLC of Briarcliff Manor, NY, USA with a major patent (with over 50 claims) for a wide range of technologies including the growth of single-crystal, highly textured or large-grained semiconductor films on inexpensive substrates, such as ordinary glass.

Solar-Tectic is a thin-film specialist with a primary focus on developing single-crystal or highly textured semiconductor films on glass or other low-cost substrates such as metal tapes. Its technology was invented by the late Dr Praveen Chaudhari, winner of the 1995 US Medal of Technology and Innovation, and have applications in various industries such as solar, displays and LEDs.

The US patent (12/774,465) 'Methods of Growing Heteroepitaxial Single Crystal or Large Grained Semiconductor Films and Devices Thereon' discloses a modified vapor-liquid-solid (VLS) thin-film (TF) growth technique that, for the first time, allows for low-temperature deposition of what is claimed to be exceptionally high-quality semiconductor films from a variety of materials such as silicon, germanium and gallium nitride (GaN) on inexpensive substrates.

Solar-Tectic says that the cost-effective nanowire-like but thin-film growth process involving eutectic alloys is well suited to large-scale industrial applications and can be carried out using existing commonly used deposition processes, such as electron-beam deposition, chemical vapor deposition (CVD) etc.

**www.solartecticllc.com**
**www.e2tac.org/e2tac/Home.aspx**

# KLA-Tencor extends 5D patterning control solution with overlay and film process control systems

Process control and yield management solutions provider KLA-Tencor Corp of Milpitas, CA, USA has introduced two metrology systems — the Archer 500LCM and SpectraFilm LD10 — that support the development and production of 16nm and below IC devices.

The Archer 500LCM overlay metrology system provides accurate overlay error feedback through all stages of the yield ramp, helping chipmakers resolve overlay issues associated with innovative patterning techniques such as multi-patterning and spacer pitch splitting, says the firm. Through reliable, precise measurement of film thickness and stress, the SpectraFilm LD10 film metrology system enables qualification and monitoring of the films and film stacks used in fabricating FinFETs, 3D NAND and other leading-edge devices. The new systems are key products in KLA-Tencor's 5D patterning control solution, which drives optimal patterning results through the characterization and monitoring of fab-wide processes.

"We have closely collaborated with our customers to understand their challenges in optimizing pattern overlay, critical dimensions and films quality," says Ahmad Khan, group VP of KLA-Tencor's Parametric Solutions Group. "Across foundry, logic and memory, our customers require production-capable metrology systems that produce the data necessary to decipher complex process issues," he adds. "Full-featured metrology systems, such as our new Archer 500LCM and SpectraFilm LD10 platforms, implement multiple innovations that facilitate measurement flexibility across a broad range of applications, helping our customers drive current-node yield and investigate next-node technologies."

With both imaging and unique laser-based scatterometry measurement technologies, the Archer 500LCM overlay metrology system offers a wide range of measurement options and supports a diverse range of overlay measurement target designs, such as in-die, small pitch and multi-layer targets. KLA-Tencor says that this flexibility enables cost-effective generation of accurate overlay error data that can be used for scanner corrections or for identification of inline excursions, helping engineers to determine when to re-work wafers or adjust processes to meet strict patterning requirements. Multiple Archer 500LCM systems are in use at foundry, logic and memory manufacturers worldwide, where they provide an independent assessment of overlay performance for advanced development and high-volume production.

The SpectraFilm LD10 introduces a laser-driven plasma light source, producing reliable, high-precision film measurements for a broad range of film layers, including the thin, multilayer film stacks used in forming complex device structures such as FinFETs. Characterization of the thick, multilayer film stacks found in 3D NAND flash devices is enabled with a new infrared-based subsystem. With a significant increase in throughput compared to the previous-generation Aleris platform, the SpectraFilm LD10 maintains high productivity while qualifying and monitoring the increased number of film layers associated with multi-patterning and other leading-edge fabrication techniques. Multiple SpectraFilm LD10 orders have been placed for use in advanced IC development and production, says the firm.

The Archer 500LCM and SpectraFilm LD10 systems join the SpectraShape 9000 critical dimension and device profile metrology platform, K-T Analyzer advanced data analysis system and many other process control systems in supporting KLA-Tencor's 5D patterning control solution. The company says that, to maintain the high performance and productivity demanded by leading-edge IC manufacturing, the Archer 500LCM and SpectraFilm LD10 systems are backed by its global, comprehensive service network.

**http://kla-tencor.com/5d-patterning-control-solution.html**

# IQE presents papers on antimonide-based IR materials at SPIE Defense, Security and Sensing Technologies conference

At SPIE Defense, Security and Sensing Technologies conference (DSS 2015) in Baltimore, MD, USA (21–23 April), epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK presented a series of three invited papers on recent key developments in advanced infrared technologies and the commercialization of materials:

- molecular beam epitaxy (MBE) growth of antimony (Sb)-based bulk nBn infrared photodetector structures on ≥6" gallium antimonide (GaSb) substrates;
- growth and characterization of ≥6" epitaxy-ready GaSb substrates for use in large-area infrared detector applications; and
- a study of doping influences on transmission of large-diameter GaSb substrates for long-wave (LWIR) to very-long-wavelength (VLWIR) infrared applications.

**http://spie.org/x6765.xml**
**www.iqep.com**

# Riber reports €3.8m loss for 2014 on sales down 29%

For full-year 2014, Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has reported revenue of €16.6m, down 29% on 2013's €23.5m due to a significant deterioration in the market.

Of this, MBE systems revenue was €9.3m, down 45% on 2013's €16.9m, due primarily to the contraction in research budgets available during first-half 2014. In second-half 2014, Riber recorded €5.8m of orders and €7.2m of billing for the systems business. In total, 11 MBE systems were billed to research customers (down from 17 in 2013).

Revenues for services & accessories (€6.1m, up 17% on €5.3m) and cells & sources (€1.1m, down 17% on €1.3m) are collectively up 10% on 2013. Growth in sales to research labs is benefiting from the development of business in refurbishing systems. Alongside this, Riber has continued moving forward with its organic LED development plan, with pilot linear cells sold in Korea during the second half of the year.

Faced with the contraction in revenues and a challenging market, gross profit has halved from €7.5m in 2013 to €3.8m in 2014, representing gross margin of 22.6% of revenue (down from 32.2% in 2013).

Sales & administrative costs are down 11% year-on-year, factoring in the savings measures rolled out by the firm at the beginning of 2013 to reduce its fixed costs. Alongside this, in order to support its development, Riber maintained a high level of R&D investment in 2014. In this context, net income showed a loss of €3.8m for 2014, compared with a €0.2m profit in 2013.

"Whilst our results for the year were affected by the marked contraction in MBE markets, Riber significantly improved its cash position at the end of 2014 [nearly €2m, an improvement on €1.7m at the end of 2013 and the low of –€0.9m at the end of June 2014] thanks to its rigorous operational management," says Frédérick Goutard, chairman of the executive board.

Riber says that, in a difficult environment marked by persistently sluggish industrial markets, it has strengthened its commercial actions in the research sector, its traditional core business and the most resilient segment, while ramping up its services & accessories sales.

"Orders picked up again during the second half of the year, which is encouraging: this confirms the upturn in demand for research, Riber's main customer base," says Goutard. "Our development strategy is positioning us to capitalize on the markets' expected recovery: in 2015, the acquisition of MBE Control Solutions [of Santa Barbara, CA, USA] will further strengthen our market share in the USA, and our continued diversification into OLEDs will also drive us forward as we return to growth."

**www.riber.com**

# University of Cambridge selects Veeco's Propel MOCVD system for R&D on GaN-on-Si power electronics and LEDs

The UK's University of Cambridge has ordered Veeco's Propel Power gallium nitride MOCVD system for GaN-on-silicon power electronics and LED research and development.

The system will be installed at the Cambridge Centre for Gallium Nitride (based in the Department of Materials Science and Metallurgy), which is headed by professor Sir Colin Humphreys. The center is said to be one of few places in the world to have, in close proximity and on the same site, GaN growth equipment, extensive advanced electron microscopy characterization facilities, advanced x-ray diffraction characterization facilities, atomic force microscopy, photoluminescence (PL) for measuring optical properties, Hall effect equipment for measuring electrical properties, and basic theory for understanding in detail physical properties.

Since 2000, Humphreys has carried out extensive studies of InGaN quantum wells used in LED development. GaN-on-Si technology is considered to be a potential cost-saving alternative to GaN-on-sapphire technology.

"After careful consideration, we concluded that Veeco's Propel MOCVD system provides a distinct advantage over other systems to improve and expand our GaN-on-silicon R&D capabilities," says Humphreys, director of research at the University of Cambridge. "Gallium nitride is the most important semiconductor material since silicon for power electronics and LEDs. The Propel PowerGaN platform enables the growth of high-performance device structures in a clean and stable process environment with low particle defects," he adds.

Featuring a single-wafer 200mm reactor platform capable of processing 6" and 8" wafers and designed specifically for the power electronics industry, the new Propel Power GaN MOCVD system deposits GaN films for the production of highly efficient power electronic devices. The single-wafer reactor is based on Veeco's TurboDisc MOCVD design and includes the new IsoFlange and SymmHeat technologies that provide homogeneous laminar flow and uniform temperature profile across the entire wafer. Users can easily transfer processes from Veeco's K465i and MaxBright MOCVD systems to the Propel Power GaN platform.

"The Propel PowerGaN single-wafer system enables the development of highly efficient GaN-based power electronic devices that we believe will accelerate the industry's transition from R&D to high-volume production," says Jim Jenson, senior VP, Veeco MOCVD operations. "Since its introduction [last November], our new Propel PowerGan system has quickly gained attention for its outstanding performance," he adds. "We are very excited to have our technology recognized and adopted by such a distinguished university that is at the forefront of GaN-on-silicon development."

According to market analyst firm IHS Research, the GaN power electronics device market is expected to rise at a compound annual growth rate (CAGR) of more than 90% from 2014 to 2020 as new devices are applied to power supplies, consumer electronics, automotive and other applications.

**www.gan.msm.cam.ac.uk**
**www.veeco.com/Propel**

# Former Solectron CFO nominated for appointment to Veeco's board

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that Susan Wang has been nominated for appointment to its board of directors. Her appointment is subject to shareholder approval, which is being sought at the firm's 2015 annual meeting of stockholders (scheduled to occur on 13 May).

Wang served as executive VP & chief financial officer of Solectron Corp (a global provider of electronics manufacturing services) until her retirement from Solectron in 2002. She joined Solectron as director, finance, in 1984 and served as CFO from 1989.

Prior to joining Solectron, Wang held financial and managerial positions at Xerox Corp, Westvaco Corp and Price Waterhouse & Co. She has served on several public and private company boards, and is currently on the board of Cirrus Logic Inc (a supplier of high-precision analog and digital signal processing components) as well as the boards of healthcare-related companies Nektar Therapeutics and Premier Inc. In addition, within the past five years, Wang served on the boards of Altera Corp (a programmable semiconductor company), RAE Systems Inc (a developer of sensory technology for hazardous materials), and Suntech Power Holdings Co Ltd (a solar energy company).

Veeco says that, over the course of her career, Wang has played an integral role in several significant and complex governance matters, and has served on the audit committee (including as audit committee chair) on several of the boards she has joined. She has extensive expertise in financial, operational and strategic matters, together with senior management and public and private board experience.

"We look forward to benefiting from her significant experience as a valued member of the team," comments Veeco's chairman & CEO John R. Peeler.

# KaiStar orders Veeco EPIK700 MOCVD systems

Veeco Instruments has received an order for multiple TurboDisc EPIK700 gallium nitride MOCVD systems from KaiStar Lighting Co Ltd of Xiamen, China (a joint venture between Taiwan's Epistar Corp and China's Shenzhen Kaifa Technology Co Ltd that began LED production in 2012). The systems will be used to ramp production of LEDs for general lighting.

"As an early adopter of Veeco's new EPIK700 MOCVD system [launched last September], we have seen its potential for significant production and cost-saving benefits for LED manufacturing," says Epistar's president Dr MJ Jou. "Late last year, we were able to seamlessly transfer our LED process and rapidly qualify the EPIK700 system for LED production in our Taiwan fab. We have now decided to expand our LED production at KaiStar in China with this new, highly productive MOCVD system."

"Since its formation, KaiStar has been an important Veeco customer," says Jim Jenson, senior VP, Veeco MOCVD operations. "Their decision to use the award-winning EPIK700 reflects the performance, reliability and production-readiness of our newest MOCVD system," he adds. "We expect that 2015 will be the crossover year in which shipments of LEDs for general lighting will surpass shipments of LEDs for backlighting, with the Epistar companies being a significant driver of that trend."

Based on Veeco's TurboDisc technology and available in one- and two-reactor configurations, the EPIK700 MOCVD system is reckoned to be the LED industry's highest-productivity MOCVD system, reducing cost per wafer by up to 20% compared with previous generations. The system features technologies including the IsoFlange center injection flow and TruHeat wafer coil technologies, which provide homogeneous laminar flow and uniform temperature profile across the entire wafer carrier. These innovations produce wavelength uniformity to drive higher yields in a tighter bin. Veeco says the EPIK700 system offers a 2.5x throughput advantage over other systems due to its large reactor size. Designed for mass production, it accommodates 31x4", 12x6" and 6x8" wafer carrier sizes. Users can transfer processes from existing TurboDisc systems to the EPIK700 MOCVD platform, enabling quick-start LED production. Because of the flexible EPIK700 MOCVD platform, more upgrades, added benefits and future enhancements will continue to differentiate the system, reckons Veeco.

**www.kaistar.com.cn**
**www.veeco.com/mocvd**

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# Aixtron acquires PECVD-based organic LED thin-film encapsulation firm PlasmaSi

## Process to be integrated into OLED cluster for customer demonstration

Deposition equipment maker Aixtron SE of Herzogenrath (near Aachen), Germany has acquired privately held PlasmaSi Inc of Fremont, CA, USA — which provides low-temperature silicon nitride plasma-enhanced chemical vapor deposition (PECVD) systems — for $16m in cash.

Founded in 2009, PlasmaSi enables the encapsulation of organic thin-films by depositing ultra-thin and flexible barrier films through its proprietary OptaCap technology. The films are well suited for next-generation organic light-emitting diode (OLED) display products including mobile phones, hand-held devices, tablets, wearables and large-screen HDTV. While initially designed and targeted at those applications, PlasmaSi's technology can also be used to manufacture large-area OLED lighting products as well as to address future opportunities in encapsulation markets. Aixtron aims to integrate PlasmaSi's thin-film encapsulation process into its existing OLED cluster for customer demonstration purposes.

"While increasingly expanding our business focus towards OLED in the coming years, we were looking to broaden our technology portfolio as well as to strengthen our customer access by adding PlasmaSi to our product portfolio," says Aixtron's president & CEO Martin Goetzeler. "Thin-film encapsulation is an essential process step for OLED high-volume manufacturing, specifically for flexible devices. In combining our OVPD [organic vapor phase deposition] technology with PlasmaSi's innovative approach, we will be able to add significant value in the production of flexible OLED applications," he adds.

"We are delighted that we have found a strong partner in Aixtron, a company that has an impressive track record in the successful commercialization of deposition technologies in the semiconductor equipment industry," comments PlasmaSi's CEO & chairman Adam Kablanian. "Therefore, joining forces with Aixtron is the best option for us and we are now looking forward to take our technology to the next level together," he adds. "We will strongly benefit from Aixtron's R&D and production capabilities as well as from its worldwide sales, service and support network."

**www.aixtron.com**

# Aixtron chooses Jordan Valley's QC3 high-resolution x-ray diffraction system for MOCVD process metrology

X-ray-based in-line metrology and defect detection tool maker Jordan Valley Semiconductors Ltd (JVS) of Migdal Haemek, Israel has received a strategic order for its QC3 high-resolution x-ray diffraction (HR-XRD) system for strain and thin-film metrology from the US R&D Center in Sunnyvale, CA, of deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany, following an extensive 6-month-long evaluation.

QC3 and QC-Velox systems are metrology and characterization tools for metal-organic chemical vapor deposition (MOCVD) chamber qualification, used for epitaxial growth of gallium nitride (GaN) and III-V semiconductors structures. Since the QC3 system's introduction in 2010, it has become the tool of record for both production monitoring and R&D in the areas of GaN-based LEDs and other devices, it is claimed.

**Jordan Valley's QC3 HR-XRD system.**

"This selection represents the customer's confidence in Jordan Valley's ability to provide valuable metrology solutions for their demanding applications, trusting the first-principle x-ray based metrology," says Jordan Valley's CEO Isaac Mazor.

The QC3 provides HR-XRD metrology with high throughput and precision in a very compact package, says the firm. The addition of its RADS analysis software enhances productivity and makes the characterization of complex epilayers routine and automatic, it adds. "By choosing the Jordan Valley QC3 platform, Aixtron Inc, the German group's US-based affiliate, acknowledged the product robustness, performance and extendibility to future technology challenges," says JVUK manager Dr Paul Ryan. "The Jordan Valley QC3 can be a strong contributor to the rapid and advanced deposition technology development," he believes.

**www.jvsemi.com**
**www.aixtron.com**

# k-Space sees Q1 sales up 34% year-on-year for BandiT temperature monitoring system

k-Space Associates Inc of Dexter, MI, USA (which supplies thin-film metrology tools for semiconductor, compound semiconductor and solar markets) has reported revenue for its patented kSA BandiT wafer and film temperature monitoring system up 34% for first-quarter 2015 over first-quarter 2014.

The kSA BandiT technology uses the inherent temperature dependence of a semiconductor's bandgap to directly measure temperature. Due to its immunity to sources of measurement errors typical with pyrometers and its ability to measure at temperatures below 200°C, the system is a preferred temperature monitoring tool for both research facilities and epi-wafer manufacturers, claims the firm.

"Customers place a high value on the information kSA BandiT can provide in real time during growth, especially in the low-temperature regime where other temperature measurement methods fail," says product development engineer Barry Wissman. "We are selling systems configured to measure a wide range of semiconductor band-gaps, from GaN at approximately 380nm to CdTe at approximately 830nm, to our best-selling systems that operate in the near-infrared for materials like GaAs and InP."

The BandiT has lately been highlighted in several publications, including Journal of Electronic Materials, Journal of Crystal Growth, Journal of Vacuum Science and Technology B, and Optics Express. In these articles, researchers worked with materials such as GaAs, InGaAs, InAs, InAlAs and HgCdTe, allowing real-time measurement of variables such as temperature, film thickness, surface roughness, and growth rate.

In 'Evaluation of HgCdTe on GaAs Grown by Molecular Beam Epitaxy for High-Operating-Temperature Infrared Detector Applications' in the March issue of Journal of Electronic Materials, Dr Jan Wenisch et al of AIM INFRAROT-MODULE GmbH note that, for growth of HgCdTe on GaAs, "it was observed that an increase in growth temperature of only 2°C led to an increase in the cadmium fraction of almost 5% for Cd-rich compositions," and that "the strong influence of growth temperature [on Cd fraction] shows that it is especially important to have an accurate and reliable temperature-measurement system." This result demonstrates the power of the kSA BandiT for reliable, reproducible temperature measurements below 200°C, concludes k-Space.

**http://link.springer.com/article/10.1007%2Fs11664-015-3713-9**
**www.k-space.com**

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LAYTEC Knowledge is key

# ClassOne partners on ECD applications lab in Shanghai

## Sinyang buys ClassOne electroplating tools for China customer demos

ClassOne Technology of Kalispell, MT, USA, which manufactures wet-chemical processing equipment (especially for cost-conscious emerging markets and users of smaller substrates), has signed a joint electrochemical deposition (ECD) applications lab agreement with China's Shanghai Sinyang Semiconductor Materials Co Ltd (which specializes in electronic chemicals for semiconductor manufacturing, advanced packaging, solar energy and other new manufacturing industries).

As a supplier of ECD chemicals, Sinyang is purchasing ClassOne electroplating equipment and will be providing a site for demonstrating ClassOne's tools in the Chinese marketplace. SPM International Ltd, ClassOne's representative in China, will also be providing product support and process assistance.

"This collaborative lab will be the first of its kind in the region," believes ClassOne Technology's president Byron Exarcos. "Now, in a single location, users will be able to see the advanced performance of ClassOne's electroplating tools and Sinyang's electroplating chemicals and also be able to evaluate processes. It allows us to provide a complete solution — and a significant convenience — to users throughout the region," he adds.

**The Solstice LT electroplating system (left) and Trident Spin Rinse Dryer (right).**

"We are looking forward to working with customers on the Solstice LT plating system because it is a high-performance tool and will provide an excellent real-world laboratory for ongoing enhancement of our chemicals," says Sinyang vice president Dr Wang Su.

"The new working arrangement will also enable us to provide direct input to ClassOne as they develop future generations of wet processing equipment."

Sinyang is purchasing ClassOne's Solstice LT electroplating system and Trident Spin Rinse Dryer (SRD). The Solstice LT is a two-chamber plating development tool designed for <200mm wafers. In Sinyang's applications, one chamber will be dedicated to copper plating and the second to nickel plating, with the Trident SRD servicing both process streams, providing significant flexibility while reducing cycle time and streamlining process development. The new equipment will be installed at the Sinyang lab facility in Shanghai, which is scheduled to begin live demonstrations in late May. The lab will be able to plate virtually all metals except gold, and it can also cross-reference with all chemicals for comparison benchmarks.

**www.sinyang.com.cn**

# Taiwan's AWSC buys ClassOne's Solstice S8 electroplater

ClassOne has delivered a fully automated Solstice S8 electroplating system to gallium arsenide foundry Advanced Wireless Semiconductor Company (AWSC) of Tainan Science-based Industrial Park, Taiwan, to be used for volume manufacturing processes such as lead-free wafer-level packaging (WLP) and through-wafer vias (TWV) for RF and other microdevices.

"Foundries often need to weigh performance and price carefully, and we believe the S8 strikes the right balance," says ClassOne's VP of technology Kevin Witt. "For example, the Solstice can enable a customer to move copper pillar, nickel, tin bump, and Cu backside via production from several wet benches onto a single automated tool that gives a better process result and higher productivity. In addition, ClassOne supports customers with process development and deployment every step of the way," he adds.

"Solstice fills a void in the market between wet benches on the low end and the large, expensive 300mm plating systems on the high end," says Win Carpenter, ClassOne's VP of global sales. "The Solstice S8 was designed to provide advanced plating performance at a reasonable cost for everyone who manufactures on 200mm and smaller substrates. Those users include many emerging markets such as MEMS, LEDs, RF, power, and sensors."

The Solstice electroplating systems were introduced in 2014 and are available in fully automated 4- and 8-chamber configurations that deliver up to 75 wafers per hour (wph) of capacity. The Solstice family handles substrates up to and including 200mm, whether transparent or opaque, and performs key processes such as electroplating of various metals and alloys. Solstice pricing is less than half that of similarly configured 300mm plating systems outfitted for 200mm from the large manufacturers, it is claimed.

**www.awsc.com.tw**
**www.classone.com/products**

# Rubicon appoints GTAT's former VP of crystal growth systems development as chief technology officer

Rubicon Technology Inc of Bensenville, IL, USA (which makes monocrystalline sapphire substrates and products for the LED, semiconductor and optical industries) has appointed Dr Christine Richardson as chief technology officer. She will take responsibility for the ongoing development of Rubicon's technology platforms and will lead R&D activities.

Richardson has over 15 years of senior technology leadership experience and was formerly VP of Crystal Growth Systems Development & Engineering at GT Advanced Technologies (GTAT). Earlier experience includes leading photovoltaic technology development for GTAT; senior director of Advanced Process Development for Evergreen Solar; and process development engineering for Advanced Micro Devices.

Richardson has a Ph.D. in Applied Physics from the California Institute of Technology (CalTech), M.S. degrees in Applied Physics and Materials Science and Engineering from Harvard University and Stanford University respectively, and a B.S. in Materials Science and Engineering from Johns Hopkins University.

"Technology is the heart of everything we do — it's the key to reducing product costs, maintaining our quality leadership, and developing industry-changing new sapphire products," says CEO Bill Weissman. "Proven leadership skills and deep technical knowledge will help us optimize our current technology and accelerate the introduction of new products."

**www.rubicontechnology.com**

# Cascade adds Lake Shore as MeasureOne partner

Cascade Microtech Inc of Beaverton, OR, USA, which provides equipment enabling precision contact, electrical measurement and test of wafers, ICs, IC packages, circuit boards and modules as well as MEMS, 3D TSV and LED devices, has announced its latest MeasureOne solutions partner as Lake Shore Cryotronics Inc of Westerville, OH, USA, which makes scientific sensors, instruments and systems for measurement and control under extreme temperature and magnetic field conditions.

The collaboration aims to accelerate the time to first device measurement for a collective customer base where early-stage research typically requires testing in extreme cold and magnetic flux. The MeasureOne partnership enables the sales and service teams from both companies — now cross-trained across each other's product lines — to quickly guide the customer to the best probe station to address their needs. Validated measurement solutions from both firms aim to deliver confidence in performance and reliability.

While both firms offer cryogenic probe stations, their respective platforms differ in functionality and address different stages of the R&D lifecycle. Lake Shore's probe stations are used in the earliest phases of new semiconductor and magnetic materials R&D. Its platform features align with the limited size and number of samples being measured, as well as the need to probe at the lowest possible temperatures (<10K) and within high magnetic fields (often over 2T), where sample stages are generally fixed in position. Cascade probe stations are focused on the next phases of device development, where multiple copies of devices have now been constructed. Its platform features align with a larger wafer size and number of devices, as well as a need to replicate measurements across those devices. Sample stages are moveable in a manual or semi-automated fashion.

"Customers begin their research of new semiconductor and magnetic materials at very low temperatures and high fields, where our probe stations excel," says Lake Shore's president & CEO Michael Swartz. "This partnership offers customers a smooth transition from the research lab into full-scale semiconductor device development, combining the significant complementary expertise of both companies," he adds.

"This latest MeasureOne alliance connects customers with best-of-breed cryogenic measurement solutions that extend all the way from basic materials research in the lab to wafer-scale production," says Cascade's president & CEO Michael Burger. "We're both fully acquainted with each other's capabilities and understand just where to position customers within the overall space that we jointly address," he adds. "Together we can deliver a level of technical know-how second to none for cryogenic probing, even in high magnetic fields."

The collaboration is expected to bolster the product lines of both firms through shared research and technology. Cascade's RF to Terahertz probing expertise is reckoned to be a natural fit with Lake Shore's expertise on measurements near the bottom of the Kelvin scale and in very high magnetic fields. Similarly, Lake Shore's cryogen-free technology and magnetic field expertise may have future applicability in Cascade's highly automated cryogenic probe stations.

Cascade's MeasureOne program is dedicated to identifying and collaborating with suppliers offering complementary technology and products that represent the best of breed in any particular category. The consolidated approach aims to offer highly optimized solutions to the challenges of test & measurement in a wide variety of environments.

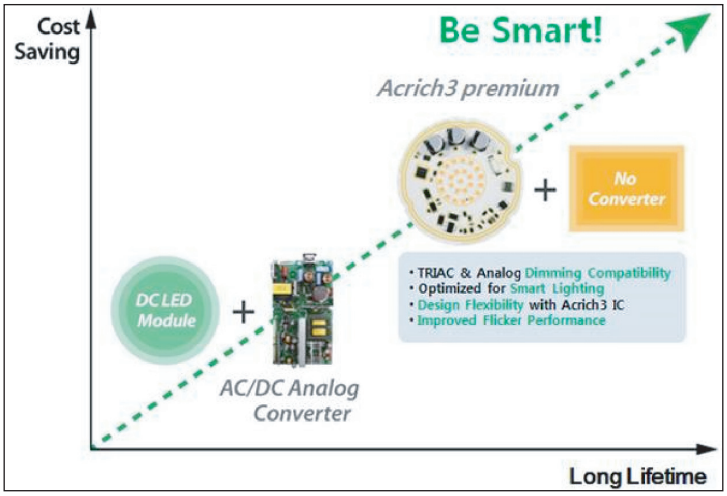
**www.cascademicrotech.com**
**www.lakeshore.com**

# Seoul Semiconductor launches Acrich3 premium line with improved flicker performance

Seoul Semiconductor has launched Acrich3 premium LED modules with improved flicker performance for a wide range of residential and commercial lighting applications.

Acrich3 premium expands on the firm's Acrich3 technology, which has a high power factor (>0.97), low total harmonic distortion (THD<15%) and a flicker index lower than 0.12. Like all Acrich3 solutions, premium modules also comply with international regulations.

All Acrich3 solutions incorporate an analog dimming input as well as increased compatibility with existing TRIAC dimmers with the capability for uniform dimming. In addition, Acrich3 solutions enable smart-lighting systems with the ability to interface through a wide variety of wireless networks and sensors.




Seoul Semiconductor offers various standard modules in different lumen outputs and form factors with Acrich3 technology to address a wide range of general lighting applications.

"Acrich3 premium is at the core of Seoul Semiconductor's patent technologies," says chief technology officer Dr Ki-bum Nam. "It provides lighting designers with an easy-to-implement advanced lighting solution without compromising on the performance or the quality of the light output," he adds. "The addition of the improved flicker performance with the Acrich3 premium modules will only further enhance the adoption of the Acrich technology," he believes.

**www.SeoulSemicon.com**

# Plessey expands distribution network

Plessey Semiconductors of Plymouth, UK has entered into two sales representative agreements to expand its Europe, Middle East and Africa (EMEA) network for its GaN-on-silicon LED products.

An agreement with Johannesburg-based Tempe Technologies Pty Ltd, a Southern African technical and sales representative company. will add coverage in the Southern African market.

Tempe's CEO Willem Hijbeek says that an advantage for his customers is that, as an LED supplier with a European wafer manufacturing base, Plessey provides access to "a local competence center for all things related to the design and production of LEDs".

"Plessey is very pleased to work with a distributor who has significant history in supplying the solid-state lighting market in Southern Africa," comments marketing director David Owen. "Tempe Technologies has a comprehensive portfolio of peripheral products aimed at lighting applications, so the addition of Plessey LEDs will enhance its ability to provide a full solution to the customer base and accelerate the time to market for Plessey GaN-on-silicon LEDs in this region," he adds.

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.

Plessey Semiconductors has also expanded its European network via a sales representative agreement with electronics distributor ROM Electronik Ltd (based near Istanbul) for coverage in the Turkish market.

"Following the rapid growth of the LED industry in recent years, our customers are now more focused in reducing manufacturing costs when selecting an LED for their lighting projects," says ROM Elektronik's director Resat Erunsal. "Plessey's MaGIC process is an innovative approach to LED production that offers potential cost savings in terms of wafer size scaling and improved binning over conventional LEDs. In addition, the chip-scale packaging techniques will open new doors for creating new design wins and expanding business to new markets and reaching new customers," he believes. "The innovative approach of Plessey will add more value to the lighting manufacturers in Turkey," he adds.

"Plessey is very pleased to work with a distributor that has been focusing on the solid-state lighting market for a considerable number of years," says Plessey's marketing director David Owen. "ROM Elektronik has a dedicated team working in the lighting segment and therefore considerable knowledge of the growing Turkish lighting industry and customer base, which will accelerate the time to market for Plessey GaN-on-silicon LEDs in this region."

**www.plesseysemiconductors.com/led-plessey-semiconductors.php**

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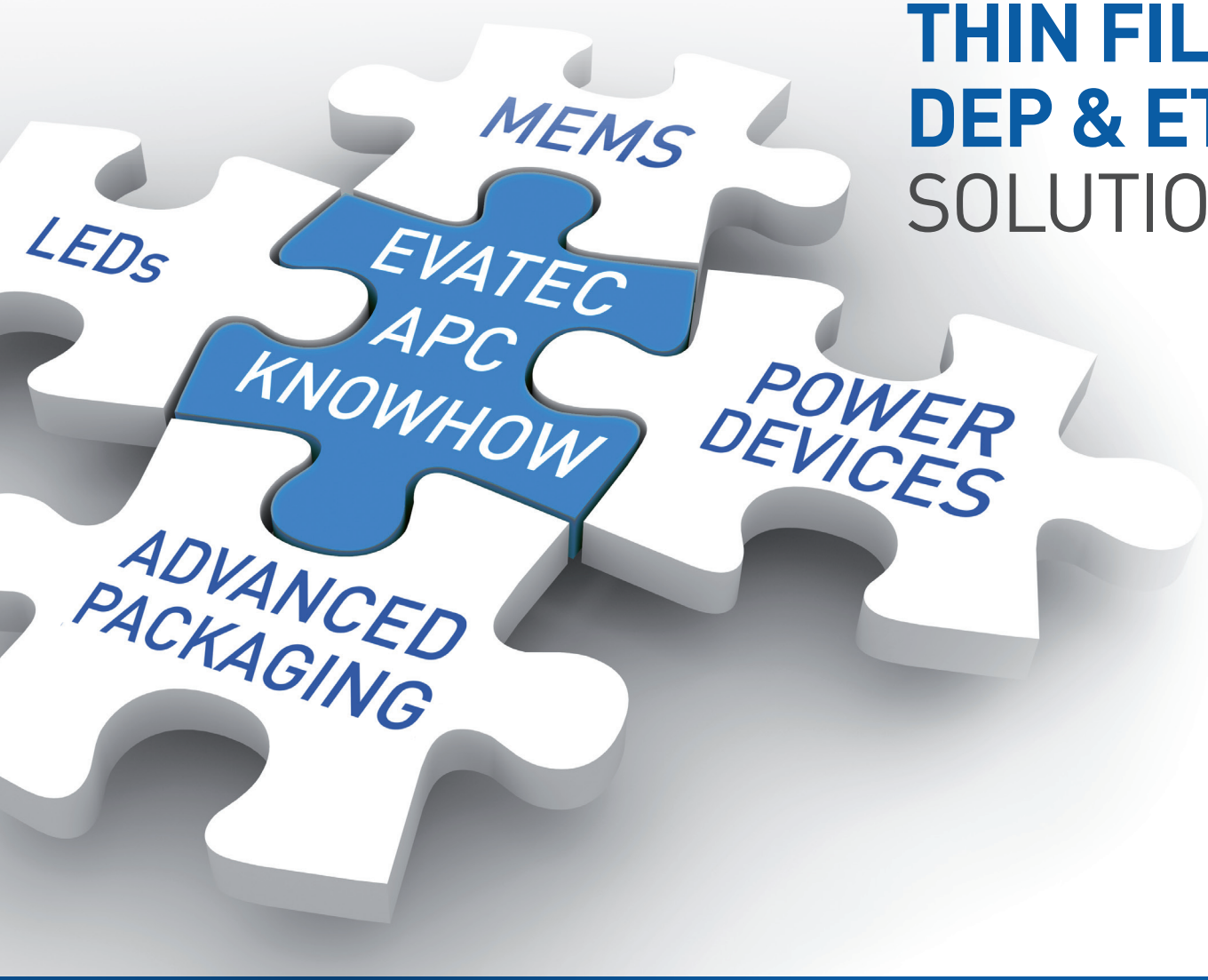


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# New customers & design wins drive SemiLEDs' recovery

## Cost reduction halves cash burn

For fiscal second-quarter 2015 (to end-February 2015), LED chip and component maker SemiLEDs Corp of Hsinchu, Taiwan has reported revenue of $4.6m, continuing the rebound from the low of $2.3m in fiscal fourth-quarter 2014 and up 56% on $2.9m in fiscal Q1/2015, and up 9.5% on $4.2m a year ago. It also exceeds the guidance of $3.4–3.7m, since some of the product scheduled to be shipped in March was shipped earlier in February due to customer demand.

Sequential revenue growth is attributed to continued efforts to develop new customers and new design wins in target end-markets.

Revenue from LED chips fell by 26% sequentially (from 24% of total revenue to 11%), but revenue from LED components rose by 99% (from 55% of total revenue to 69%) and revenue from lighting products rose by 118% (from 13% of total revenue to 19%).

Gross margin has improved from –75% a year ago and –53% last quarter to –14%. Selling, general & administrative (SG&A) expenses have fallen further, from $2.26m a year ago and $2.15m last quarter to $1.88m. Research and development (R&D) expenses have been cut from $1.22m a year ago and $0.75m last quarter to $0.61m. Operating margin has hence improved from –159% a year ago and –152% last quarter to –62%. On a non-GAAP basis, net loss was $2.5m, cut from $3.9m last quarter and $5.9m a year ago.

"Our cost-reduction policy continued to show positive effects and resulted in a substantial decrease in cash used in operations [$1.4m, almost halved from $2.7m last quarter and a third of the $4.2m a year ago]," chairman, president & CEO Trung Doan. Capital expenditure has been cut from $0.93m a year ago and $0.6m last quarter to $0.42m. Hence free cash outflow has been cut further, from $5.1m a year ago and $3.3m last quarter to $1.8m. During the quarter, cash and cash equivalents fell from $8.7m to $6.7m.

**New design wins and improved operating efficiency have given us better-than-forecasted second quarter results**

"As expected, new design wins and improved operating efficiency have given us better-than-forecasted second quarter results," says Doan. "We are looking forward to new design wins and developing key customers to bring us closer to profitability," he adds.

For fiscal third-quarter 2015 (to end-May), SemiLEDs expects revenue of $3-4m. "Based on our growing pipeline of design wins in the LED component products, we believe that the second half of 2015 will show further growth," says Doan.

**www.semileds.com**

# San'an licenses US patents of Japanese LED patent portfolio to subsidiary Luminus

Xiamen-based San'an Optoelectronics Co Ltd (China's largest producer of full-color ultra-high-brightness LED epiwafers and chips, as well as compound semiconductor solar cells and CPV solar products) has licensed the US patents of an LED patent portfolio (acquired recently from a major Japanese company) to its subsidiary Luminus Devices Inc of Sunnyvale, CA, USA, which makes LEDs and solid-state lighting (SSL) sources.

The portfolio comprises over 125 issued patents, including over 30 US patents as well as issued patents in China, Japan, Korea, Taiwan, and Germany. The earliest patents in the portfolio have priority dates reaching back to the mid-1990s, and more recent patents are from the mid-2000s. These patents in the acquired portfolio relate to a range of fundamental LED chip and wafer-level technology, such as p-type branch electrodes (for example, US Patents 6,881,985 and 6,384,430), transparent ZnO layers, and reflecting electrodes, barrier layers (US Patent 6,265,732), spacer layers, doped active layers (US Patent 6,081,540), optimized MQWs (US Patent 6,501,101), direct-bonded substrates, and GaInP current spreading layers.

"We were quite pleased to acquire this well-respected LED patent portfolio as it complements the San'an patent portfolio nicely in time and subject matter and increases the San'an patent holdings to over 280 issued patents and published applications," says San'an president Zhiqiang Lin. "San'an recognizes the importance of a strong patent portfolio in the LED industry and we are committed to growing our patent base organically and by strategic acquisition."

The license of the US patents to Luminus is exclusive, subject to prior issued licenses, with the right to enforce. "The addition of the licensed patents to our existing patent portfolio further reinforces the position of Luminus Devices in the LED market," comments Luminus' CEO Decai Sun. Luminus has over 80 patents worldwide including 50 US patents and is the exclusive licensee of key patents related to laser lift-off and patterned sapphire substrates.

**www.luminus.com**
**www.sanan-e.com/en**

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# Philips selling 80.1% of LED components & Automotive lighting business to GO Scale Capital

## Philips to retain 34% stake in Lumileds US operations

Royal Philips NV of Amsterdam, The Netherlands (the world's largest lighting producer) has agreed to sell an 80.1% stake in its combined LED components and Automotive lighting business to GO Scale Capital, a new growth-stage investment fund sponsored by GSR Ventures and Oak Investment Partners. Philips will retain the remaining 19.9% interest (including a 34% stake in the Lumileds US operations).

With about 8300 staff in more than 30 countries, Lumileds supplies lighting components to the general illumination, automotive and consumer electronics markets, and generated revenue of about $2bn and a double-digit EBITA margin in 2014.

The transaction values the business at about $3.3bn. Philips expects to receive cash proceeds (before tax and transaction related costs) of about $2.8bn and a deferred contingent payment of up to $100m. The deal is expected to be completed in third-quarter 2015 (subject to closing conditions, including customary regulatory approvals).

The new firm will continue under the name Lumileds, led by CEO Pierre-Yves Lesaicherre. Philips says that it will remain an important customer of Lumileds and will continue the existing innovation and supply partnership. The transaction includes the transfer of a broad portfolio of more than 600 patent families related to LED manufacturing and automotive lighting from Philips to Lumileds.

With consortium partners including Asia Pacific Resource Development, Nanchang Industrial Group and GSR Capital, the GO Scale Capital team says it has deep technology expertise and a track record in scaling up disruptive technologies in China. Current investments include electric-vehicle battery maker Boston Power and Xin Da Yang (a fast-growing Eco-EV company in China). Through past investments in the LED industry, it has access to complementary technologies and manufacturing capacity, complementing Lumileds' high-power LED manufacturing footprint and expertise. The combination offers opportunities for the new firm to pursue further growth and scale through the GO Scale model, it is reckoned.

"The Lumileds acquisition will be a perfect example of how GO Scale turns cutting-edge technologies into world-class companies," says Sonny Wu, co-founder & managing director of GSR Ventures and chairman of GO Scale Capital, who will serve as interim chairman of Lumileds. "GO Scale Capital will focus on expanding Lumileds' opportunities by investing in its global centers of operation and in the fast-growing general lighting and automotive industries," he adds. "Through Lumileds' world-leading technology in key verticals such as LED chips, LED mobile flash and automotive lighting — together with a customer base including the likes of BMW, Volkswagen and Audi — we expect to see significant growth and unparalleled inroads into new opportunities such as electric vehicles."

**GO Scale Capital will focus on expanding Lumileds' opportunities by investing in its global centers of operation and in the fast-growing general lighting and automotive industries. Through Lumileds' world-leading technology in key verticals such as LED chips, LED mobile flash and automotive lighting — together with a customer base including the likes of BMW, Volkswagen and Audi — we expect to see significant growth and unparalleled inroads into new opportunities such as electric vehicles**

"Philips is very positive about this transaction with GO Scale Capital as its principals are long-term, growth-oriented investors with a track record of building and expanding technology companies," comments Philips' CEO Frans van Houten. "We have significantly improved the performance of the LED components business and optimized the industrial footprint in the Automotive lighting business over the last few years, and established a strong management team and innovation pipeline. We are therefore convinced that, together with GO Scale Capital, Lumileds can grow faster, attract more customers and increase scale as a standalone company," he adds.

"Together with the new investors led by GO Scale Capital, Lumileds will extend its leading product portfolio of lighting components and continue to achieve robust growth," believes Lesaicherre.

Following the separation of Lumileds, Philips Lighting will focus on the lighting solutions markets. As announced last September, it has started the process of creating two companies focused on HealthTech and Lighting Solutions. As part of that strategic repositioning, Philips aims to transition the Lighting Solutions business into a separate legal structure through an initial public offering (although other options will continue to be reviewed).

**www.philipslumileds.com**
**www.lighting.philips.com**

## Sale to China-focused investor in Lattice Power raises questions

Lumileds began 2015 strongly after gaining market share in 2014, according to a Research Note from the IHS LED Intelligence Service.

While the overall packaged LED market only grew by single digits from 2013 to 2014, Lumileds was one of only two of the top 10 LED suppliers (with China-based MLS) to record growth of over 20%. Lumileds' market share hence rose from 5% in 2013 to 6% in 2014.

In 2013 Lumileds' revenue was similar to that of LG Innotek, Seoul Semiconductor and Cree, ranking fifth, says IHS. However, in 2014 it established itself as the fourth-largest packaged LED firm, joining three others (Nichia, Samsung and Osram) with over $1bn in annual packaged LED revenue. By fourth-quarter 2014, Lumileds had also overtaken Samsung, to third in the quarterly rankings.

Lumileds' 2014 performance resulted from growth in lighting, automotive, mobile camera flash and other key areas. Notably, it has smaller share in backlighting — a market that disappointed, especially in second-half 2014. Lumileds's areas of growth helped it to gain against competitors with a larger share in backlighting, such as Nichia, Samsung, Seoul Semiconductor, LG Innotek, Lumens and Toyoda Gosei. However, its growth is also based on share gains at certain customers. "Can Lumileds continue this strong performance under its new owner," questions IHS.

Philips said last July that, by spinning off Lumileds, it would be better positioned to compete for new business from customers that regard Philips as a competitor. The sale ends years of speculation about Lumileds' future, during which Korean, Taiwanese and US LED firms were variously rumored to be potential suitors, says IHS. But in recent weeks it became clear that it would be a private-equity deal, bringing Lumileds stability and helping staff and partners move forward with more clarity, IHS says.

As often happens, however, answers lead to more questions. With GSR Ventures' focus on China, and its existing investments in China-based Lattice Power and other companies, might Lumileds consider moving some of its production to China in the future? Is there any relationship between Lattice Power, GSR Ventures and the Nanchang regional government, as has been reported by certain Chinese media outlets? Is this a sign of increasing future Chinese involvement in the packaged LED industry?

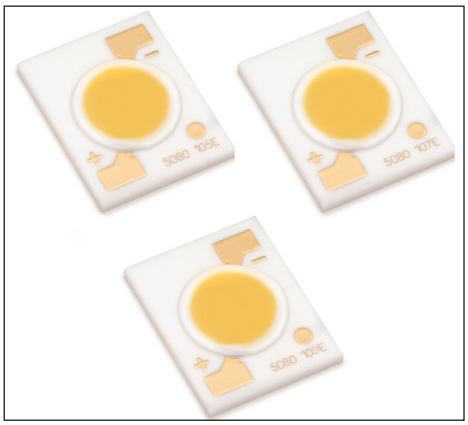
Sonny Wu, who will serve as interim chairman of Lumileds, is also chairman of Lattice Power, which — along with Toshiba/Bridgelux and Plessey — is one of the few firms to produce LEDs on silicon, while almost all other LED companies (including Lumileds) produce LEDs on sapphire. As little as a week ago, Wu said that he saw "tremendous opportunity for the GaN-on-silicon technology, which offers the ideal choice for next generation silicon chips". Will Lumileds consider any transition to GaN-on-Si over time, or will it continue to use sapphire, questions IHS.

**https://technology.ihs.com/Services/467369/LED**

# Lumileds launches LUXEON CoB Compact Range

Philips Lumileds of San Jose, CA, USA has launched the LUXEON CoB Compact Range, its most cost-effective line of chip-on-board (CoB) LED arrays, enabling cost-competitive solutions for PAR, GU10 and MR16 lamps. Also, the same optic can be used for both a 35W-equivalent and a 50W-equivalent GU10 or MR16 lamp, reducing system cost and development effort for the lamp manufacturer.

"The LUXEON CoB Compact Range is designed to deliver unsurpassed center-beam candle power (CBCP), making it the ideal choice for designers of PAR lamps and other compact directional lamps," reckons product manager Ahmed Eweida. The range of 5W, 7W and 9W CoBs produce luminous flux of between 600lm and 1100lm at luminous efficacy of 110lm/W, making 100lm/W GU10, MR16, PAR 16 and PAR30 equivalents a reality.



**Lumileds LUXEON CoB Compact Range.**

The combination of high efficacy, high flux and a small LES (light-emitting surface) of 6.5mm enables high punch at low beam angles, says Lumileds. In a GU10 lamp, the LUXEON CoB 109 achieves 70,000 candelas and 1500 lumens with a 10° beam angle. The CoB Compact Range 109 will also be available with CrispWhite Technology.

Lumileds says that lighting designers are using CoB Compact Range arrays to produce their most cost-competitive retrofit and directional lamps for retail, home and hospitality applications. The firm adds that it has worked with several key partners, for the CoB family, to release compatible drivers, optics and holders to help speed the time-to-market of all lamps.

**www.lumileds.com/LUXEONCoBCompact**

# Cree reports better-than-expected quarterly LED sales

## Accelerated inventory reduction yields larger-than-targeted reduction of profit margins

For its fiscal third-quarter 2015 (to 29 March), Cree Inc of Durham, NC, USA has reported revenue of $409.5m, down about 1% on $413.2m last quarter but up 1% on $405.3m a year ago (and on the higher end of the targeted range of $395–415m), as better-than-forecast LED product demand offset worse-than-expected weather-related seasonality in LED lighting.

Power & RF product revenue was $31m, similar to last quarter but up 13% on $27.4m last year (remaining about 7% of total revenue). Power & RF gross margin was 53.1%, down on 55.5% last quarter and 57.1% a year ago due to product mix.

Lighting product revenue (LED lighting systems and bulbs) was $224m, up 27% on $176.7m a year ago but down 3% on $230m last quarter (falling back slightly to 55% of total revenue, after rising from 44% a year ago to 56% last quarter), as the severe winter weather in north-eastern USA delayed commercial LED fixture sales (although commercial fixture demand rebounded in late March and should grow in fiscal Q4). Lighting gross margin was 26%, down on 28.1% last quarter, due to an unfavorable product mix (as LED bulbs rose as a proportion of total sales, and commercial LED lighting projects suffered weather-related delays) and factory under-loading in the first half of the quarter (driven by inventory reductions and the timing of orders).

LED product revenue (LED components, LED chips and silicon carbide materials) was a better-than-expected $154.4m, down 23% on $201.1m a year ago but up slightly on $152m last quarter (rebounding slightly to 38% of total revenue, after falling from 49% a year ago to 37% last quarter). This was due to external customer demand stabilizing, offsetting the normal decline related to the Chinese New Year holiday.

However, LED gross margin fell further, from 45.6% a year ago and 39.1% last quarter to 35.9%, due mainly to Cree slowing LED factory utilization further (reducing internal LED shipments, as part of the effort to reduce Lighting inventory). LED pricing was also slightly lower than forecast as Cree reduced channel inventory for certain older-generation LED products.

As a result of the lower LED and Lighting margins, overall gross margin (on a non-GAAP basis) was 31.4%, down on 33.9% last quarter and 37.8% a year ago (and below the expected 33.5%). "We burned $33m or 10% of inventory in the quarter, which is faster than expected and resulted in a larger margin impact than targeted," says chairman & CEO Charles Swoboda.

As part of the firm's targeted inventory reduction plan, inventory was reduced by $33.2m during the quarter, from $332.5m to $299.4m (improving from 108 days to 95 days, nearing the 90-day target). "Although the inventory reduction is causing some near-term gross margin pressure, we believe it is the prudent choice and in line with our strategy to continue to innovate and rapidly bring new products to market to meet the evolving demands of our customers," says Swoboda.

**Although the inventory reduction is causing some near-term gross margin pressure, we believe it is the prudent choice and in line with our strategy to continue to innovate and rapidly bring new products to market to meet the evolving demands of our customers**

During the quarter, Cree added to its XLamp MH family of LEDs by launching the MHD-E and MHD-G, which leverage the Cree SC5 Technology platform to combine the high lumen density and reliability of a ceramic chip-on-board LED with the design and manufacturing advantages of a surface-mount package. It also added to its CXA LED array family by launching the CXA2, which delivers up to 33% higher efficacy in the same form factors by utilizing elements of the SC5 Technology Platform. Cree also expanded its LED bulb portfolio with the TW Series LED T8 Tube Replacement for consumers (designed for simple, wire-free installation). Cree also launched the LED Rural Utility Light (RUL) Series for the estimated 10–13 million rural street and areal light fixtures currently installed in North America.

Operating expenses were reduced from $106m last quarter to a better-than-expected $102m ($3–4m lower than targeted). However, due mainly to the lower gross profits in LEDs and Lighting, operating income was $26.1m (operating margin of 6.4%, on the low end of the target range), down on $34m (8.2% margin) last quarter and $53.6m (13.2% margin) a year ago.

Net income was $25m ($0.22 per diluted share), down on $37.9m ($0.33 per diluted share) last quarter and $47.7m ($0.39 per diluted share) a year ago, as the lower tax rate (9%, less than the 17% target due to lower forecasted earnings for fiscal 2015) has offset the reduced gross profit due to lower factory utilization.

Cash generated from operations has risen from $14.8m last quarter to $65.6m. As well as the regular patent spending of about $5m, spending on property, plant & equipment has been cut from $50m to $44.9m, reducing total capital expenditure from $55m to

$50m (in line with the plan to reduce property, plant & equipment spending to $200m for full-year fiscal 2015). Free cash flow hence improved from –$40m last quarter to +$15.8m. In addition, Cree spent $70m to repurchase 1.9 million shares of its common stock (totaling $390m spent to repurchase 11.2 million shares — equal to 10.6% of Cree's outstanding stock — during the first nine months of fiscal 2015's $550m authorized share repurchase program). During the quarter, cash and investments hence fell by $47.9m, from $829.9m to $782m.

For fiscal fourth-quarter 2015 (ending 28 June), Cree expects revenue to grow to $420–440m, consisting of strong growth in Lighting revenue (led by higher commercial fixture sales), growth in Power & RF revenue, and stabilizing LED sales. The more favorable product mix in Lighting should drive a slight rise in overall gross margin to 32%. Lighting factory utilization remains high, while LED factory utilization is targeted to remain low. "We plan to continue to closely manage inventories in Q4, which may create some additional near-term margin headwinds," says Swoboda. Operating expenses are expected to rise by $5m, due primarily to higher patent and litigation spending and higher sales commissions related to greater Lighting revenue. Net income is expected to be $26–31m ($0.24–0.28 per diluted share).

**With the external LED business stabilizing over the last two quarters and inventory levels moving back towards our target range, we are well positioned to deliver incremental operating leverage in Q4 and into fiscal 2016**

"LED volumes are targeted to improve in fiscal 2016, driven by new design wins for SC5 LED products and growth in our lighting business," says Swoboda. "With the external LED business stabilizing over the last two quarters and inventory levels moving back towards our target range, we are well positioned to deliver incremental operating leverage in Q4 and into fiscal 2016," he adds.

**www.cree.com**

# Shuji Nakamura wins 2015 Global Energy Prize

Shuji Nakamura — professor of materials and of electrical and computer engineering at University of California Santa Barbara (UCSB) — has been announced as a winner of the 2015 Global Energy Prize.

To be presented at the St. Petersburg International Economic Forum on 19 June, the annual Russian award "honors outstanding achievements in energy research and technology from around the world that are helping address the world's various and pressing energy challenges". Joining 31 former Energy Prize laureates from 10 countries, Nakamura receives the award "for the invention, commercialization and development of energy-efficient white solid-state lighting technology".

The award — which comes with a cash prize of 33 million rubles (about $645,000) — is shared by Nakamura with Jayant Baliga — professor in the Department of Electrical and Computer Engineering at North Carolina State University (NCSU) and director of its Power Semiconductor Research Center — who is honored for the "invention, development and commercialization of the insulated-gate bipolar transistor (IGBT)… one of the most important innovations for the control and distribution of energy".

Nakamura was one of three 2014 Nobel Prize winners in physics for the invention of the indium gallium nitride (InGaN) bright blue LED, which has led to the creation of the white LED and the ability to save energy, reduce carbon emissions and provide a low-energy, durable and sustainable light source for those with little or no access to electricity.

Following by the development of first red then green, orange and yellow LEDs, the blue LED was the most challenging to invent and was the remaining primary color. Nakamura not only used the promising but difficult-to-grow material gallium nitride but also invented a means to manufacture high-quality GaN crystals. He debuted his high-efficiency bright blue LED in 1993.

"The applications and consequences of his pioneering work in solid-state lighting continue to grow, with far-reaching impact on fields ranging from information and communication, to energy and the environment, to health care and life sciences," comments UCSB's chancellor Henry T. Yang. "By making it possible to bring affordable, energy-efficient lighting to developing countries, professor Nakamura has made a tremendous humanitarian contribution to our world," he adds.

Nakamura is currently also co-director of the campus's Solid State Lighting & Energy Electronics Center (SSLEEC), where his research focuses on growth and device fabrication of light-emitters based on GaN. "The Solid State Lighting and Energy Electronics Center is so pleased that LED lighting is saving the world billions in energy costs and with further potential to bring cost-effective lighting to the developing world," comments Steve DenBaars, professor of materials and SSLEEC co-director.

**www.globalenergyprize.org/en/laureates/2015**

# Germany's InteGreat project targets optimized production of high-efficiency LEDs

## Osram collaborating with Fraunhofer, LayTec, Würth and Mühlbauer

Supported by the German Ministry for Education and Research (BMBF) as part of the 'Photonic Process Chains' initiative, the project 'Integrated High-Volume Production along the LED Value-Added Chain for Large Wafers and Panels' (InteGreat) is being coordinated by LED maker Osram Opto Semiconductors GmbH of Regensburg, Germany together with five partners from industry and research: Osram GmbH, Fraunhofer-Gesellschaft, LayTec AG, Würth Elektronik GmbH & Co KG and Mühlbauer GmbH & Co KG.

Running from 1 December 2014 to end-November 2017, the project's objective is to research new approaches to the production of high-efficiency LEDs along the entire production process, in order to remove the boundaries between the individual value-added stages and hence to create new functionality and high flexibility. A holistic view of the manufacturing process — from epitaxy (crystal growth) to the light source itself — should enable synergies to be exploited to maximum effect and new approaches and procedures to be developed. It is reckoned that fully optimized production for LED components and light modules in which all process steps are coordinated with each other could lead to completely new types of LEDs, as well as reducing their manufacturing costs.

"For the duration of the project we will be researching completely new concepts for LED production and allow ourselves to question the traditional paradigms of the manufacturing process," says Dr Jürgen Moosburger, project coordinator at Osram Opto. Established technologies and processes from the classic microelectronics industry will be used and adapted to the specific requirements of LED production. Steps that until now have been isolated will be networked, allowing cost-intensive sorting and testing processes to be replaced by comprehensive routines. This could enable production of modern high-power LEDs to be a unified process for the first time, it is reckoned. "With the new production concepts, we want to be in a position to develop both low-cost miniaturized LEDs and highly integrated modules," adds Moosburger.

As coordinator of the project, Osram Opto brings its experience in LED technologies, and is responsible for integration and evaluation of the new processes. As a specialist in lighting solutions, Osram GmbH will integrate the newly developed LED components in low-cost luminaires and also adds its expertise in process technologies.

As a technology partner for the smart-card, ePässe, RFID and solar back-end sectors, Mühlbauer is contributing its engineering know-how to the high-precision processing of electrical components on flexible and fixed substrates, including the development of new processes. Würth Elektronik is contributing its experience in individual solutions for printed-circuit board production. Specifically, it will be researching ways in which the LED chip can be connected to the PCB. Berlin-based in-situ metrology equipment LayTec is analyzing innovative process-control systems for LED manufacturing.

Also, the Fraunhofer Institute for Reliability and Microintegration (IZM) and the Fraunhofer Institute for Integrated Systems and Device Technology (IISB) are researching the basic technical principles of process control and mounting technology. IZM will contribute its expertise in connection technology, and IISB will work on the intelligent control of production processes.

## Osram's Duris E 5 mid-power LEDs used by Sistemalux

Osram Opto Semiconductors GmbH of Regensburg, Germany says that its Duris E 5 mid-power LEDs have been selected by lighting manufacturer Sistemalux for its Linear Series LED fixtures. The new generation of linear recessed and pendant modular lighting fixtures are claimed to be the most complete and flexible systems of its class using LED technology.

Sistemalux offers indoor and outdoor luminaires for commercial, institutional, urban and residential applications. Collaborating with Osram enabled it to take advantage of recent advances in LED efficacy.

"Our linear series required a highly efficient mid-power LED in order to perform at the level we were looking to meet," says Sistemalux's CEO Salvatore Folisi. "Osram's Duris E 5 LEDs provide high lumens per watt and lumens per dollar, along with good quality of light and color consistency."

The linear fixtures are available in multiple configurations such as continuous rows, corners, and square and rectangle pendants. Direct or indirect light distribution is standard with the two circuits option, allowing the lighting planner to achieve optimal layouts while minimizing energy consumption.

"The Duris E 5 meets the requirements of our customers who are striving for the highest efficacy and a uniform light distribution," says Osram Opto's marketing & business development manager Martin Wittmann. "It is a great option for indoor area lighting such as troffers and linear fixtures."

**www.osram-os.com**

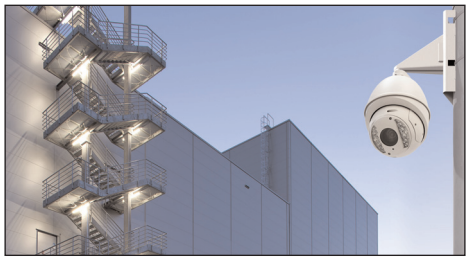
# Osram boosts output of Oslon Black IR LEDs again for longer-reach surveillance cameras

Osram Opto Semiconductors GmbH of Regensburg, Germany says that it has increased the output of its IR Oslon Black family for the second time in six months, making the new SFH 4715AS and SFH 4716AS the most powerful infrared light-emitting diodes (IREDs) yet from the firm.

Compared with the standard version, the increase in optical output of over 70% (to 1.37W at a current of 1A), has been achieved by combining the latest generation of chips, an optimized package design and, most importantly, Nanostack technology, in which each chip has two emission centers. Depending on the type of external optics and the particular application, the IREDs can provide illumination over a distance of more than 100m, making them better light sources for many camera-based applications.

"The new Oslon Black Stack generates more light and can therefore provide even better illumination over large distances than the previous versions," says Dr Jörg Heerlein, marketing infrared at Osram Opto. The power IREDs are the preferred light sources for surveillance cameras, adds the firm. Depending on the type of camera and the number of integrated IREDs, distances of more than 100m can be illuminated with infrared light.

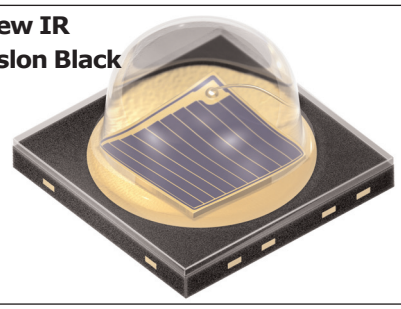
In addition to their main application in surveillance cameras, the IREDs are also suitable for many other industrial camera based applications, notes Osram Opto, for example, in 3D process control cameras to determine distance from an object by measuring the propagation time.

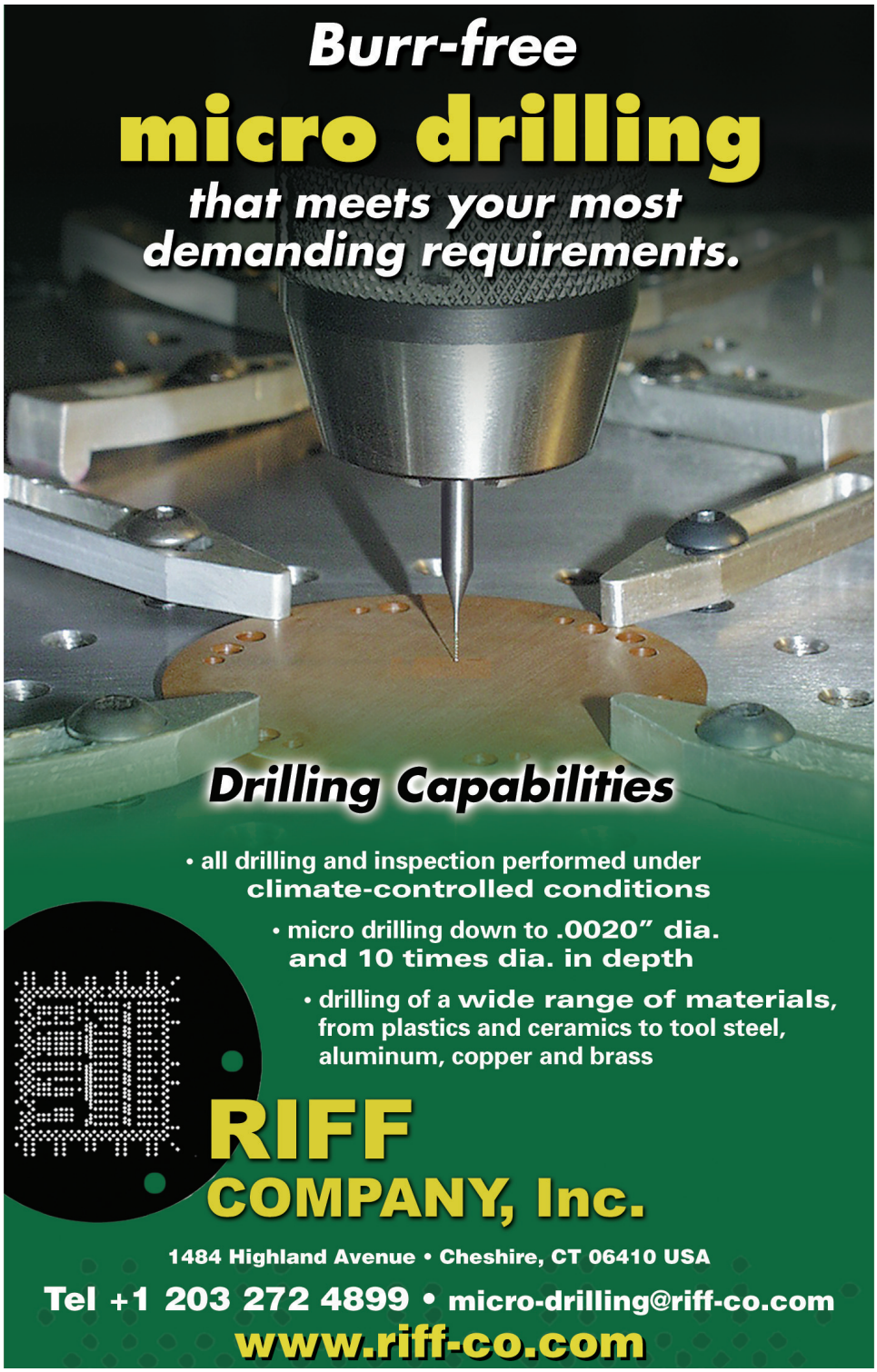


The Oslon Black Stack's package dimensions remain unchanged at 3.85mm x 3.85mm x 2.29mm or 3.85mm x 3.85mm x 1.51mm. There is also still a choice between beam angles of 90° and 150°, so replacement is straightforward.

www.osram-os.com

New IR Oslon Black





# University of Texas at Arlington developing UV lasers to detect chemical and biological weapons agents

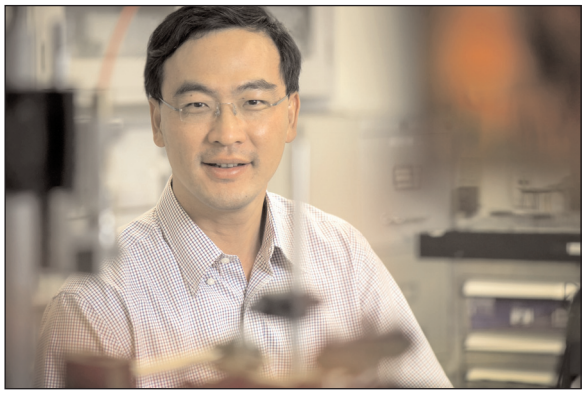
## Weidong Zhou awarded $600,000 as part of Michigan State University-led $4.3m DARPA project

Weidong Zhou, an electrical engineering professor at University of Texas at Arlington who specializes in nanophotonics, is using a federal grant to construct a small laser for detection systems to do a more efficient job at spotting chemical and biological agents used for weapons.

The $600,000 award is part of an overall, three-year, $4.3m US Defense Advanced Research Projects Agency (DARPA) grant to make ultraviolet laser detection more available in the field. The multi-institutional project is led by Michigan State University.

Zhou aims to develop low-cost, compact UV lasers to detect very small amounts of chemical and biological agents. The goal is to create a new class of UV lasers that are more than 300 times smaller and 10 times more efficient than current lasers.

The resulting technology could be dropped into current detection systems to save size, weight and power or to create new systems that are smaller and more sensitive. "It's like shining a light to find one of these chemical or biological agents… like finding these agents' fingerprints," Zhou says.



**University of Texas at Arlington professor of electrical engineering Weidong Zhou.**

"The Army needs something that's portable," he adds. Existing laser technologies that use light to determine where agents are present are huge and bulky. The systems sometimes require trucks to be transported. "They certainly can't be taken into the field or moved easily," Zhou notes. DARPA wants to reduce the size to something a person could carry, and to reduce the cost too.

Khosrow Behbehani, dean of the UT Arlington's College of Engineering, says that Zhou's laser technology has applications beyond how the US Department of Defense might use it. "Zhou's cutting-edge technology could aid physicians in medical diagnostics through those same ultra-sensitive lasers that detect harmful chemical or biological agents," he adds.

Zhou says other applications of the new lasers could include advanced manufacturing, secure communications, environmental monitoring and compact atomic clocks.

**www.uta.edu**

# DILAS launches 450nm visible blue diode laser system

Diode laser maker DILAS of Mainz, Germany is offering a diode laser system in the visible blue wavelength of 450nm, suitable for a range of applications in illumination and materials processing.

At 450nm, the new wavelength delivers both high power and brightness within the COMPACT platform, with up to 25W output power from a 200μm- or 400μm-diameter, 0.22 numerical aperture (NA) fiber. Specifically, DILAS says that the COMPACT series offers integrated, easy-to-use platforms of small physical size and facilitates ease of use and operational versatility. The system is equipped with a standard interface used for external control and does not require deionized (DI) water due to DILAS' passive cooling technology. DILAS also offers 19-inch rack-mountable cooling unit and fiber cables in various lengths.

**DILAS' COMPACT diode laser system, now available at 450nm wavelength.**

Also, the 450nm modules are scalable up to 100W optical output power. Other applications include the illumination of phosphorous materials for the generation of white light or 'red material processing' (processing gold and copper). In addition, investigations are ongoing for applications in solid-state laser pumping such as Ti:sapphire lasers or praseodymium pumping at 444nm.

DILAS notes that the COMPACT platform has a field-proven track record, with hundreds of systems being installed worldwide.

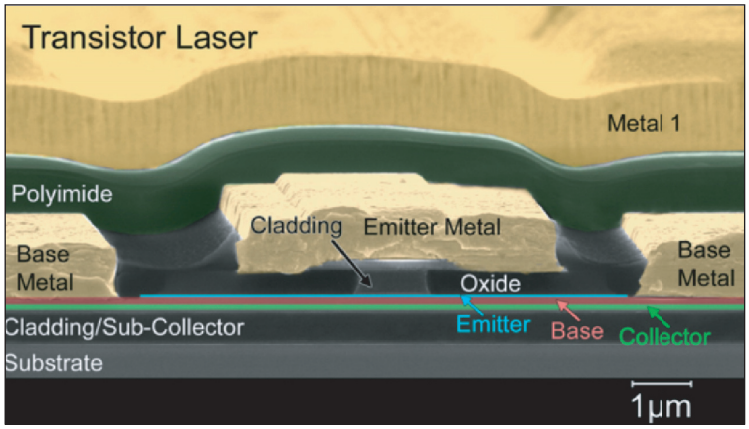
**www.dilas.com**

# Grant for UIUC's transistor laser research to push modulation speeds into terahertz range

Milton Feng, a professor of Electrical and Computer Engineering (ECE) at the University of Illinois at Urbana-Champaign (UIUC), has received a $657,000 grant from the US Air Force Office of Scientific Research (AFOSR) to enhance the modulation speed performance of the transistor laser, a novel 3-terminal device that he and ECE colleague professor Nick Holonyak Jr invented in 2004. The transistor laser offers the potential for much faster broadband communications, both for long-haul telecom networks and for short-haul connections between and within chips for photonic integrated circuits (PICs).

Feng's group has demonstrated a transistor laser with a fast (30ps) recombination lifetime and modulated optical output with 22Gb/s error-free transmission. By incorporating multiple quantum wells (MQWs) and reflectors and even coupling them with quantum dot regions, Feng is optimistic about reducing the recombination lifetime to 5ps.

Feng holds the record for the fastest (800GHz) heterojunction bipolar transistors (HBTs). He aims to leverage this expertise with advanced processing techniques to produce the ultra-low-threshold, high-speed transistor laser.




Over the course of the three-year grant, Feng and his students are investigating ways to reduce the average recombination lifetime (light generation) and push the laser's modulation speed into the terahertz range.

"In the first year, we'll establish the theoretical framework for pushing the modulation speed of the transistor laser into the terahertz and beyond," says Feng, a resident faculty member of the Micro and Nanotechnology Laboratory (MNTL) at UIUC. "In the second year, we'll pursue the epitaxial design for optimizing the quantum wells necessary to reduce recombination lifetime below 10ps. In our final year, we'll demonstrate a transistor laser made of quantum dots and quantum wells with a lifetime below 5ps and modulation of 0.3THz."

Professors Feng and Holonyak have received over 20 US patents covering the transistor laser for optical interconnects, photonic integrated circuit signal mixing, and feedback control of the laser and collector outputs.

Since 2013, Feng and his students have also produced record-setting research on 850nm oxide vertical-cavity surface-emitting lasers (VCSELs) with low relative intensity noise and 40Gb/s error-free data transmission. Widely used by the datacom industry for short-distance (<300m) applications, VCSELs have limited modulated bandwidth below 30GHz due to a relatively slow recombination lifetime of ~0.5ns. Based on the picosecond recombination lifetime of a THz transistor, the transistor laser modulates very quickly, making it a good candidate to compete with oxide VCSELs in a variety of optical interconnect applications.

**http://hsic.mntl.illinois.edu**

# JDSU signs exclusive Europe-wide distribution agreement with Laser 2000

JDSU of Milpitas, CA, USA has signed an exclusive distribution agreement with Laser 2000 GmbH of Munich, Germany, an optical solutions provider of almost 30 years, to provide its kiloWatt-class fiber laser and kW-class direct-diode laser products throughout Europe.

Laser 2000 can now offer kW-class laser systems that JDSU jointly developed with Amada of Kanagawa, Japan (a manufacturer of machine tools for metal cutting). Solutions include a range of new kW-class fiber laser and direct-diode products that JDSU launched in February related to its CORELIGHT platform. Applications include cutting and welding of metals including mild steel, aluminium, titanium, brass and copper. Various material deposition applications such as 3D printing are possible.

"The CCOP [Communications and Commercial Optical Products] unit at JDSU has a strong history of collaboration with its customers and partners," says Alan Lowe, CCOP president at JDSU. "This new distribution agreement will help machine tool manufacturers across Europe sharpen their competitive edge with kW-class laser solutions that help to improve efficiencies of metal manufacturing processes while lowering overall costs."

**www.laser2000.de**
**www.jdsu.com/en-us/Lasers**
**www.amada.co.uk**

# BAE Systems to provide foundry services for POET's Lab-to-Fab transition

## Initial phases on 3" wafers, but full process flow on 6" targeted

POET Technologies Inc of Toronto, Canada — which, through subsidiary OPEL Defense Integrated Systems (ODIS Inc) of Storrs, CT, USA, has developed the proprietary planar-optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — has signed a collaboration agreement for BAE Systems Microelectronics to provide non-exclusive third-party foundry services in support of its 'Lab-to-Fab' transition plan.

The current phase of the work will be performed between March and August. Key objectives of the collaboration include process transfer, prototype builds and design enablement kit development. POET says that using BAE Systems' ISO-certified manufacturing facility should improve the quality, process control and analytical capacity of prototype builds. The result will be both a more manufacturable process and improved optimization of the device structures included in the POET technology, the firm adds.

Initial phases of the program will be performed using 3-inch wafers, but from the onset the program will work towards the objective of achieving the full process flow on 6-inch wafers. Virtually all production GaAs-based processes currently use 6-inch wafers. The firm believes that using BAE Systems' manufacturing and test capabilities will help it to fabricate devices that dramatically demonstrate the disruptive nature of the technology.

"The POET technology incorporates silicon processes into GaAs integrated circuits, producing multi-function chips such as photonics and electronics that will provide enhanced commercial and military products," says BAE Systems' technical director Dr P.C. Chao. "Working with BAE Systems will enable the acceleration and maturation of the POET fabrication process for a faster prototype demonstration and a smoother transition to manufacturing," he adds.

"Our agreement with BAE Systems is a significant step in our 'Lab-to-Fab' transition," says POET's chief technology officer Daniel DeSimone. "BAE Systems has a long history of high-quality manufacturing with III-V materials, and brings process development expertise and manufacturing discipline to the relationship," he adds. "We have collaborated with BAE Systems numerous times over the last 2 years, most recently to successfully transfer our most critical process loop into their facility. Encouraged by this track record, we are excited to be extending this collaboration to develop the full flow on 3" and later 6" wafers."

**Formation of Technology Roadmap Advisory Board**

The firm has formed a Technology Roadmap Advisory Board consisting of Dr Geoff Taylor, Ajit Manocha and Tony Blevins. The firm says that the board collectively has extensive expertise in the semiconductor industry, supply chain management and operations, consumer products, and key technology markets, with more than 100 years of combined experience.

The Advisory Board will act as advisors to the board of directors and executive team, with a primary focus on optimizing and accelerating the company's 'Lab-to-fab' transition and commercialization plans.

**www.poet-technologies.com**

## POET appoints chief operating officer

POET has appointed Dr Subhash Deshmukh as chief operating officer (from 8 June, to allow time to fulfill duties with his current employer).

Most recently, Deshmukh has been VP of emerging technologies & products at Applied Materials Inc. Prior to rejoining Applied, he was VP & general manager of the Plasma Products business unit as well as VP of business development for Varian Semiconductor Equipment Associates Inc (acquired by Applied in November 2011). Before moving to Varian, Deshmukh was general manager of Applied Materials' Dielectric Etch products division. He previously served in executive and management roles with increasing responsibility at Applied, Lam Research, and AMI Semiconductors. Deshmukh has a PhD in Chemical Sciences, has authored and co-authored over 55 technical articles and has been granted over 27 patents (plus several pending).

Deshmukh has "a proven track record in leading technology companies, both in technology development and strategies to create sustainable revenues," says interim CEO & executive co-chairman Peter Copetti. "Subhash's appointment marks another crucial step in the company's succession plan as it moves towards monetizing the POET process," he adds.

"I see tremendous potential with POET Technology's innovative approach to combining Si-based ICs with III-V materials-based optical components on the same chip that could revolutionize the mobility, telecommunications/networking, large data management, and other technology sectors," comments Deshmukh.

Current COO Stephane Gagnon has agreed to stay on and help the firm through a period of transition in senior management.

# POET appoints new directors

POET Technologies Inc of Toronto, Canada – which, through subsidiary OPEL Defense Integrated Systems (ODIS Inc) of Storrs, CT, USA, has developed the proprietary planar-optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer – says its board has appointed two new directors to fill vacancies, the most recent of which was caused by the resignation of director Adam Chowaniec, as a result of the illness that led to his passing (announced on 17 February).

"The Corporate Governance and Nominating Committee (CGNC) has been engaged in an extensive search to find suitable candidates to fill the role of permanent CEO and supporting executive staff and directors," says executive co-chairman & interim CEO Peter Copetti. "The search has provided a short list of extremely capable and impressive candidates," says CGNC's chairman John O'Donnell. Final decisions are not expected to be made until May with respect to the top executive roles, however the process has produced, to date, two very exceptional new directors with the semiconductor industry experience and relationships to help propel the firm through its lab-to-fab transition.

Subject to all necessary regulatory approvals, the board has approved the following appointments:

- Todd A. DeBonis is a veteran semiconductor executive with over 27 years of expertise in sales, marketing and corporate development. For the last decade, he was VP of global sales & strategic development at TriQuint Semiconductor, during which TriQuint experienced dramatic growth and recognition in the industry as the technology leader in RF solutions. DeBonis played an integral part in its recent merger with RF Micro Devices and subsequent creation of Qorvo Inc.

DeBonis previously held the position of VP, worldwide sales & marketing at Centillium Communications. He also served as VP, worldwide sales for Ishoni Networks and VP, sales & marketing for the Communications Division of Infineon Technologies North America. DeBonis has a B.S. degree in Electrical Engineering from the University of Nevada.

- David E. Lazovsky is the founder of Intermolecular and was its president & CEO and a member of its board of directors from September 2004 to October 2014. He has an in-depth knowledge of the semiconductor industry, technology and markets. Lazovsky raised significant amounts of venture capital and other strategic private investments in Intermolecular's initial public offering.

Previously, he held several senior management positions at Applied Materials. From 1996 through August 2004, Lazovsky held management positions in the Metal Deposition and Thin Films Product Business Group, responsible for managing more than $1bn in Applied Materials' semiconductor manufacturing equipment business. From 2003 until 2004, he managed key strategic accounts in Business Management, working with integrated circuit manufacturers to ensure that Applied Materials was developing and providing cutting-edge technology solutions. From 2002 until 2003, Lazovsky served as technology program manager for the Endura 2 Platform, Applied Materials' flagship 300mm metal deposition platform. From 2000 until 2002, he was based in Grenoble, France and served as director of business management for the European region in the Metal Deposition Product Business Group. Previously, Lazovsky served as a business manager from 1997 to 2000, and account product manager from 1995 to 1997.

Lazovsky holds a B.S. in mechanical engineering from Ohio University and, as of end-March 2014, held 41 pending or issued US patents.

Both Lazovsky and DeBonis are residents in Silicon Valley. The firm expects they will play a key role in helping it to position itself in this critical heart of the semiconductor ecosphere, which is a key part of the focus of future development plans.

**www.poet-technologies.com**

# Marktech launches high-speed 0.9–1.7μm InGaAs PIN photo-detector

Marktech Optoelectronics of Latham, NY, USA, whose capabilities span wafer growth through finished packaging and custom solutions, says that its newest series of InGaAs PIN photodiode near-infrared detectors — with a standard spectral range of 0.9–1.7μm — offers low noise, high sensitivity and high-speed response.

Packaged in a TO-46 metal can with active areas of 0.1mm, 0.3mm and 0.8mm, applications include optical communication devices such as receivers, sensors and high-speed fiber modules. In particular, for telecoms and other high-speed applications they offer considerable speed improvements over the existing offerings, it is claimed.

"This series of InGaAs photodetectors are ideally suited for data communications applications with very high data rates, low dark current and capacitance along with very small active areas," says chief technology officer Vincent Forte.

Through its expertise in optoelectronic packaging, Marktech offers the high-reliability TO-46 metal can packages as well as custom package options. Additional testing and sorting options are also available through the firm's on-site testing lab.

Marktech exhibited at the SPIE DSS 2015 event in Baltimore, MD, USA (21–23 April).

**www.marktechopto.com**
**http://spie.org/**

# Mitsubishi Electric unveils 25G DFB laser with 10mW output at 85°C for 100G fiber-optic systems

At the Optical Fiber Communication conference & exposition 2015 (OFC 2015) in Los Angeles, CA (22–26 March), Tokyo-based Mitsubishi Electric Corp unveiled a distributed feedback (DFB) laser diode for 25Gbps fiber-optic communications in 100Gbps systems operating over a wide range of temperatures from –20°C to 85°C. Four DFB laser diodes can be mounted on 100Gbps high-speed communication transceivers in order to achieve lower power consumption and enhanced communication performance for increased efficiency in data centers. The new DFB laser diode should also help to simplify the requirements for transceiver design, says the firm.

During attempts to develop a DFB laser with high-speed response suited to 25Gbps operation, a current-blocking structure using semi-insulating semiconductors (doped with impurities to achieve high electrical resistance) showed promise. However, high output power was not possible due to poor current injection efficiency in the active region. In response, Mitsubishi Electric developed a new current-blocking structure using semi-insulating semiconductors that achieves low capacitance, yielding efficient current injection in the active region without degrading high-speed response. The current injection efficiency in the active region improved by 12% compared with the firm's existing products. More than 10mW output power at 85°C is obtained.

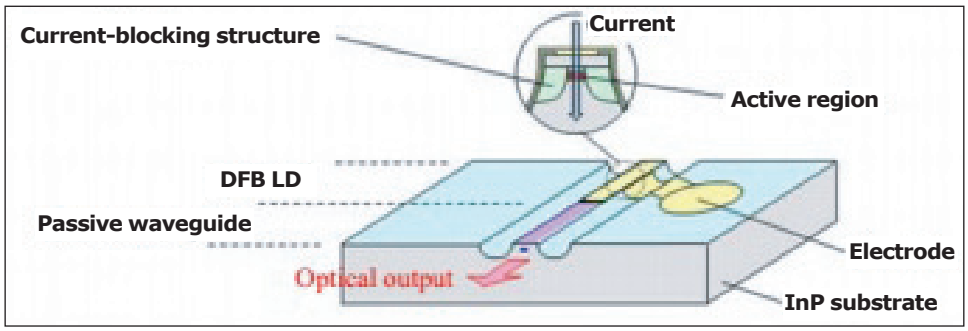



**Figure.1 Schematic of DFB laser for 25Gbps fiber-optic communications.**

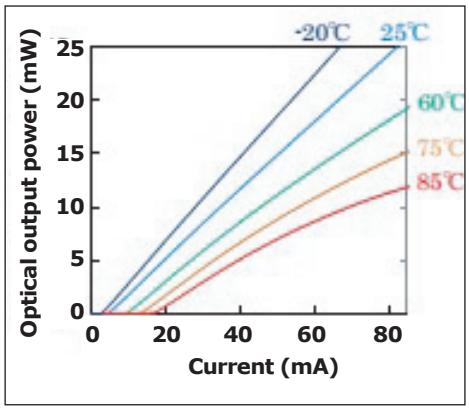



**Figure.2 Current dependence of optical output power.**

The transmitter optical subassembly (TOSA) for 100Gbps transmission includes 4-wavelength 25Gbps DFB lasers, whose high output power compensates for the optical loss caused by an optical multiplexer inside the TOSA.

Also, wide-ranging temperature operability eliminates the need for cooling, helping to reduce power consumption. This, together with a high-quality modulation waveform, helps to simplify 100G transmission system design. Due to having low capacitance and a short laser length (75% the length of the firm's existing products), the current-blocking structure enables what is claimed to be a high-quality modulation waveform with a mask margin of more than 20%. The high-quality modulation waveform simplifies laser-driving circuit design and hence communication transceiver design.

Mitsubishi Electric says that in future it will continue to develop DFB lasers with the aim of realizing wider-temperature-range operation and higher conversion efficiency from electric current to optical output power. This should contribute to high-density packaging and low power consumption in fibre-optic communications transceivers.

**www.MitsubishiElectric.com**

# DILAS unveils fiber-coupled pump module

Diode laser maker DILAS of Mainz, Germany has launched a fiber-coupled diode laser pump module, developed for fiber-laser pumping with kHz modulation capabilities.

The fiber-coupled pump module is based on a single-emitter platform in a sealed housing. It offers up to 30W laser power from a 105μm pigtailed fiber into a 0.15 numerical aperture (NA) at either 915nm or 976nm (with optional wavelength stabilization from 976nm-VBG).

The laser pump module's low height and rugged architecture make it suitable for applications requiring fiber-combined pump power with kHz modulation capabilities, fostered by the serial connection of the multiple single emitters' inside and its low operating current maximum of 12A.

Developed for ytterbium fiber-laser pumping applications, the module is equipped with a filter to protect against back-propagating light at >1μm. The module is also suitable for medical or materials processing applications that require a small fiber core diameter or low numerical aperture in a small footprint.

**www.DILAS.com**

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Multi-junction CPV cells
HBTs pHEMTs BiFET/BiHEMTs

# First linear EML driver for 400G demonstrated

At the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March), M/A-COM Technology Solutions Inc of Lowell, MA, USA demonstrated the newest additions to its portfolio of drivers for 100Gbps and beyond Ethernet applications.

The MAOM-003115 is a very compact and high-bandwidth linear EML (electro-absorption modulator laser) driver that can deliver up to $2V_{pp}$ single-ended output. This surface-mount device offers variable gain control and what is claimed to be excellent linearity over the operating range. The driver has been used to demonstrate a 400Gbps link over 2km of single-mode fiber (SMF) using four wavelengths running at 100Gbps each.

MACOM says that data-center providers have challenged optical module vendors to provide a low-power and low-cost approach to 400G in a QSFP form factor to maximize port density in new mega data-centers. Higher-order complex modulation schemes enable 100Gbps data rates on a single wavelength using currently available optical components. A low-power, linear driver is critical to achieving system-level performance in these modules, says the firm.

The device is the industry's first linear EML driver for 400G applications, claims product manager Ray Moroney. "This further expands MACOM's extensive portfolio of drivers for long-haul, metro and data-center applications," he adds.

## MACOM debuts 46Gbps quad-channel linear modulator driver for 400G long-haul applications

At OFC, MACOM launched the MAOM-003418 wideband quad-channel linear modulator driver with 46Gbaud capability to support 200G and 400G ultra-long-haul applications. The firm says this latest addition to its portfolio of drivers for optical infrastructure enables system designers to address the growing demand for higher data rates and greater bandwidth in the long-haul network.

The MAOM-003418 integrates four linear driver channels in a high-performance package with differential surface-mount inputs and single-ended GPPO outputs for direct connection to an OIF-compliant LiNbO (lithium niobate) modulator. MACOM says that the device is distinguished by its wide bandwidth, low power dissipation and linearity, which supports the implementation of higher-order modulation schemes that enable 400G data rates.

"MACOM's technology leadership in modulator drivers for 100G has set a strong foundation for 400G innovation," claims Ray Moroney, marketing director for optoelectronics.

The MAOM-003418 modulator driver is currently sampling to customers.

**www.macomtech.com**

# MACOM launches 10G burst-mode laser driver with integrated limiting amplifier and CDR for next-gen PON

At OFC, MACOM demonstrated the M02180, a new low-power, highly integrated, programmable burst-mode laser driver integrated with continuous-mode limiting amplifier and clock & data recovery (CDR) for passive optical networks (PON) ONU/OLT (optical network unit/ optical line terminal) applications up to 12.5Gbps.

The M02180 laser driver can be configured in three selectable modes of operation. It offers open-loop operation with look-up tables, single closed-loop control using monitor photodiode feedback or MACOM's proprietary dual closed-loop operation for low-cost bi-directional optical subassembly (BOSA)-on-board applications. The device features a limiting amplifier with 6mV input sensitivity and integrated CDR with reference-free operation and can be bypassed to support non-standard data rates.

The M02180 includes an internal state machine controller and non-volatile memory with digital diagnostics, performing all the functions necessary for standalone operation without an external microcontroller. The internal state machine provides customers with the ability to acquire and scale industry-standard monitoring parameters in real time. The M02180 also has a high-voltage DC–DC controller for avalanche photodiode (APD) biasing with a built-in temperature-based look-up table stored in an EEPROM.

The M02180 provides low-power operation of I<90mA (typical). The device also offers sleep modes, burst-off current reduction modes, and optional 2.5V power supply operation for further power reduction.

"This highly integrated device minimizes power consumption and external parts count, provides design flexibility and simplifies manufacturing processes, enabling our customers to develop the best in class 10G PON optical solutions," says Angus Lai, director of High-Performance Analog product marketing.

The M02180 is available in a low-cost 4.5mm x 4.5mm QFN package and supports industrial temperature operations. Device, evaluation board and reference design are sampling now.

# MACOM extends optical portfolio with dual-channel high-gain linear TIA for 100G metro

At the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March), M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) is demonstrating a new dual-channel linear transimpedance amplifier (TIA) for next-generation coherent receiver applications.

The MATA-003806 TIA has transimpedance gain that can be adjusted from 100Ω up to 10kΩ with manual and automatic gain control modes of operation. Input and output peak detectors are available for RSSI (received signal strength indicator) and AGC (automatic gain control) functionality. With what is claimed to be excellent linearity and noise performance over the complete dynamic range, and power dissipation of 300mW per channel, the device is suitable for the next generation of micro-ICRs (integrated coherent receivers) for metro applications at 100Gbps and beyond.

"These devices further complement MACOM's expanding optical portfolio," says product manager Ray Moroney. "MACOM intends to expand on its leadership position in modulator drivers to provide industry-leading solutions for optical receivers as well."

Samples of the MATA-003408 are available now.

**www.macomtech.com**

## MACOM launches VCSEL driver and TIA with integrated CDR chip-set for 100Gbps applications

MACOM has launched the MALD-37045, a four-channel 25.78G/28.05G vertical-cavity surface-emittng laser (VCSEL) driver, and the MATA-37044, a transimpedance amplifier (TIA)/limiting amplifier, both with integrated clock & data recovery (CDR) functionality for use as a complete transmit and receive solution in optical modules and on-board optical engines. The devices consume ultra-low-power, making them suitable for small-form-factor applications.

The CDRs in the MALD-37045 and the MATA-37044 are programmable and re-time at 25.78Gbps, 27.95Gbps and 28.05Gbps. They are reference-free and can be bypassed to support legacy or non-standard data rates. These companion devices have their respective outputs and inputs spaced on 250μm centers to maintain compatibility with standard optical interfaces, and each device can be individually controlled through the 2-wire serial interface.

The MALD-37045 driver features a high-performance CDR and an equalizer. The device provides programmable bias and modulation current, and a configurable alarm pin to flag faults on any channel.

The MATA-37044 includes a high-sensitivity TIA with selectable bandwidth to support legacy data rates, a limiting amplifier and an output driver with programmable output swing and de-emphasis. The amplifier features programmable slice level adjust, LOS threshold and an average photodiode current monitor (RSSI).

**The devices consume ultra-low-power, making them suitable for small-form-factor applications.**

**The new chip-set expands MACOM's family of CDRs, laser drivers and TIA products and, by utilizing our expertise in low-power and high-performance semiconductors for optical applications, we enable our customers to develop the best-in-class 100G module solutions**

MACOM says that the companion devices are optimal one-stop solutions for optical modules, active optical cables (AOCs) and on-board optical engines. They can be used in 100G Ethernet, EDR InfiniBand and 32G Fibre Channel applications, providing a low-power solution, reducing the overall cost of optical subassemblies.

"These devices further complement MACOM's expanding optical portfolio," says Marek Tlalka, director of marketing. "The new chip-set expands MACOM's family of CDRs, laser drivers and TIA products and, by utilizing our expertise in low-power and high-performance semiconductors for optical applications, we enable our customers to develop the best-in-class 100G module solutions," he adds.

The MALD-37045 and MATA-37044 are both available in die form, supplied in waffle packs, whole wafers or quartered wafers. Devices are sampling now to development partners.

MACOM demonstrated its CDR, laser driver and TIA product portfolio at the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March).

**www.ofcconference.org**

# Qorvo launches family of high-speed infrastructure products for next-generation optical networks

## High gain and low power dissipation target long-haul, metro and data-center applications

At the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March), Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides RF solutions for mobile, infrastructure and aerospace/defense applications) announced the expansion of its portfolio of high-performance optical transport products.

Qorvo is adding new high-speed products for long-haul, metro and data-center applications to deliver new multi-channel and low-power-consumption options that reduce cost, enable market-leading channel-to-channel isolation while shrinking product form factor, and maximize integration and signal fidelity for network equipment manufacturers.

Sampling of devices began in fourth-quarter 2014 to tier-1 and -2 network equipment manufacturers (NEMs) and leading optical module manufacturers. Qorvo says that it has penetrated the data-center market with an initial design-win into equipment used by non-traditional datacoms providers.

Qorvo's newest infrastructure products include dual- and quad-channel limiting and linear drivers that deliver high gain, low power dissipation, high channel-to-channel isolation and low total harmonic distortion (THD). The devices target DP-QPSK and 16QAM, 100G, 200G and 400G applications in module solutions supporting both CFPx and QFSP28 reduced-form-factor (SFF) footprint standards.

"Qorvo products support both limiting and linear transmit and receive through 400G," says James Klein, president of Infrastructure and Defense Products. "Qorvo's newly released portfolio of optical infrastructure products provide the building blocks for next-generation optical networks that require increased bandwidth, higher transmission capacity, and lower cost to the network equipment providers," he adds.

The new driver portfolio consists of the following products:

- TGA4960-SL — a 100G CFP2 SMT differential in/out quad-channel linear driver for metro and long-haul applications;
- TGA4893-SL — a dual-channel SMT driver for 16QAM 200G/400G linear applications;
- TGA4851-SL — a 100G CFP4 and QSFP28 quad-channel SMT driver for emerging extended-reach data-center applications.

The TGA4960-SL is suitable for CFP2-ACO module form factors and is Qorvo's most advanced quad-channel modulator driver, with what is claimed to be the smallest package in the industry (at 14mm x 8mm x 2.6mm).

Qorvo also recently expanded its optical portfolio to include new 100G limiting and linear transimpedance amplifiers (TIAs) for metro and long-haul applications in both dual- and quad-channel versions. The new products include:

- TGA4872 — a 100G DP-QPSK dual-linear TIA;
- TGA4874 — a 100G/400G quad-linear TIA with digital or analog control.

The TGA4874 quad-channel linear TIA features high transimpedance gain, automatic gain/output level control, and a high-bandwidth option for 400G applications. Unique to the industry is the TGA4874, which includes a selectable control interface with either digital or analog control for maximum flexibility for receiver designers.

General availability for the new portfolio of products will begin in second-quarter 2015.

**www.qorvo.com/optical**

## Qorvo boosts optical bandwidth with new 90nm GaAs pHEMT process for next-gen high-frequency amplifiers

At OFC, Qorvo launched new GaAs pHEMT process technology that provides higher gain/bandwidth and lower power consumption than competing semiconductor processes, it is claimed.

TQPHT09 is a 90nm pHEMT process that supports the firm's next-generation optical product portfolio. Coupled with reliability, the new process is suitable for next-generation high-frequency, high-performance amplifiers required for 100G+ linear applications.

Manufactured in Qorvo's GaAs fabrication facility in Richardson, Texas, TQPHT09 is the newest process in the firm's well-established pHEMT portfolio. It serves as the basis for several new optical modulator driver products including the TGA4960-SL, the firm's most advanced quad-channel 100G modulator driver. The TGA4960-SL is available in the CFP2 form factor for metro and long-haul applications, and is also well suited to upgrading the 100G linear dual-channel drivers for line-card applications. It is optimized for high performance, low power dissipation and high channel-to-channel isolation, and is packaged in a 14.0mm x 8.0mm x 2.6mm SMT module (claimed to be the smallest footprint in the industry).

# Inphi adds quad linear differential to single-ended MZM driver to first 45GBaud linear coherent product family

Inphi Corp of Santa Clara, CA, USA, a provider of high-speed mixed-signal ICs for communications, data-center and computing markets, is adding to its 45GBaud linear coherent product family by sampling the IN4518SZ quad linear differential to single-ended Mach–Zehnder modulator (MZM) driver.

Pin-compatible with the field-deployed linear driver IN3214SZ, for 200G coherent optical interconnect applications, the IN4518SZ extends the reach of 200G coherent for long-haul applications and enables one set of hardware to serve multiple segments in the long-haul and metro markets. The IN4518SZ was showcased at the Optical Fiber Communications conference & exposition (OFC 2015) in Los Angeles (24–26 March).

Inphi's 45GBaud linear coherent product family was originally launched at September's European Conference on Optical Communications (ECOC 2014) with the IN4514SZ octal linear differential to single-ended MZM driver and the IN4550TA quad linear TIA/VGA (trans-impedance amplifier/variable gain amplifier).

Due to the ever-growing demand for more bandwidth, service providers and data-center operators are actively deploying 100G and 200G for long-haul and metro, while development accelerates for the next-generation higher capacity, says Inphi. The family of IN4514SZ, IN4518SZ and IN4550TA is designed to take network infrastructure to the next level, enabling the critical implementation of more complex and flexible modulation formats for 200G and 400G coherent systems in the long-haul and metro networks.

"Cost is currently the primary limitation to wider adoption of coherent technology for metro and long-haul applications," comments Andrew Schmitt, principal analyst Carrier Transport Networking at Infonetics Research. "With this new product Inphi is helping to reduce the cost and accelerate the adoption of 200G coherent systems," he adds.

"The IN4518SZ is the latest addition to our 45GBaud linear family to address market demands for high-performance linear drivers that can manage the growing traffic between data centers," says Lian Zhao, product line manager, Optical Interconnect, at Inphi. "It affirms Inphi's market leadership to enable dynamic, next-generation optical networking and gives existing 100G/200G coherent system designs an efficient upgrade path to 400G beyond," he claims.

# Inphi demos single-wavelength, single-fiber 100GbE, showcasing PAM4 56GBaud electronics to enable cost-effective 100G and 400G

At OFC, Inphi demonstrated a 100GbE four-level pulse amplitude modulation (PAM4) 56GBaud transmission system up to10km single-mode fiber, specifically with 100GbE running over a single full-duplex fiber pair using Inphi's real-time digital signal processing (DSP) engine, PAM4 electronics with multiple forward error correction (FEC) options and high-speed linear drivers and amplifiers. The demo showcased the technology that enables cost-effective 100G, with a roadmap to 400G and beyond, for intra-datacenter and datacenter-to-datacenter connectivity.

Existing 100G datacenter solutions use either four fibers or four wavelengths at 25Gbps per wavelength, putting a limit on bandwidth scalability and cost of future solutions. The demonstration at OFC shows that, by transferring the complexity from optics into CMOS electronics with PAM encoding, DSP and FEC technologies, one can attain four times as much bandwidth improvement compared with existing solutions, at a lower cost. Coupled with the availability of Inphi's high-speed linear driver and amplifier solutions, the demonstration showcases a complete electronics platform for single-lambda 100G solutions.

"Inphi led the industry by demonstrating a two-wavelength 100G solution at OFC last year," says Siddharth Sheth, VP marketing, Networking Interconnect, at Inphi. "The technology advances in this demonstration are invaluable to our datacenter, carrier and networking customers, who are relying on Inphi to build the next-generation datacenter and the network that supports it," he adds.

**Growth in the datacenter for 100GbE is on the horizon, but the cost and power consumption of 100G optics continues to be the biggest barrier**

"Growth in the datacenter for 100GbE is on the horizon, but the cost and power consumption of 100G optics continues to be the biggest barrier to more rapid deployment," comments Loring Wirbel, senior analyst at market research firm The Linley Group. "Single-wavelength designs such as PAM4 offer the most cost-efficient solution, so Inphi's demonstration today is an important milestone in accelerating that market growth for 100G," adds Wirbel.

**www.inphi.com**
**www.ofcconference.org**

# Avago introduces Micro-ITLA for coherent DWDM in 100G/400G transmission systems

Avago Technologies Ltd (which designs and supplies III-V-based analog interface components for communications, storage, consumer and industrial applications) has announced the availability of its new AFCU-UITLAXX micro-integrated tunable laser assembly, a high-performance, narrow-linewidth Micro-ITLA designed for both the transmission and local oscillator laser in coherent dense wave division multiplexing (DWDM) systems.

Based on Avago's proprietary external-cavity laser (ECL) technology and proven indium phosphide (InP) and silica-on-silicon chip technology and packaging platform, the new Micro-ITLA delivers a very narrow linewidth, low phase noise and what is claimed to be superior frequency accuracy (with a fine tuning frequency range of ±6GHz), improving system performance by reducing signal-to-noise penalties. With no moving parts, the device achieves excellent operational shock and vibration resistance.

Besides its narrow linewidth (<100kHz), the Micro-ITLA features high optical output power, off-grid tuning capability, and a gridless channel plan (with a user-defined optical frequency channel enabling Flex-grid or Gridless architecture). The device also features in-operation wavelength and power adjustment capability (with variable optical power tuning, ranging from +8dBm to +16dBm) suitable for applications in 100G PM-QPSK and 200G 16-QAM modulation formats. The device conforms to the OIF Micro-ITLA implementation agreement. With only one-third the size (a form factor of 20mm x 40mm x 7mm) and 25% less in electrical power consumption (<3.5W at 16dBm, 75°C) compared to the industry-standard large-form-factor ITLA, the new Micro-ITLA enables users to migrate to smaller-size optical line-card solutions or pluggable transceivers for next-generation 100G and 200G/400G transmission systems.

"The availability of high-performance, narrow-linewidth Micro-ITLA like the Avago AFCU-UITLAXX shall help accelerate the deployments of 100G and 400G transmission systems," says Stefan Rochus, director of Optical Components product marketing. "Leveraging Avago's volume proven optical and packaging technologies, our new Micro-ITLA enables transceiver and line-card manufacturers alike to deliver high-performing and more efficient coherent DWDM solutions," he adds.

Avago is ramping up production of its C-band tunable AFCU-UITLAXX now, with L-band tuning capability available in second-half 2015.

## Avago launches compact 4x10G TOSA and ROSA for 40G LR4 Lite

Avago has announced availability of its new 40GE-LR4 Lite transmit optical subassembly (TOSA) and receive optical subassembly (ROSA). The AFCP-CT4X10D and -CR4X10P respectively are designed for use in a quad small-form-factor pluggable (QSFP) transceiver module, providing long-range 40GbE interconnects for routers and switches in large-scale data-center networks.

The AFCP-CT4X10D TOSA delivers four coarse wavelength division multiplexed (CWDM) wavelengths in the 1310nm window on a single optical output. With a footprint of 15.9mm x 6.35mm and a height of 4.8mm, the device integrates four high-reliability, high-performance uncooled 10Gbps directly modulated lasers (DML), an optical multiplexer to combine the laser wavelengths, and four PIN photodetectors for back-facet power monitoring. The average TOSA launch power is

over -5.0dBm (per channel).

With a 15.8mm x 5.00mm footprint and a height of 4.4mm, the AFCP-CR4X10P ROSA integrates an optical de-multiplexer to separate four incoming CWDM wavelengths using four high-reliability, high-performance 10Gbps PIN photodetectors with integrated trans-impedance amplifiers (TIA). The average ROSA receiver sensitivity is under −13.5dBm (per channel).

The temperature range of both devices is −5°C to +75°C. Link distances are up to 2km at 4x10.3125Gbps over standard G.652 single-mode fiber (SMF).

"The introduction of our new 40GE-LR4 Lite TOSA and ROSA reinforces Avago's continued commitment to providing high-performance, cost-effective component solutions for data-center applications," says Stefan Rochus, director of Optical Components product marketing. "Leveraging Avago's proven indium phosphide (InP) laser technology — with over 1 trillion device service hours in the field — and low-cost component packaging infrastructure, these new TO-can based TOSA and ROSA enable more compact transceiver solutions while lowering system power consumption and costs for next-generation data-center networks," he adds.

**www.avagotech.com/fiber**

# Avago samples first production-worthy 100G QSFP28 SR4 and CFP4 LR4 transceivers

## New-generation 100G optical transceivers enables broad adoption of 100GE links for data centers

Avago Technologies Ltd (a designer and supplier of III-V-based analog interface components for communications, storage, consumer and industrial applications) has announced sample availability of its 100G QSFP28 SR4 and CFP4 LR4 transceiver module devices.

The AFBR-89CDDZ QSFP28 transceiver is designed for 100 Gigabit Ethernet (100GbE) short-range data-center interconnects, compliant with IEEE 802.3 100GBASE-SR4 and 100m multi-mode fiber media.

The AFCT-8450Z CFP4 transceiver is designed for 100GbE long-range data communications, compliant with IEEE 802.3 100GBASE-LR4 and 10km single-mode fiber media.

The AFCT- 8450Z is also compliant with OTN/OTL4.4 data applications.

"Avago is the industry leader in providing high-speed optical interconnects utilizing proprietary short-wave parallel optic and long-wave WDM technologies," claims Philip Gadd, senior VP & general manager of Avago's Fiber Optics Product Division. "The availability of 100G QSFP28 and CFP4 transceivers shall enable broad adoption of 100GE fiber links for data centers and accelerate the transition of data networks to 100G speeds to meet the ever increasing demand for bandwidth," he adds.

Avago showcased the AFBR-89CDDZ and AFCT-8450Z at the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March). The firm is sampling both the AFBR-89CDDZ and AFCT-8450Z and accepting orders now.

**www.avagotech.com**

# Avago gives live demonstrations of 32G Fibre Channel, 40G Ethernet, 100G Ethernet and 128G Fibre Channel transceiver technologies for next-generation data-centers and enterprise storage

At the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March), Avago Technologies gave live demonstrations of its latest optical transceiver technologies for next-generation data-center and enterprise storage applications.

As data-center networks transition to 100G speeds to support higher bandwidth demands, technical challenges emerge across various levels of the network from storage endpoints to servers to top-of-rack (ToR) and core switches. Avago says that it has re-thought the designs of chips, packaging, optics, modules and systems and developed new technologies addressing critical challenges of modern data-center design. The latest technologies are designed to support new data speed requirements while preserving existing infrastructure and, more importantly, meet the growing needs of modern data centers.

Avago's demonstrations at OFC included the following:

- vertical-cavity surface-emitting laser (VCSEL)-based optical PAM-4 technology for next-generation optical transceivers;
- extended-reach 100G QSFP28 eSR4 transceivers communicating over 300m of multi-mode fiber (MMF);
- 128GFC QSFP28 transceiver interoperating with 32GFC SFP+ transceivers;
- 40G BiDi MMF QSFP+ transceivers operating over duplex fiber; and
- PCIe-over-Optics ToR switch solution enabling high-density rack connectivity.

**Avago has re-thought the designs of chips, packaging, optics, modules and systems. The latest technologies are designed to support new data speed requirements while preserving existing infrastructure and, more importantly, meet the growing needs of modern data centers**

"Avago has consistently been in the forefront of data-center technologies," says Philip Gadd, senior VP & general manager of the Fiber Optics product division. "The great breadth of our new technologies showcasing at OFC 2015 further demonstrates Avago's leadership and continued commitment to addressing the growing data-center market," he adds.

**www.ofcconference.org**
**www.avagotech.com/fiber**

# Finisar announces technology roadmap for next-generation multimode fiber interfaces

At the Optical Fiber Communication conference & exposition (OFC 2015) in March, fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA announced details of its technology roadmap for next-generation multimode fiber (MMF) interfaces. This includes a new suite of products capable of links as long as 300m at 40Gb/s and 100Gb/s.

Multimode fiber uses technology based on vertical-cavity surface-emitting lasers (VCSELs), which represents the lowest-power, lowest-cost and highest-density interconnect technology available. MMF is the most common optical interconnect between systems (i.e. servers, network switches and routers), and Finisar says that its investment in the technology will help to ensure that multimode fiber continues to be the most cost-effective interconnect for all but the largest data centers.

According to market research firm Gartner (in a consulting project for Corning Optical Communications), 94% of all data-center sites built in 2014 were smaller than 250,000ft$^2$, and this percentage is not expected to change through 2018. A 300m optical link is sufficient for even the longest distances inside a 250,000ft$^2$ data center. Finisar says that its MMF technology roadmap will support current- and next-generation requirements for the vast majority of data centers at cost points typical of traditional VCSEL-based solutions.

To support this roadmap, Finisar and industry partners aim to drive major advances in multimode technology, designed to enable higher bandwidth, longer reach and reduced infrastructure cost for both enterprise and data-center applications. The firm's multimode technology roadmap is based, in part, on four key themes:

1. Support of the installed base: support for 40GbE, 100GbE and beyond on the existing installed MMF fiber plant;
2. Short-wave wavelength division multiplexing (SWDM): the ability to multiplex multiple lanes onto a single fiber to reduce the fiber count and enable duplex-LC interfaces for 40GbE, 100GbE, and beyond;
3. Lane rates of more than 25Gb/s: developing and standardizing technology that enables multimode VCSELs to operate at 50Gb/s and beyond, to enable future generations of both single-lane and multi-lane optical interfaces; and
4. Wideband MMF: support for the definition and standardization of wideband multimode fiber to enable WDM transmission over links that are greater than 300m.

**Product demonstrations at OFC**

At OFC, Finisar demonstrated various implementations of its MMF technology roadmap. Based on the firm's SWDM VCSEL technology, these demonstrations included:

- a 40Gb/s SWDM4 transceiver in a QSFP+ form factor, capable of 300m on duplex OM3 MMF (at less than 1.5W power consumption, this device enables a simple upgrade path for data centers that have deployed duplex MMF for 10Gb/s applications);
- a 100Gb/s SWDM4 technology demonstration of 70m transmission over duplex OM3 MMF and 100m over OM4 MMF, and with a roadmap to 300m using OM4 MMF.

"Finisar is committed to the most cost-effective technologies for our enterprise and data-center customers, and we are investing more in VCSEL-based products than ever before," says Rafik Ward, VP of marketing. "Through these investments, we expect to build a pipeline of new high-speed products that ensures MMF continues to be the most cost-effective deployment decision for data centers for years to come."

## Finisar launches SFP28 and QSFP28 modules for high-port-count 25G and 100G data-center applications

At OFC, Finisar demonstrated multiple new products, including a variety of optical modules based on the 100G QSFP28 MSA form factor, as well as the what is claimed to be the first 25G Ethernet SFP28-SR transceiver, based on the SFP+ form factor.

The optical modules are designed for 100G Ethernet applications within the data center. The product portfolio includes what is reckoned to be the first 100G-CWDM4 module, the first 100GBASE-LR4 module under 3.5W, and a 100GBASE-SR4 module breaking-out to four SFP28-SR modules.

**100G LR4 and CWDM4 QSFP28**

Finisar demonstrated new products that enable the implementation of various reaches in the QSFP28 MSA form factor in high-port-count 100G systems for data centers. Targeting duplex single-mode fiber applications, a new 100GBASE-LR4 QSFP28 optical transceiver module was demonstrated on a 10km 100G link, interoperating error-free with a CFP2 LR4 transceiver. By using a new generation of low-power distributed feedback (DFB) laser technology, the module supports a maximum power dissipation of 3.5W, enabling up to 4Tb/s in a 1RU Ethernet switch or router card. It provides a re-timed 4x25G electrical interface to the host board, meets IEEE 802.3 standards, and interoperates with existing 100GBASE-LR4 CFP, CFP2 and CFP4 modules.

Also, Finisar demonstrated the first

# Finisar demonstrates 200G coherent portfolio, launching CFP2-ACO & first 5"x7" Flex-Rate transponder

## UltraSpan technology for 100G ultra-long coherent links

At the Optical Fiber Communication conference (OFC 2015) in March, Finisar demonstrated several new coherent transport products, including a pluggable CFP2-ACO coherent transceiver supporting 100G QPSK and 200G 16QAM applications, and what is claimed to be the first 5" x 7" Flex-Rate (40G to 200G) coherent transponder with internal DSP. Separately, Finisar demonstrated a 100G ultra-long repeater-less fiber-optic link, using its Ultraspan products.

**Flexible coherent technology supporting 40 /50G BPSK, 100G QPSK and 200G 16QAM**

With its new Flex-Rate transponder and CFP2-ACO transceiver, Finisar brings next-generation coherent 200G technology to datacenter-interconnect and metro/long-haul DWDM applications. Coherent 200G technology offers the lowest cost-per-bit solution available, says the firm, and enables 400G transport using two wavelengths. The demonstration shows 200G 16QAM interoperability between Finisar's Flex-Rate transponder and a CFP2-ACO module. These flexible solutions support multiple combinations of modulation format, data rate and reach, simplifying system integration.

The Flex-Rate transponder offers what is claimed to be industry-leading performance and high output powers up to +7dBm. Supported by the embedded Lightspeed II CL20010 DSP (digital signal processor) from ClariPhy, the module is said to provide exceptional optical signal-to-noise ratio (OSNR) tolerance and extended chromatic dispersion tolerance, reducing the need for regeneration. The module is suitable for applications in transport and routing systems. A variant supporting 40/50G BPSK is also available for ultra-long-haul and submarine applications.

Based on Finisar's indium phosphide (InP) technology, the CFP2-ACO transceiver offers a flexible architecture. Using linear RF drivers, it can support any modulation format from 40/50G BPSK to 200G 16QAM. Separate lasers for transmit and receive allow the module to support different wavelengths in each direction. The module follows the mechanical and management interface defined by the CFP MSA and supports all three classes defined by the draft OIF Implementation Agreement. While existing router and transport equipment typically offer 1–2 coherent ports per line-card, the CFP2-ACO can enable system vendors to offer high-density pluggable interfaces supporting 1Tb/s or more on a line-card. Both products are currently sampling.

**With its new Flex-Rate transponder and CFP2-ACO transceiver, Finisar brings next-generation coherent 200G technology to datacenter-interconnect and metro/long-haul DWDM**

**UltraSpan technology for ultra-long fiber-optic links**

Finisar also showcased new technology based on its UltraSpan amplifiers to extend the reach and capabilities of traditional telecom systems. For ultra-long (400km) fiber-optic links (as used in applications such as oil, gas, mining, energy, and transportation), the firm demonstrated a 100G coherent link that does not require repeaters. UltraSpan products are currently shipping in volume.

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www.finisar.com

QSFP28 CWDM4 module, operating error-free over a single-mode fiber link of 2km. Using the firm's new-generation, low-power DFB laser technology, the module also supports a maximum power dissipation of 3.5W. The module meets the CWDM4 MSA optical requirements.

**Emerging 25G Ethernet standard**

Finisar also demonstrated the first commercially available SFP28-SR module, supporting the emerging 25GBASE-SR Ethernet standard. Based on the SFP+ MSA form factor, the vertically integrated solution enables error-free transmission of 25Gb/s over 100m of OM4 multimode fiber. The module is intended to enable a new generation of high-density 25G Ethernet switches and NIC cards, facilitating server connectivity in data centers, and a conventional and cost-effective upgrade path for enterprises deploying 10G Ethernet links today in the ubiquitous SFP+ form factor.

The demonstration showed four SFP28-SR modules interoperating with a 100GBASE-SR4 module in QSFP28 form factor. The QSFP28 SR4 module is a vertically integrated solution that meets IEEE 802.3 standards and MSA requirements with power dissipation well under 3.5W. The module supports both 100GBASE-SR4 as well as 4x25G breakout applications.

The QSFP28 CWDM4 and LR4 and the QSFP28 SR4 and SFP28-SR modules are all sampling now.

"We see a future ecosystem of high-density 100G QSFP28- and 25G SFP28-based switches that will leverage Finisar's high-volume capabilities, vertical integration and investment in underlying 25Gb/s components," says director of strategic marketing Craig Thompson.

# Source Photonics announces production ramp and general availability of 100G QSFP28 transceiver

Optical communication product maker Source Photonics Inc of West Hills, CA, USA has announced volume shipments of its 100G QSFP28 LR4 and LR4 Lite products from its expanded manufacturing facilities.

Source Photonics says that, since demonstrating the products at OFC 2014 in San Francisco, it has made extensive investments in its wafer fab and fully automated manufacturing lines for 100G transmitter and receiver optical subassemblies (TOSAs and ROSAs).

In parallel to the roll-out of the TOSA and ROSA manufacturing lines, the firm has expanded matching 100G capacity in its transceiver module assembly & test line to support aggressive volumes projected by industry analysts. "Our current forecast reflects the increased urgency of hyper-scale data-center builders to ramp 100GbE in their switching fabrics," comments Dale Murray, principal analyst for LightCounting Market Research.

"This market wants to go directly to the QSFP28 form factor," he adds. "Combined with our manufacturing investments, we are very excited to be able to support our lead Tier-1 customers' ramp to volume."

The QSFP28 form factor represents the most compact 100G interfaces available, and enables data-center and network operators to achieve the maximum front-plate density. Two versions of the transceivers now shipping in volume are available: a 100GBase-LR4-compliant product and a 2km-reach version targeted at high-density data-center applications.

"The market interest in our small-form-factor 100G products has been tremendous," says Source Photonics' chief technology officer Mark Heimbuch. "Featuring a typical power consumption of less than 3W including a full duplex CDR [clock & data recovery] for a wide range of use cases, it is interoperable with standard IEEE LR4 larger form-factor 100G optics," he adds. "Combined with our manufacturing investments, we are very excited to be able to support our lead tier-1 customers' ramp to volume."

**Our current forecast reflects the increased urgency of hyper-scale data-center builders to ramp 100GbE in their switching fabrics**

Source Photonics hosted a live demonstration of the QSFP28 module operating in an Arista 7280SE-68 Top-of-Rack switch at the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March).

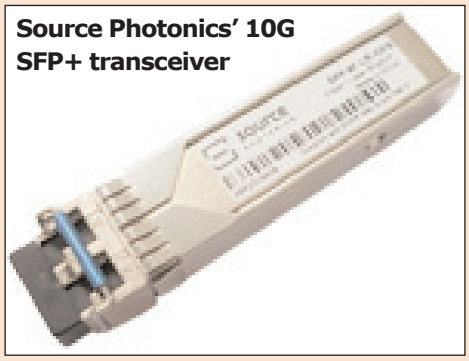
In addition to the 100G QSFP28 LR4 and LR4 Lite, Source Photonics is also shipping the 100G CFP4 LR4 (designed for router and transport systems and supporting multi-rate Ethernet and OTU4 applications) from the same manufacturing line.

**www.sourcephotonics.com**
**www.ofcconference.org**

## Source Photonics adds extreme-temperature-hardened SFP+ transceivers for wireless infrastructure

At the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March), optical communication product maker Source Photonics Inc of West Hills, CA, USA announced the addition of extreme-temperature-hardened products to its portfolio of CPRI SFP+ transceivers for antenna front-haul in wireless infrastructure deployments.

The new 10G LR-Lite SFP+ modules will operate to full spec compliance up to a case temperature of 90°C with standards-compliant power dissipation. The extended temperature range facilitates deployment of more compact and efficient remote radio units (RRU), enabling higher density and more efficient use of infrastructure and tower investment.



**Source Photonics' 10G SFP+ transceiver**

The new 90°C LR-Lite SFP+ product is based on 10G laser chips developed and manufactured in Source Photonics' own indium phosphide (InP) foundry. It has completed all Telcordia GR-468 requirements for 90°C operation, and is available for volume orders.

The extreme-temperature SFP+ builds on Source Photonics' first-to-market release of the 6G 2km SFP+ used in 3G networks and the 10G LR-Lite deployed widely in LTE networks globally.

With a broad portfolio of temperature-hardened interfaces covering CPRI data rates from 1Gb/s to 10Gb/s in single- and dual-fiber versions, as well as key WDM interfaces for deployments where fiber economy is critical, Source Photonics says that its products support a wide range of wireless network architecture options. The 90°C SFP+ is the newest addition to this portfolio, improving tower infrastructure return on investment in addition to network architecture alternatives, says the firm.

# Oclaro demonstrates first SFP transceiver transmitting 28Gbps over 10km single-mode fiber

## Doubles transmission rate for Gen 6 Fiber Channel (32GFC) applications compared to 16GFC

At the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles (24–26 March), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) is demonstrating prototypes of what is claimed to be the first SFP28-LR transceiver capable of transmitting 28Gbps data rates over 10km with about 1 Watt of power consumption.

The SFP28-LR transceiver is SFF-8432 compliant and delivers data rates of 25.78125Gbps (25GE)/ 28.05Gbps (32GFC) with a reach of up to 10km. Additional features include a bit-error rate (BER) of less than $10^{-6}$, C-Temp, and a power consumption of about 1W. Target applications for SFP transceivers operating at 24–28Gbps include Ethernet (25GE) and Fiber Channel (32GFC).

Timed with the market availability of Gen 6 Fiber Channel (32GFC, 28.05Gbps) applications, the new SFP28 transceivers double the transmission rate of previous Fiber Channel solutions (16GFC, 14.025Gbps) and enable the high throughput, energy efficiency and enhanced security required by new hyper-scale SSD storage systems and data centers.

Hyper-scale SSD storage systems and data centers are a vital part of the core infrastructure used in cloud computing, where rapid and reliable storing, accessing, and processing of Big Data represent major technical challenges, says Oclaro. Serial transmission rates of around 25Gbps may also be required in a variety of emerging applications, such as 25G Ethernet, which is being standardized by the IEEE. In these next-generation network architectures, SFP28 transceivers provide a cost-effective migration path from existing 10G SFP+ designs by offering a 2.5x increase in capacity. Oclaro says that SFP28 modules are also lower in cost, smaller in size, and consume less power than other available options to upgrade the bandwidth, such as 40G QSFP+ transceivers, which are based on four 10G lanes that are multiplexed in wavelength for applications requiring a reach of 10km.

"With the SFP28-LR transceiver, Oclaro customers will be ready to meet the needs of Gen 6 Fibre Channel applications," says Yves LeMaitre, president of Optical Connectivity Business at Oclaro. "In addition, enterprise and data-center hardware customers will be able to leverage this innovative new product, which represents Oclaro's first contribution to the fast expanding 25G Ethernet eco-system," he adds.

"We see initial demand for 32G Fiber Channel materializing in early 2016, and a large portion of the revenue will be in the single-mode segment," comments Vladimir Kozlov, founder & CEO of LightCounting Market Research. "In addition, we are expecting demand for data rates above 10Gbps in next-generation applications such as wireless or 25G Ethernet, once these become standardized."

Oclaro expects to start sampling the SFP28-LR transceivers in second-half 2015, with a production release scheduled for early 2016.

**www.oclaro.com**

# Oclaro expands presence in Southern California through sales representative deal with Infinity Sales

Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has signed a sales representative agreement with Infinity Sales, a semiconductor manufacturers' representative in Southern California. The partnership will enable Oclaro's portfolio of optical transceiver solutions for 10G, 25G, 40G, and 100G applications to reach a wider range of data center, telecom, enterprise and storage customers.

Founded in 1989, Infinity Sales provides partners with commercial and technical representation. Its team of sales engineers has over 120 years of combined experience at Infinity Sales and over 200 years of electronics industry tenure.

"Oclaro is the established leader of complete 10G through 100G transceiver solutions that deliver high performance and long reach with low power dissipation and best-of-class reliability," comments Infinity Sales' general manager Robert Flournoy. "The Infinity team of sales engineers is ideally suited to execute strategic sales campaigns that will build on the long-term customer engagements Oclaro currently enjoys in the Southern California region," he believes.

"Oclaro's vertically integrated optical transceivers are critical for enabling the next-generation high-speed networks that telecom operators, cloud service providers and enterprises need to be competitive in today's age of Big Data," says Oclaro's chief commercial officer Adam Carter. "By partnering with Infinity Sales, we can bring these solutions to a broader range of customers."

**www.infinitysales.com**

# Oclaro samples dual micro-ITLA, cutting footprint by 25% and power dissipation by 1W for 200/400G coherent links

Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) is sampling a new dual micro-ITLA (integrable tunable laser assembly) featuring a 25% reduction in size and 1 Watt lower power consumption compared to two discrete micro-ITLAs.

Users will now have the flexibility of either employing a separate laser for transmit and local oscillator for 100G/200G deployments or benefitting from the high output power of the dual micro-ITLA in dual-carrier applications for next-generation 200G/400G coherent links. This will enable significant savings in board space on line-cards, which require components that provide high density and low power dissipation.

"Oclaro is now delivering the critical connectivity solutions for 200G and 400G networks needed to meet the world's growing demand for more bandwidth," says Richard Craig, president of Oclaro's Integrated Photonics Business. "Many of our customers are already completing 400G trials, and Oclaro components will be there with the performance, power and size requirements needed to accelerate the deployment of these next-generation networks," he adds.

The dual micro-ITLA features Oclaro's DS-DBR (digital supermode distributed Bragg reflector) wide-band tunable laser technology, which is based on a fully monolithic indium phosphide chip designed for high-volume and low-cost manufacturing. With no moving parts, the dual micro-ITLA is a low-voltage, electronically tuned device that can enable rapid wavelength switching. The new product is suitable for 200G and 400G coherent applications because its small footprint and reduced power consumption enable users to design higher densities into their systems, says Oclaro.

Key features of the dual micro-ITLA include the following:

- full C-band dual-laser tunable source (1529–1568nm);
- high power: +15.5dBm nominal EOL (end-of-life) and variable output power range of 8dB;
- 0.1GHz minimum channel grid spacing and electronic shutter for dark tuning;
- low power dissipation, 8W (EOL);
- narrow line-width, 400kHz maximum, excellent side-mode suppression ratio (SMSR) >40dB, and low RIN (relative intensity noise).

The dual micro-ITLA is sampling now. Oclaro expects to begin ramping up volume production in April.

**www.oclaro.com**

# Emcore demonstrates end-to-end DOCSIS 3.1 CATV link

At the Optical Fiber Communications conference & exposition (OFC 2015) in Los Angeles (24–26 March), Emcore Corp of Alhambra, CA, USA (which provides compound semiconductor-based optical components, subsystems and systems for the broadband and specialty fiber-optics market) hosted a demonstration of its end-to-end DOCSIS 3.1 CATV transmission link capabilities.

A DOCSIS 3.1-compliant prototype of Emcore's Medallion 6000 Series 1550nm CATV Transmitter was featured, along with the new Medallion 2100 Optical A/B Switch and Medallion 7100 CATV Fiber Amplifier transmitting over a 40km fiber link to Emcore's RFoG (radio frequency over glass) Transceiver.

Based on Emcore's proprietary continuous wave laser technology, the Medallion 6000 externally modulated transmitter couples high optical output power up to 11.0dBm with low optical linewidth, resulting in what is claimed to be unmatched performance. The transmitter leverages proprietary pre-distortion circuitry to provide superior CTB (composite triple beat) and CSO (composite second order) performance with SBS (stimulated Brillouin scattering) suppression levels of over 21dBm through 40km of fiber.

The Medallion 2100 Optical A/B Switch is a high-performance solution for network protection and optical redundancy in CATV/FTTx networks. Its automatic switching protects the network from inadvertent service outages due to upstream optical signal degradation.

The Medallion 7100 Fiber Amplifier provides very stable optical outputs over a wide operating temperature range, as well as the exceptionally high power and low noise figures demanded by CATV applications.

Emcore's RFoG Transceiver is passive optical network (PON)-compatible and supports 1310/1590/1610nm burst mode analog return-path, and digital or QAM upstream.

"Our end-to-end DOCSIS 3.1 demonstration at the OFC shows Emcore's capabilities to deliver the highest-quality video and audio, along with high-speed data transmission in a DOCSIS 3.1-compatible system," says Gyo Shinozaki, director of marketing for CATV products. "Emcore's line of CATV components and systems will support cable operators as they move to this latest DOCSIS standard for higher-speed data transfer over their existing CATV networks," adds Shinozaki.

Also at OFC, Emcore presented its complete line of laser and optical receiver components for the transmission of video, voice and data signals over high-speed fiber optics, as well as components for wireless and distributed antenna system (DAS) applications.

**www.emcore.com**

# Oclaro sampling second-generation tunable SFP+ module, targeting FTTH and wireless front-haul

## Operation extended to 85°C with maximum power consumption of 1.8W

Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) is sampling its second-generation tunable SFP+ module operating at very high temperatures of up to 85°C with very low power consumption.

Building on Oclaro's history of 10G tunable dense wavelength division multiplexing (DWDM) products, the new tunable SFP+ module delivers the size and power needed for next-generation data-center, metro and regional optical networks, the firm says. It also serves as a building block for emerging new applications such as fiber-to-the-home (FTTH) and 4G/5G LTE wireless front-haul networks that might require DWDM functionality in the future.

Oclaro says that tunable SFP+ modules are key building blocks for next-generation network equipment because they can reduce the size and power consumption for 10G connections while supporting the network operators' rapidly increasing bandwidth capacity needs driven by data-intense applications. The firm has been shipping its first-generation tunable SFP+ module in volume production since Autumn 2014 and is now sampling this second-generation module to key customers. The firm showcased its complete line of tunable laser products at the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles in March.

"To effectively address the bandwidth bottlenecks in the network caused by increased internet and mobile traffic, our customers are under constant pressure to deliver higher-density line-cards operating at high temperatures without sacrificing power and performance," says Yves LeMaitre, president of Optical Connectivity Business at Oclaro. "Our tunable SFP+ modules solve these pain points by leveraging Oclaro's indium phosphide (InP) leadership in photonic integration to achieve market-leading performance across a wide temperature range, and it also positions us well for future high-volume applications where low cost and operation at high temperatures are of the essence," he adds.

The second-generation tunable SFP+ module is fully compliant with the SFP MSA form factor, operates below 1.5W from 0°C to 70°C without CDR (clock and data recovery), and supports extended temperatures up to 85°C with a maximum power consumption of 1.8W.

Key features of the tunable SFP+ module include:

- support for high Tx power (up to +1.2dBm);
- support for SONET/SDH applications with CDR version;
- multi-rate operation from 9.95Gb/s to 11.3Gb/s;
- tunability across the full C-band with 96 channels on the ITU-T 50GHz grid; and
- an avalanche photodetector (APD) supporting limiting or linear electrical interfaces.

Because tunable lasers enable network operators to easily switch between different wavelengths in order to optimize network performance, they have been rapidly replacing fixed-wavelength DWDM-XFP/SFP+ or tunable XFP modules in metro WDM networks, notes Oclaro.

Oclaro's broad tunable SFP+ portfolio also includes zero chirp, L-band, and PIN ROSA variants.

**www.oclaro.com**

# InnoLight launches 100G QSFP28 and CFP4 transceivers

InnoLight Technology Corp of Suzhou, China, which designs and makes optical transceivers for the cloud computing market, has released its full family of 100G QSFP28 and 100G CFP4 transceivers.

As data-center traffic is expected to triple in the next five years, the communications industry needs to upgrade its networks from 10G to 40G and to 100G, says the firm. The IEEE 802.3bm 100G QSFP28 and CFP4 offer the latest technology to enable this rapid bandwidth expansion, it adds.

InnoLight's new 100G QSFP28/CFP4 product family includes:

- TF-FCxxx-N00 — 100G QSFP28 AOC, up to 100m OM3 transmission;
- TR-FC85S-N00 — 100G QSFP28 SR4, up to 100m OM3 transmission;
- TR-FC13L-N00 — 100G QSFP28 LR4, up to 10km SMF transmission;
- TR-VC13T-N00 — 100G QSFP28 PSM4, up to 2km SMF transmission;
- TR-KC85S-N00 — 100G CFP4 SR4, up to 100m OM3 transmission;
- TR-KC13L-N00 — 100G CFP4 LR4, up to 10km SMF transmission;
- TR-KC13E-N00 — 100G CFP4 ER4, up to 30km SMF transmission.

In addition, in second-quarter 2015 InnoLight is introducing 25G SFP28 AOC, SR and LR Lite products.

"QSFP28 is emerging as the preferred form factor for data-center networks in 100G following the wide adoption of the QSFP+ form factor in 40G," says chief marketing officer Osa Mok. "InnoLight's QSFP28 design is based on a unique and low-cost optical platform which delivers the highest optical coupling efficiency in the industry," he claims.

InnoLight's QSFP28 and CFP4 100G transceiver product family is now ready for sampling. Mass production is planned for second-half 2015.

**www.innolight.com**

# Molex expands fiber-optic range through Oplink

High-speed fiber-optic interconnect firm Molex Inc of Lisle, IL, USA has expanded its fiber-optic technology platform following the acquisition in late December of Oplink Communications Inc of Fremont, CA, USA by Molex's parent firm Koch Industries Inc of Wichita, KS, USA. Molex will now manage Oplink, a provider of optical communication components, intelligent modules and subsystems. "Molex collaborates closely with customers to directly address their fiber optic design challenges through innovative electronic solutions"

"Oplink's capabilities, expertise and proven technologies, combined with our optical product portfolio and global engineering and manufacturing platform, will put Molex in a unique position to deliver complete fiber-optic solutions to our customers worldwide," reckons Doug Busch, VP & general manager of the Molex optical solutions group.

Acquired by Koch in Autumn 2013, Molex supplies fiber-optic interconnect systems, including connectors and adapters, optoelectronics, optical assemblies, backplanes, optical circuitry and integrated systems for telecoms, datacom, medical, military/aerospace and other industries. The firm reckons that Oplink's record in supplying passive optical products, OMS (optical manufacturing solutions) and active optoelectronics adds breadth and depth to its portfolio of optical connectivity products.

Oplink specializes in creating solutions using optical transport and transmission technologies for wireline, wireless telecom and datacom infrastructure markets and data-center applications, as well as adjacent the sectors of CATV, government/military and optical sensing. As bandwidth-intensive applications continue to drive upgrades and expansion across networks, Oplink addresses DWDM/CWDM bandwidth creation, bandwidth management, optical amplification, switching and routing, wavelength conditioning, monitoring and protection, connectivity and system-level integration of active optoelectronics and passive optical components. These optical solutions are fully supported by vertically integrated design and manufacturing services, says the firm.

"As our customers confront increasingly complex challenges, Molex is committed to creating more customer value by offering integrated solutions that leverage a broad range of high-quality optical products and technologies," says Busch.

**www.molex.com/opticalsolutions**

## Molex and Oplink demonstrate transmission and transport solutions

At the Optical Fiber Communication Conference & exposition (OFC) in Los Angeles in March, high-speed fiber-optic interconnect firm Molex Inc of Lisle, IL, USA featured demonstrations of new products plus a product showcase of solutions for optical communications and networking applications.

Live demonstrations included:

- QuatroScale zQSFP+ (QSFP28) 4x28G (100G) active optical cable (AOC) connected to a Mid Board Optical Module (MBOM) 8x28G (200G). The new QuatroScale solutions are based on silicon photonics CMOS technology, achieving the longest reach coupled with the highest reliability of any 28Gbps product on the market, it is claimed. QuatroScale 100Gbps zQSFP+ AOC and on-board module solutions run at low power consumption of 2W per 100G, but can reach up to 4km. The demo showcases an optical link consisting of a zQSFP+ module on one end and an MBOM module on the other, with data passing between at 25.78Gbps.
- iPass+ (Mini-SAS) HD AOC, which delivers SAS-3.0, 48Gbps data rates over four lanes at 12Gbps each, with reaches of up to 100m. The fiber-optic cables complement copper iPass+ HD connectors and cables and provide an end-to-end solution for large-scale enterprise and data-center storage applications. The demo showcased traffic at 12Gbps.
- RayXpress ROADM subsystem platform, an end-to-end solution based on a wavelength-selective photonic engine and a Programmable Broadcast-Route-and-Select (PBRS) architecture that performs as a wavelength-selective cross-connect (WSX or WXC) while supporting the CDC add/drop ports. This subsystem features a different wavelength-selective core engine and additional in-house built-in key functional blocks of flexible grid OCM, OSC transceiver, amplifiers/amplifier array, fiber shuffle and multicast switches, as well as the turnkey circuit pack- or chassis-level integration capable of executing network interface protocols. PBRS-based RayXpress offers a complementary alternative in terms of savings on cost, space and power for the lower degree nodes found in the metro regional, enterprise, data-center and Cloud networking applications.
- 4x28G DWDM CFP transceiver. The 4x28G DWDM CFP transceiver is based on NRZ modulation format, and direct detection with advanced digital signal processing to achieve transmission of 100Gbps data over 80km without external dispersion compensation. The strong digital signal processing also enables the use of low-cost mass-produced optical components and makes it an alternative to more complex coherent-detection-based product offerings. The 100Gbps DWDM CFP presents an economic solution for bandwidth-demanding inter-data center and metro optical networking applications, says Molex.

# Mellanox's LinkX 100Gb/s cables deployed commercially

Mellanox Technologies, Ltd, a supplier of end-to-end InfiniBand and Ethernet interconnect solutions and services for data-center servers and storage systems, has announced commercial deployments of its new 100Gb/s LinkX active optical cables (AOCs) and direct attach copper cables (DACs) for data-center and high-performance computing applications. The new LinkX cables use the high-density, low-power, low-cost QSFP28 form factor, enabling 36 ports in a 1U switch, making 100Gb/s deployments as easy as 10Gb/s.

"With the high performance and the amazing $10^{-15}$ BER [bit error rate] of LinkX DACs and AOCs, we are achieving 100Gb/s full wire speed," comments Jorge Vinals, director at Minnesota Supercomputing Institute at the University of Minnesota. "Our EDR InfiniBand cluster is the first of its kind in the US and, with 100Gb/s capabilities, the EDR InfiniBand large-scale cluster will help us perform critical research at the University of Minnesota," he adds.

"Mellanox is the first and only company to offer plug & play 100Gb/s copper, VCSEL and silicon photonics cables in the QSFP28 form factor," claims Mellanox's VP of marketing Gilad Shainer. "Our ability to drive 100Gb/s throughput over long-distance DAC cables delivers a major cost advantage to our customers and reduces overall data-center CapEx and OpEx," he adds. "All our cables are designed to make 100Gb/s deployments as simple as 10Gb/s."

Mellanox says that its 100Gb/s active optical cables take advantage of a new generation of ICs that fully integrate multiple 25Gb/s clock & data recovery functions (CDR). These ICs also dramatically reduce power consumption for the optical engine to far less than 3.5W, the requirement of the small QSFP package.

Mellanox adds that, to ensure that all LinkX cables and transceivers work the first time and every time, it subjects its products to a full system test in a stressed environment. Network engineers do not have to waste time debugging a new installation with untested products. With LinkX products, installation experts can bring up new clusters fast, with fewer interconnect problems and higher quality and signal integrity.

All commercial versions of LinkX interconnect products endure full system testing to $10^{-15}$ BER in order to maximize overall data-center performance. A BER of $10^{-15}$ provides 1000x fewer transmission errors than many competing products, it is claimed. Fewer transmission errors translate to fewer re-tries, higher system performance, and more revenue-generating traffic, the firm adds.

**www.mellanox.com**

## Mellanox launches next-gen 100Gb/s silicon photonics transceivers

Mellanox introduced three new LinkX 100Gb/s solutions with a live demonstration at the Optical Fiber Communications expo (OFC 2015) in Los Angeles in March.

All LinkX 100Gb/s transceivers and cables support the high-density, low-power, QSFP28 connector-based Switch-IB switch platform. The Switch-IB 36-port 100Gb/s InfiniBand switch delivers 7.2Tb/s of aggregate throughput in a 1U, making it the world's highest-performance, ultra-dense end-to-end platform, it is reckoned. The robustness, density and standard QSFP connectors and cables enables 100Gb/s networks to be as easy to deploy as 10Gb/s, the firm adds.

The new LinkX products include:

- 100Gb/s 1550nm parallel single-mode transceivers in the QSFP28 form factor, capable of reaches up to 2km. Using a new generation of LinkX drivers, trans-impedance amplifiers (TIAs) and silicon photonics chips, the low-power transceiver consumes at most 3.5W (2.5x more efficient than most 40G QSFP solutions). The new transceiver provides data centers with a 2km-reach, high-density, low-cost solution using single mode fiber.
- 100Gb/s VCSEL transceivers — Mellanox has also introduced its 100G vertical-cavity surface-emitting laser (VCSEL) transceiver in the QSFP28 form factor with reaches of 100m over multi-mode fiber (MMF). New drivers and TIAs enable a low-power, low-cost solution for existing installations of OM3 or OM4 fiber. The transceiver consumes only 2.0W (maximum) with no re-timing, and 2.8W (maximum) with full retiming.
- 100Gb/s splitters to connect 100G ports to 25G and 50G ports — New copper splitter breakout cables efficiently interconnect 100Gb/s QSFP28 switch ports to a new generation of high-performance servers and storage appliances with 25G and 50G ports. Using zero power, they are the low-power, green solution for connectivity inside the rack, says the firm.

OFC demo features plug & play 100Gb/s LinkX cables and transceivers in end-to-end network using new generation of 7.2Tb/s switches and 100Gb/s adapters

At the core of the OFC demonstration are multiple Mellanox Switch-IB EDR 100Gb/s InfiniBand switches that achieve what is claimed to be record port-to-port latency of less than 90ns. Switch-IB has 36-ports of 100Gb/s to provide 7.2Tb/s of switching capacity and ultra-low latency and power consumption. Compared with the previous generation of InfiniBand switches, Switch-IB delivers nearly twice the throughput per port with half the latency.

# IBM attaches silicon photonic chips directly onto processor package

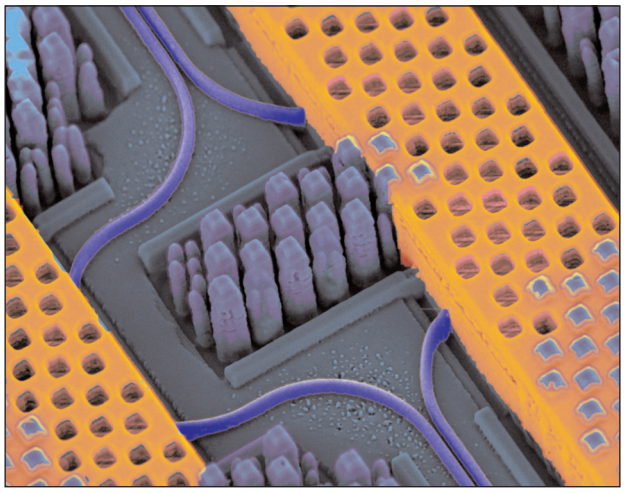
## Transceiver-free integration promises faster, cheaper and more energy-efficient cloud data centers

The computing and telecoms industries are developing systems to store information in the cloud and analyze enormous amounts of data. IBM Research says that it has demonstrated what could be a key step toward commercializing this next generation of computing technology by establishing a method to integrate silicon photonic chips with the processor in the same package, avoiding the need for transceiver assemblies. "This integration scheme has the potential to massively reduce the cost of applying silicon photonics optical interconnects in computing systems"

The new technique, presented on 25 March at the Optical Fiber Communication conference & exposition (OFC 2015) in Los Angeles, CA, USA (Presentation W3A.4, 'Silicon Photonics for the Data Center'), should be able to lower the cost and increase the performance, energy efficiency and size of future data centers, supercomputers and cloud systems.

Compared with traditional electronic links in existing computers, optical links using photonic devices can transmit more information over larger distances and are more energy efficient than copper-based links. To optimally benefit from this technology, a tight integration of the electrical logic and optical transmission functions is required. The optical chip needs to be as close to the electrical chip as possible to minimize the length of electrical connection between them. This can only be accomplished if they are packaged together, says IBM.

"IBM has been a pioneer in the area of CMOS-integrated silicon photonics for more than 12 years," claims Bert Offrein, manager of the photonics group at IBM Research – Zurich. "In addition to the silicon technology advancements at the chip-level, novel system-level integration concepts are also required to fully profit from the new capabilities silicon photonics will bring," he adds.



**Angled view of part of IBM silicon nanophotonics chip.**

Optical interconnect technology is currently incorporated into data centers by attaching discrete transceivers or active optical cables (AOCs), which come in pre-assembled building blocks. The pre-packaged transceivers are large and expensive, limiting their large-scale use, Offrein says. Furthermore, such transceivers are mounted at the edge of the board, resulting in a large distance between the processor chip and the optical components.

Offrein and his IBM colleagues from Europe, the USA and Japan instead proposed an integration scheme in which the silicon photonic chips are treated similarly to ordinary silicon processor chips and are directly attached to the processor package without pre-assembling them into standard transceiver housings. This improves the performance and power efficiency of the optical interconnects while reducing the cost of assembly. Challenges arise because alignment tolerances in photonics are critical (sub-micron range) and optical interfaces are sensitive to debris and imperfections, requiring the best in packaging technology.

The team demonstrated efficient optical coupling of an array of silicon waveguides to a substrate containing an array of polymer waveguides. The significant size difference between the silicon waveguides and the polymer waveguides originally presented a major challenge, says IBM. The researchers overcame this obstacle by gradually tapering the silicon waveguide, leading to efficient transfer of the optical signal to the polymer waveguide.

The method is scalable and enables the simultaneous interfacing of many optical connections between a silicon photonic chip and the system. The optical coupling is also wavelength and polarization insensitive and tolerant to alignment offsets of a few micrometers, Offrein says.

"This integration scheme has the potential to massively reduce the cost of applying silicon photonics optical interconnects in computing systems," Offrein reckons. Cheaper photonic technology enables its deployment at a large scale, which could lead to computing systems that can process more information at higher performance levels and with better energy efficiency, he adds.

"Such systems will be key for future applications in the field of cloud-computing, big data, analytics and cognitive computing," Offrein continues. "In addition, it will enable novel architectures requiring high communication bandwidth, as for example in disaggregated systems."

**www.research.ibm.com/photonics**
**www.ofcconference.org**

# NeoPhotonics launches micro-integrated coherent receiver for 100G and 400G coherent transport

## OIF Type 2 ICR and high-power micro-ITLA now generally available; capacity increased for ICR and external-cavity micro-ITLA

NeoPhotonics Corp of San Jose, CA, a vertically integrated designer and manufacturer of both indium phosphide (InP) and silica-on-silicon photonic integrated circuit (PIC)-based modules and subsystems for high-speed communications networks, has launched a micro-integrated coherent receiver (Micro-ICR) designed to fully support the OIF implementation agreement OIF-DPC-MRX-02.0, Type 1.

The Micro-ICR has a compact form factor that is about a quarter the size of the standard OIF 1.2 Type 1 ICR and half the size of the new OIF 1.2 Type 2 ICR. It is designed to be used in coherent analog CFP2-ACO pluggable modules as well as in high-density line cards. The Micro-ICR offers features for optical power monitoring and adjustment using variable optical attenuators (VOAs) and is designed for use with a single laser for both the local oscillator and transmitter.

The new Micro-ICR joins a broad suite of optical products for 100G coherent communications, including the OIF 1.2 Type 2 small-form-factor ICR (Type 2 ICR) and the high-power narrow-linewidth, micro-integrable tunable laser assembly (micro-ITLA), both of which are now generally available and shipping to customers. These small-form-factor products are also designed to scale to 200G and 400G applications using higher-order modulation schemes. In addition, NeoPhotonics is continuing volume shipments and increasing manufacturing capacity for its standard OIF 1.2 Type 1 ICR and its standard-power ultra-narrow-linewidth external-cavity micro-ITLA.

"We are excited to use our hybrid photonic integration technology in our Micro-ICR to take another significant step in reducing the size of 100G optical components and thus allow our customers to increase the density of their 100G and beyond line-cards," says chairman & CEO Tim Jenks. "We are increasing manufacturing capacity to meet market demand for our currently shipping 100G coherent optical components and plan to transition that capacity to our newer, higher-density 100G and 400G products as demand grows," he adds.

NeoPhotonics exhibited its suite of standard and small-form-factor PIC-based components and its modular multi-cast switches, both for 100G coherent line-side applications — along with its 100G client-side CFP2 and CFP4 transceivers and its next-generation transceivers for access networks — at the Optical Fiber Communications (OFC 2015) conference and exposition in late March.

Also at OFC, NeoPhotonics presented the following talks:

- Flexible Optical Network Workshop: 'CDC ROADM with Minimum EDFAs' by Winston I. Way.
- 'Degree-Expandable Colorless, Directionless, and Contentionless ROADM without Drop-Side EDFAs' by Wen-Jr Jiang, Ilya Vorobeichik and Winston I. Way.
- '112 Gb/s PAM4 Transmission Over 40km SSMF Using 1.3 μm Gain-Clamped Semiconductor Optical Amplifier' by Trevor Chan and Winston I. Way.
- 'InP Integrated Coherent Transmitter for 100 Gb/s DP-QPSK transmission' by Maxime Poirier.

**www.ofcconference.org**

# NeoPhotonics launches dual-rate 100G CFP4 LR4 transceivers

NeoPhotonics has introduced a new compact and dual-rate 100G CFP4 LR4 transceiver for telecom and datacom applications.

The 100G CFP4 LR4 requires much less power and is half the size compared to the current-generation CFP2 form factor. The 100G CFP4 is hence an attractive next-generation 100G module for bandwidth-hungry data-center applications, where both port density and lower power are highly desired, says the firm. "We are pleased to support our customers with their growing demand for 100G by adding production capacity for our CFP2 LR4, which was released last year"

The new transceiver is designed to fully comply with the IEEE 802.3 100GBASE-LR4 and CAUI-4 electrical interface and OTN OTU4 standards for links up to 10km. It combines CFP4 MSA and MDIO functionality and is interoperable with previous-generation CFP and CFP2 modules. NeoPhotonics says that the 4-channel PIC-based integrated transmitter utilizes its proven performance and high-volume manufacturing platform of 28G EML lasers and drivers, enabling what is claimed to be best-in-class module performance, especially in OTN applications, interoperability and easy deployment.

"The introduction of our new 100G CFP4 LR4 client transceiver module underlines our commitment to the ultra-high-speed segment of the transceiver market," says chairman & CEO Tim Jenks. "We are pleased to support our customers with their growing demand for 100G by adding production capacity for our CFP2 LR4, which was released last year."

**www.neophotonics.com**

# Infinera makes $350m offer to acquire Transmode

## Transmode's metro focus in Europe complements Infinera's long-haul strength in North America

Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical transport networking systems incorporating its own indium phosphide-based photonic integrated circuits (PICs), has made a recommended public offer to shareholders to acquire Transmode AB of Stockholm, Sweden (a provider of packet-optical networking solutions). The acceptance period of the offer is expected to run from 26 June to 17 July.

For every 10 shares of Transmode (listed on Nasdaq Stockholm, Mid Cap, as 'TRMO'), shareholders will receive SEK300 in cash and 4.705 Infinera shares. The purchase price implies a price per share of about SEK109, and a total equity value for Transmode of about SEK3020m ($350m). Infinera will deliver about $96m in cash (funded from its balance sheet) and will issue about 13 million new Infinera shares (about 10.1% of its shares outstanding) to Transmode shareholders. As of 27 December, Infinera's total cash holdings were about $391m. Post-transaction, Transmode shareholders would hold 9.2% of Infinera's outstanding shares and voting power in the combined company (and 8.7% of the combined company on a fully diluted basis).

As of 27 December, Infinera had cash, cash equivalents, investments and restricted cash of $391m and carried $150m in convertible debt. Cash flow from operations in 2014 was $36m. Infinera can hence finance the cash portion of the offer through its existing cash resources, without any financing conditions.

The acquisition has been approved by the board of directors of Infinera. Also, Transmode's board of directors has unanimously recommended that its shareholders accept the offer. Largest shareholder Pod Investment AB (which holds about 33% of total shares and voting rights) has undertaken to accept the offer (subject to customary conditions).

Complementing Infinera's strength in the long-haul optical transport market and its early lead in the metro Cloud market, Transmode's suite of metro core, edge and access solutions should allow Infinera to address the entire end-to-end WDM market and to capitalize on the transition of major 100G metro aggregation deployments expected by industry analysts to commence in 2016. Infinera says that Transmode's products provide a rich set of application-specific features including broadband aggregation, mobile backhaul and fronthaul along with business Ethernet MEF certifications. Both firms bring complementary customers and technology, with Transmode positioned primarily in metro applications in Europe and Infinera historically positioned in long-haul and metro cloud, particularly in North America.

**Complementing Infinera's strength in the long-haul optical transport market and its early lead in the metro Cloud market, Transmode's suite of metro core, edge and access solutions should allow Infinera to address the entire end-to-end WDM market and to capitalize on the transition of major 100G metro aggregation deployments**

"The acquisition of Transmode accelerates the realization of our long-held vision of providing an end-to-end portfolio of world-class optical transport products. Further, the combination ensures we are well positioned to be a leading provider in the metro aggregation market as this market transitions to 100G," says Infinera's CEO Tom Fallon. "Transmode's services-rich metro platforms, broad European customer base and profitable business model are naturally complementary to Infinera," he adds.

"Drawing on the complementary and synergistic skill sets of Infinera and Transmode, the combined company will be able to compete more effectively, develop differentiated and advanced products, and provide greater value to its most important stakeholders," believes Transmode's CEO Karl Thedéen.

The offer is expected to close in third-quarter 2015 (on or around 29 July), subject to certain closing conditions, including acceptance by more than 90% of the total number of shares of Transmode. The transaction is expected to be neutral to slightly dilutive to Infinera's non-GAAP earnings in second-half 2015, and accretive to non-GAAP earnings in 2016.

Infinera's revenues rose from $544m in 2013 to $668m in 2014, making net profit of $13.7m compared with a loss of $32m in 2013. Transmode made a net profit of SEK61.5m ($7.08m) on revenues of SEK930m ($107.09m) in 2014.

For the near-term, Infinera does not intend to make any material changes to Transmode's staffing or to its existing organization and operations, including the terms of employment and locations of the business. Each firm's engineering structure is expected to remain substantively intact, and Infinera intends Transmode's current CEO to lead metro aggregation business operations. Long term, the optimal structures of each function will be determined following completion of the offer.

**www.infinera.com**
**www.transmode.com**

# JePPIX's 2015 roadmap forecasts a €1bn integrated photonics market in 2020

## InP may be more cost effective than silicon photonics for PICs for prototypes and low- to medium-volume manufacturing

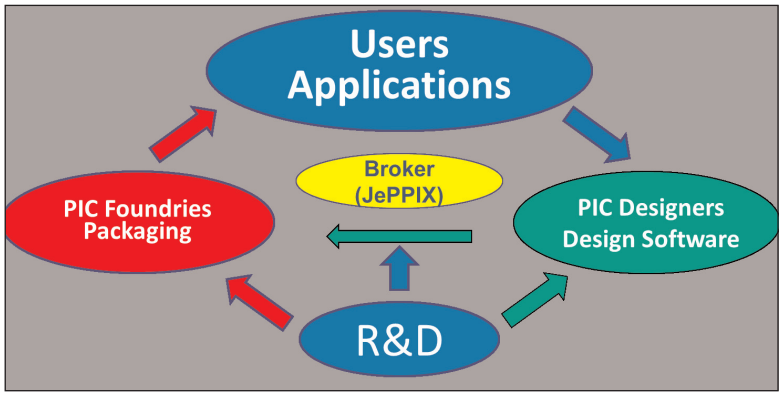
In its recently updated roadmap document (first published in 2011, and last updated in 2013), the Joint European Platform for Photonic Integration of Components and Circuits (JePPIX) predicts a €1bn market size for PIC-enabled products in 2020.

JePPIX brings the European InP community together as a coherent force dedicated to building a generic foundry technology infrastructure, which requires coordination of the work of many independent businesses spread across process development, chip fabrication, packaging, software development, design and training.

The generic foundry approach is initiating a revolution in micro- and nanophotonics, just as it did in microelectronics more than 30 years ago, says JePPIX. Generic integration causes a dramatic reduction in entry costs when applying photonic integrated circuits (PICs) in novel or improved products and brings them within reach for many small- and medium-sized enterprises (SMEs) and larger companies.

Up to now, most applications have been in telecoms and datacoms, but they are now becoming much broader. Examples are fiber sensor readout units, gas sensors, medical diagnostics, metrology, terahertz (THz) and antenna systems.

The business case for many firms targeting PICs in novel or improved products is a strong one, reckons JePPIX, which also sees a rapidly growing market for PIC designers. For foundries manufacturing generic PICs there will be an increasingly attractive business case as the market volume grows, it reckons. However, in the start-up phase (which may last a few years) foundry operation will be combined with other chip-based products and services.




In the coming years JePPIX foresees a further increase in the performance and maturity of its four foundry platforms (provided by Oclaro, Fraunhofer HHI, SMART Photonics and LioniX) to a level where the technology is extremely competitive with application-specific processes. The development of process capabilities and performance will be accompanied by the development of fab-calibrated process design kits (PDKs), which will provide users with models and tools for accurate and efficient PIC design. Standardized packages are also being developed within the JePPIX community. Access to a high-performance package available at a reasonable cost is equally important for rapid prototyping and product development, says JePPIX.

Through application of the generic foundry model, the entry costs for developing a PIC prototype are dramatically reduced, to a level that is affordable for many SMEs and universities, reckons JePPIX. It is shown that for developing prototypes, and also for low- to medium-volume manufacturing, indium phosphide (InP) PICs may be more cost effective than silicon photonics PICs, contrary to the widespread belief that InP technology is inherently much more expensive.

The first generic PIC-based products should become commercially available this year. Based on the rapid development of industry participation in multi-wafer project (MPW) runs, JePPIX expects that the PIC-enabled market will develop into a billion euro market by 2020.

The anticipated growth of the market will demand a rapidly increasing number of PIC designs and hence designers. A more than tenfold increase in the existing design capacity will be required within the next few years, forecast JePPIX. Training and educational activities must therefore have high priority.

Very significant investments in photonic foundries have recently been announced in the USA. For Europe to retain its competitive edge, continued public and private investment is important, believes JePPIX. Funding should therefore focus on raising awareness of the opportunities that PICs offer for novel or improved products for a wide range of applications, increasing training and education capacity, and creating the appropriate conditions for enabling PIC foundries to provide the required manufacturing services, it adds.

JePPIX says that it is playing a central role in the eco-system for foundry-based PIC development and manufacturing. Because of the large overlap in skills and tools for designing InP and LioniX's dielectric $Si_3N_4/SiO_2$ (TriPleX) chips — and the increasing synergy between the two technologies in packaging and hybrid platform technology — JePPIX is taking on the role of broker for both InP and TriPleX technology.

**www.jeppix.eu/document_store/JePPIXRoadmap2015.pdf**

# China's Hanergy to build 10MW plant in Wuhan for Alta's flexible GaAs solar cells

China-based Hanergy Thin Film Power Group Ltd and the Huangpi District People's Government in Wuhan City have entered into an investment cooperation agreement to construct a gallium arsenide (GaAs) thin-film solar cell R&D and manufacturing plant with a capacity of 10MW on a 150 acres site in Huangpi Linkong Industrial Park in Wuhan. Also, a Huangpi project company will be established to implement the project.

The project is Hanergy's first thin-film solar call R&D manufacturing plant in China using GaAs technology, following its acquisition of Alta Devices Inc of Santa Clara, CA, USA on 27 January. Founded in 2007, Alta's GaAs PV cells are fabricated in a micron-thick thin-film that is then lifted off the growth GaAs substrate (which can then be reused multiple times to amortize its high cost). The thin-film cell can then be placed on a flexible substrate. Hanergy Thin Film Power Group's parent company Hanergy Holding Group aims to explore the use of flexible, lightweight thin-film GaAs PV products in mobile applications such as power-cord-free mobile, portable and wearable consumer electronic devices, drone systems, and solar-powered vehicles.

The project is receiving support from the Huangpi District People's Government in Wuhan City. Specifically, the Wuhan Huangpi District Government will be responsible for construction of the production site, warehouse, factory facilities and power systems being completed within 10 months, and will lease the plant to the project company for an annual rent. It will also help it to become eligible to apply as a high-tech enterprise for support from the Innovation and Technology Fund and the High-end Industrial Support Fund. The government will also promote use of the firm's photovoltaic products in the local market.

The project will be implemented in two phases. The first phase involves constructing a plant with production capacity of 3MW on about 50 acres of land. The aims to install equipment and assemble production lines for testing within 12 months, and to start production within 18 months.

Wuhan Huangpi District Government will also reserve an additional 100 acres of land for a period of three years, during which it will not levy any tax or fees before the land is either used (for construction of the project's second phase) or sold.

After seven years of leasing the plant and related factory facilities, the firm may apply to Wuhan Huangpi District Government to extend either the lease or the direct buyback of the plant (at a price determined according to the construction costs and land price after deducting rent paid).

Wuhan Huangpi District Government targets the use of thin-film photovoltaic systems on 100,000 new residential buildings and across 20,000 acres of agricultural greenhouses (totaling 600MW of power generation). It will also help the firm to construct demonstration projects for not only household power generation systems (a pre-launch involving 100 families in the countryside) and 100 acres of photovoltaic agricultural greenhouses (involving the Bureau of Agriculture) but also roof-top building-integrated photovoltaic (BIPV) projects of about 100m2 for municipal buildings and public facilities.

**www.hanergy.com**
**www.altadevices.com**

# Nanoco wins £400,000 Innovate UK grant for collaboration with Loughborough University

Nanoco Group plc of Manchester, UK, which produces cadmium-free quantum dots and other nanomaterials for applications including LCD displays, lighting, solar cells and bio-imaging, has been awarded a £399,562 grant from UK Government agency Innovate UK (formerly the Technology Strategy Board) — under its Energy Catalyst program — in connection with the further development of the firm's printable solar cell technology.

The grant will fund Nanoco's part of a collaborative project with Loughborough University's Centre for Renewable Energy Systems Technology (CREST), which will also receive an Innovate UK grant for the project. CREST is a UK center for photovoltaic research, offering facilities and technical expertise.

The aim of the two-year project, which has a total value of almost £1m, is to build on Nanoco's progress in solar energy by using its copper indium gallium diselenide (CIGS) solar ink to create a solution-processed, integrated, thin-film photovoltaic mini-module.

Nanoco and CREST will work together to optimize the CIGS mini-module architecture. CREST's wide range of analytical techniques will be used to assist in the mini-module's development and measurement.

"We have already achieved an efficiency of around 17% from the solar ink and it is the objective of this grant-funded project to scale the technology up to the size of a mini-module," notes Nanoco's CEO Michael Edelman.

**www.lboro.ac.uk/crest**
**www.nanocotechnologies.com**

# Manz sets CIGS PV module efficiency record of 16% using mass-production line

## Record 21.7%-efficient cells transferred from lab of development partner ZSW

At the 9th SNEC International Photovoltaic Power Generation Conference & Exhibition in Shanghai, China (27–30 April), Manz AG of Reutlingen, Germany (a supplier of integrated production lines for crystalline silicon solar cells and thin-film solar modules) has announced that it has set a record solar energy conversion efficiency of 16% for a copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) module, as certified by testing organization TÜV Rheinland.

Made on Manz's mass-production line in Schwäbisch Hall, the record CIGS modules are based on transfer of the laboratory cells of exclusive development partner ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung — or Center for Solar Energy and Hydrogen Research — Baden-Württemberg) of Stuttgart, Germany, which in autumn 2014 demonstrate record efficiency of 21.7% (superiority to that of crystalline solar cells).

The performance increase was achieved mainly using the next generation of CIGS semiconductor material, which Manz applies to a glass substrate in a co-evaporation process. Additional innovation includes a new module design for increasing the active module surface area. In addition, Manz was able to sustainably reduce optical losses.

"Building on the know-how of ZSW and our own experts, it is thus absolutely realistic that we will already be able to present module efficiencies of significantly higher than 17% in the near future, produced on our innovative production line in Schwäbisch Hall," says founder & CEO Dieter Manz. "We have already mastered the necessary processes in the lab, such as the after-treatment of CIGS coatings. The goal of our joint efforts is the further reduction of electricity costs – around the world, under all climatic conditions," he adds.

"With significantly lower production costs compared to crystalline solar cells, CIGS technology will play a large role in the coming investment cycle of the photovoltaics industry," believes Manz. The firm's CIGS modules already offer the lowest electricity generation costs compared with existing crystalline silicon technology, it is claimed.

The firm adds that it offers potential investors in CIGS production systems a long-term roadmap for further efficiency increases, whose milestones have always been achieved ahead of schedule in recent years.

**www.manz.com**
**www.zsw-bw.de**

# Solar Frontier completes construction of Tohoku Plant and begins ramp-up

## Operational testing of model CIS PV production plant begins

Tokyo-based Solar Frontier — the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — has completed construction of its fourth production plant. The 150MW Tohoku Plant in Miyagi, Japan, is now moving into the ramp-up phase.

As a cornerstone in the firm's global growth strategy, based on the proven production process at its existing 900MW Kunitomi Plant in southern Japan, the Tohoku Plant features upgrades to Solar Frontier's existing CIS production lines using technology developed at its Atsugi Research Center. The new plant also serves as a model for Solar Frontier's future production plants as it looks to expand its global production footprint. The firm will use the ramp-up phase to test and verify its latest CIS line technology, while also including what it learns during this period.

**Exterior of Tohoku Plant.**

The introduction of the new plant comes as Solar Frontier works to bring its CIS technology to more customers worldwide. Compared with crystalline silicon, CIS modules generate a higher energy yield (kilowatt-hours per kilowatt-peak) in real-world conditions. The Tohoku Plant is intended to build on the performance advantages of CIS with new product upgrades. This includes module conversion efficiencies of over 15% and adjustments to the voltage and current of its CIS thin-film modules, enabling more freedom in system design, says the firm.

**www.solar-frontier.com**

# Electrical injection of rolled-up heterostructure lasers

**Semiconductor tubes could lead the way to coherent light sources for applications in chip-level optical communications integrated on a silicon platform.**

McGill University in Canada claims to have created the first electrically injected rolled-up semiconductor tube laser [M. H. T. Dastjerdi et al, Appl. Phys. Lett., vol106, p021114, 2015]. Although rolled-up heterostructure lasers have been achieved using optical pumping, the researchers say that electrically injected rolled-up semiconductor tube lasers have not previously been reported.

Rolled-up heterostructures are grown with a strain profile that causes the material to roll up when released from the growth substrate. Rolled-up semiconductor tubes can be used to create laser cavities with ultra-high quality (Q) factors (i.e. low loss), directional emission, and controlled polarization.

The McGill electrically injected device could lead the way to coherent light sources for applications in chip-level optical communications. The researchers also believe that the device can be integrated into a silicon platform without performance degradation.

The heterostructure (Figure 1) was grown on indium phosphide (InP) using molecular beam epitaxy (MBE). The structure was coherently strained so that it would roll up when released from the InP growth substrate. The light emission was from two quantum wells of indium gallium arsenide ($In_{0.53}Ga_{0.47}As$). The structure's photoluminescence (PL) peak was at 1.57μm wavelength. Optical communications are often based on wavelengths around 1.5μm.

**Rolled-up heterostructures are grown with a strain profile that causes the material to roll up when released from the growth substrate. Semiconductor tubes can be used to create laser cavities with ultra-high Q factors, directional emission, and controlled polarization. The McGill electrically injected device could lead the way to coherent light sources for applications in chip-level optical communications... The device can be integrated into a silicon platform without performance degradation**

Silicon doping during heterostructure growth created n-type conductivity with negative charge electron carriers. Hole carriers were achieved with ion implantation with beryllium p-type doping of part of a U-shaped mesa region around the tube structure (Figure 2). The p-type doping was thermally activated

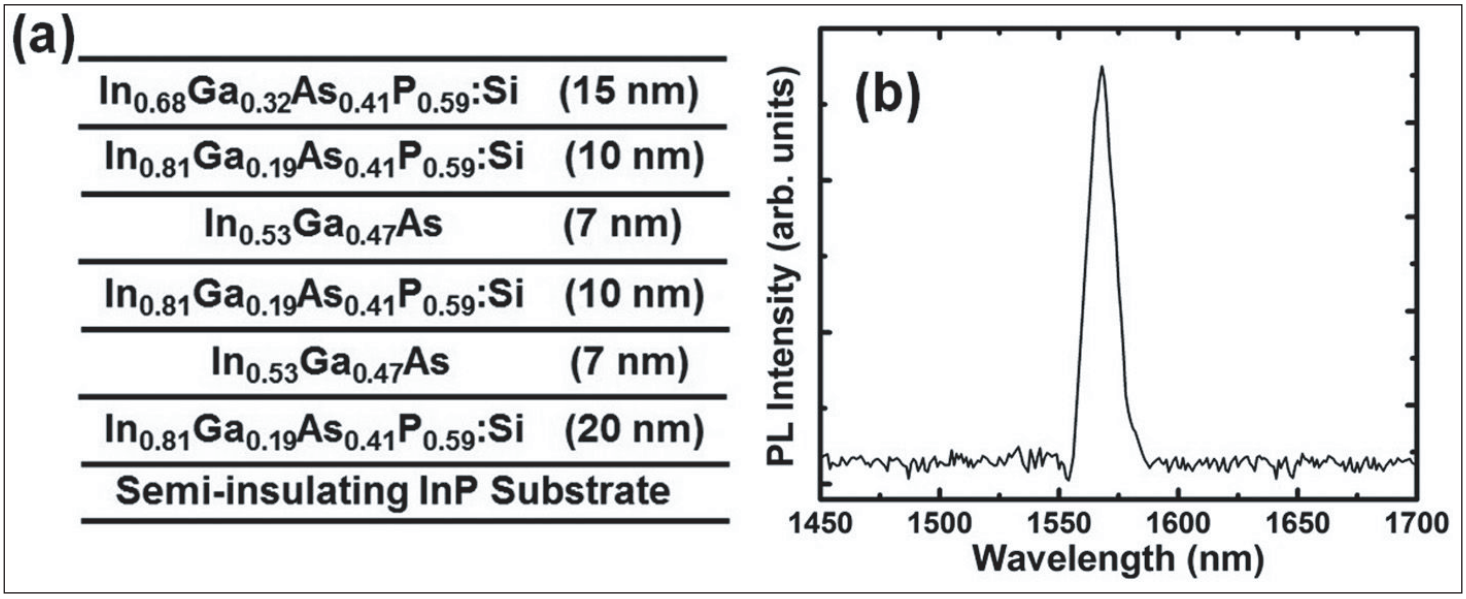



**Figure 1. (a) Schematic of coherently strained InGaAs/InGaAsP quantum well heterostructures grown on semi-insulating InP substrate. (b) PL spectrum measured at room temperature.**

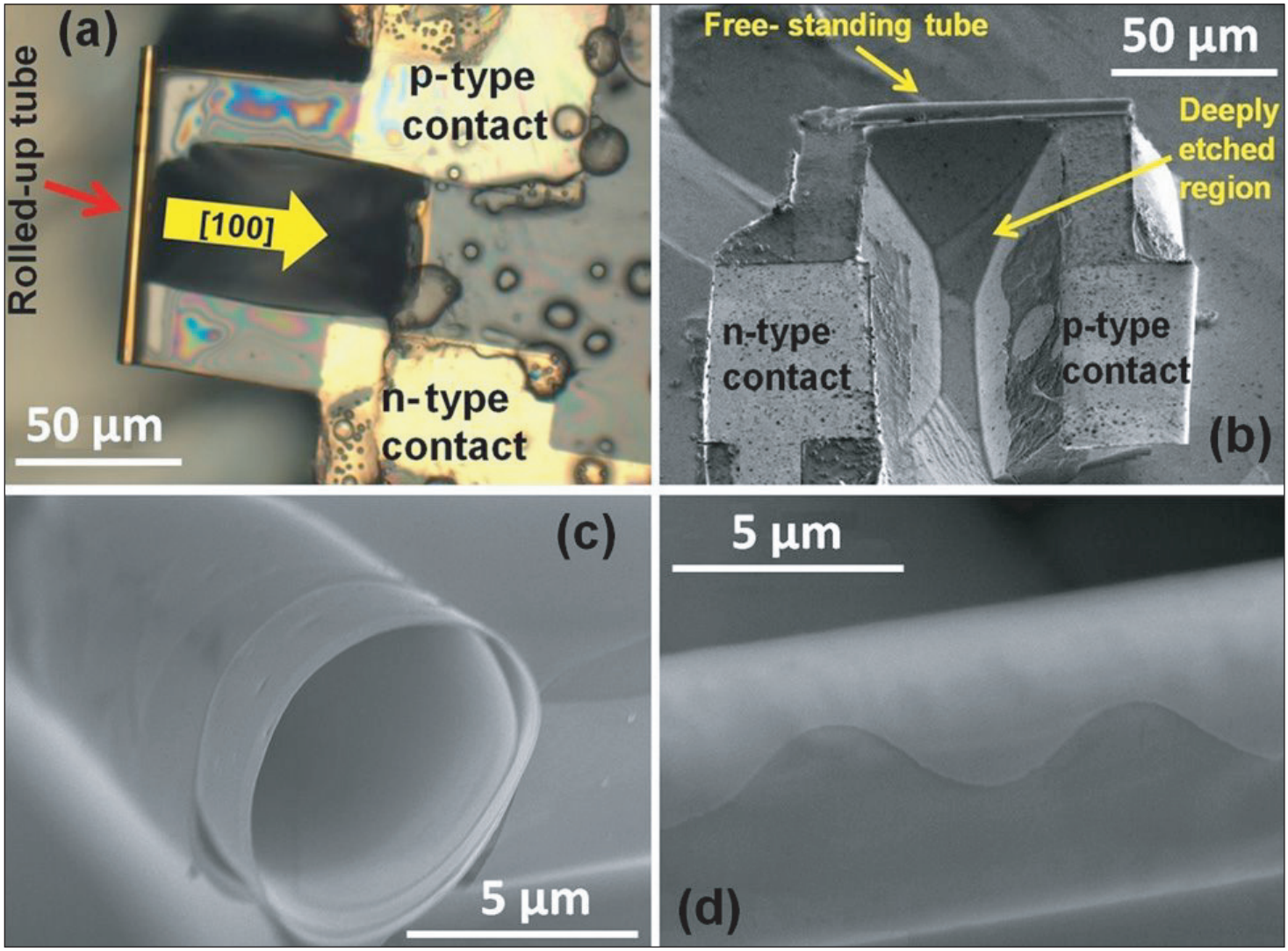



**Figure 2. (a) Optical microscopy image of free-standing rolled-up tube device with n- and p-metal contacts on either side. (b) SEM of fabricated tube device with n- and p-metal contacts. (c) SEM side view of tube cavity. (d) SEM of free-standing part of tube device showing surface corrugations for axial mode confinement.**

at ~600°C for 35 seconds. Out-diffusion of arsenic and phosphorus atoms during activation was avoided by depositing 40nm of silicon nitride.

Nickel/germanium/gold and palladium/titanium/palladium/gold were used as the n- and p-type metal contacts, respectively. The contacts were annealed at 400°C for 1 minute.

Various wet etches were used to create the U-shaped mesas and to under-cut the heterostructure so that it would release and curl up into tubes. The resulting devices were 100µm long with 140nm wall thickness. The tube diameter was 5µm.

The researchers comment: "Shown in Figure 2(d), the presence of corrugations on the tube surface can be clearly identified, which provide strong optical confinement along the tube axial direction. The controlled surface geometry was defined by the corrugations introduced at the inner edge of the U-shaped mesa."

The turn-on voltage of 3V at 80K is described by the researchers as 'relatively high'. Limitations in the p-dopant activation annealing step are blamed. Proper activation would require higher temperatures of 800–900°C, but then the heterostructure would not roll up properly. "This is probably due to alterations in the crystalline structure of the strained bilayer at temperatures significantly higher than the growth temperature of the device heterostructure," the researchers write.

The 80K laser threshold current for a mode at 1485nm was 1.05mA, where the full-width at half-maximum (FWHM) reduced to 2nm from 3.3nm subthreshold. The FWHM increased at higher currents due to self-heating effects. The other modes of the device did not show any lasing effect.

The Purcell factor of the enhancement over the spontaneous emission rate in the cavity was estimated to be 4.3, based on a quality (Q) factor of 800, effective mode volume of 4µm$^3$, and effective refractive index of 2.26. ■

**http://dx.doi.org/10.1063/1.4906238**

*Author: Mike Cooke*

# Ultraviolet random AlGaN nanowire array lasers

**Researchers at Canada's McGill University have claimed the shortest wavelengths ever for an electrically injected semiconductor laser.**

Researchers at McGill University in Canada have claimed the shortest wavelengths ever reported for any electrically injected semiconductor laser [K. H. Li et al, Nature Nanotechnology, published online 19 January 2015]. The devices were based on disordered aluminium gallium nitride (AlGaN) nanowire arrays grown on silicon using plasma-assisted molecular beam epitaxy (PAMBE) without using metal catalysts.

The researchers see a lithography-free process for fabricating defect-free nanowire array lasers on large-area silicon substrates as having potential for low cost scalable and controllable processing of ultralow-power-consumption ultraviolet (UV) devices. With further tuning of the nanowire parameters, ultralow-threshold nanowire lasers across the entire UV-A (400–315nm), UV-B (315–280nm) and UV-C (280–100nm) spectral ranges could be developed for biochemical purification and analysis, sensing, communication and lighting applications.

Two-dimensional simulations based on the idea of 'Anderson localization' suggested that high-Q (quality factor) cavities could be created with high probability by arrays of 70–75nm diameter wires with filling factors of ~30% (Figure 1). Anderson localization refers to a mechanism for confining waves (electromagnetic, acoustic, electron, etc) where there is a large quantity of randomness provided by defects, impurities and

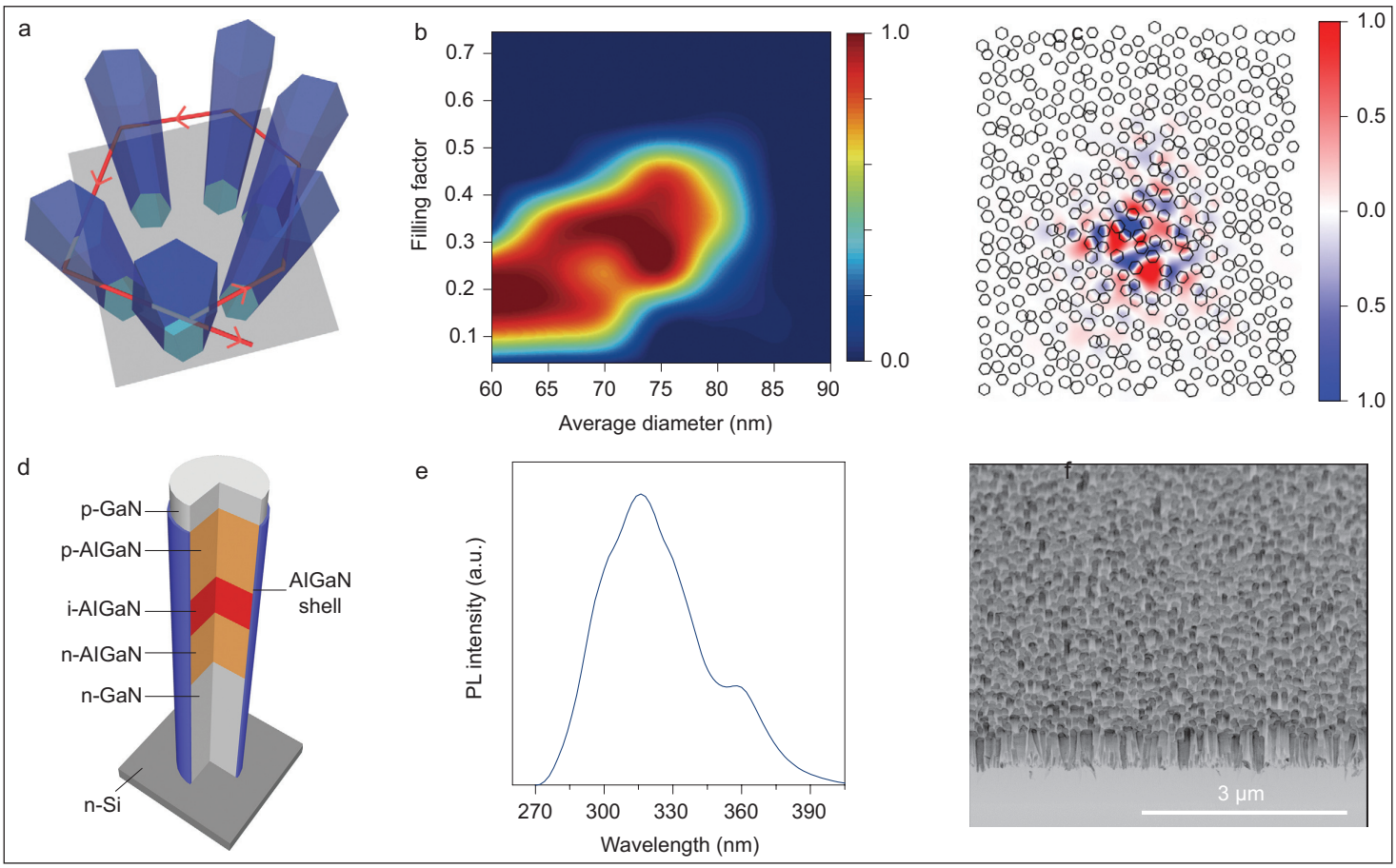



**Figure 1. a, Schematic formation of closed-loop photon path inside AlGaN nanowire arrays on which Anderson localization is based. b, Probability of forming high-Q cavity versus filling factors and diameters of nanowires. c, Simulation showing profile of electric field for high-Q cavity. d, Schematic of AlGaN nanowire double-heterostructure. e, Photoluminescence spectrum at room temperature. f, A 45° tilted SEM of nanowire arrays grown on silicon substrate.**

such like. The McGill simulations suggested that random cavities with Q factors of 20,000 could be achieved for UV-AII light of ~330nm wavelength.

Vertical confinement was provided by designing double heterostructures within the AlGaN nanowires with 50nm undoped active material sandwiched between 150nm p-type and n-type cladding regions. The active region had ~30% Al content, while the cladding had 56% Al. The wires were grown on an n-GaN template on (111) n-Si substrates. The structure was finished off with a ~25nm p-GaN top contact layer.

The researchers performed "extensive growth optimization" to achieve the design requirements of nanowire diameter and filling factor. The laser diodes were produced by filling the gaps between the wires with polyimide, etching back to reveal the p-contact, mesa etching for the n-contact, and deposition and annealing of metal contacts.

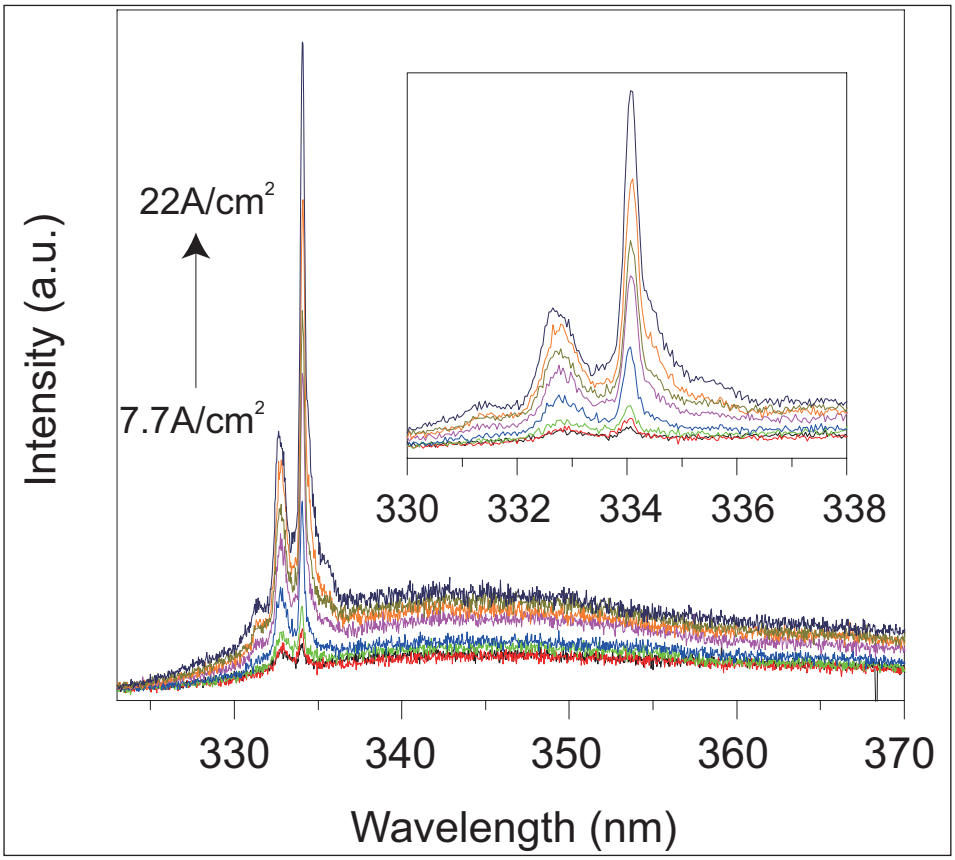



**Figure 2. Electroluminescence emission spectra measured at 6K under different current densities. Inset: enlarged view of lasing spectra. Integrated intensity.**

Electroluminescence measurements at 6K showed two sharp peaks above the background at 332.7nm and 334.1nm (Figure 2). The 334.1nm peak was dominant, with a lasing threshold of ~12A/cm$^2$. The line-width was as small as 0.2nm at threshold. The researchers say that the threshold is nearly three orders of magnitude lower than for previously reported GaN-based UV lasers.

At 30A/cm$^2$ injection current the output power was ~2μW. Stability of the lasing wavelengths at up to 6x the threshold current suggested to the researchers that "the lasing emission is dominated by the extremely stable excitonic transition rather than by the emission related to electron–hole plasma." (Excitons are often modeled as electron–hole bound states.)

The researchers add: "The ultralow threshold is attributed to the high-Q optical resonance, the nearly defect-free AlGaN nanowires, the drastically reduced non-radiative surface recombination offered by the AlGaN core–shell structures and possibly the strong quantum-confinement effect related to the nanometric compositional fluctuations of the active region."

Increasing the temperature to 100K caused the peaks to red-shift by~0.7nm. This is thought to be due to shrinkage of the AlGaN bandgap in the active region and a shift of the refractive index in the random cavity. ■

**http://dx.doi.org/10.1038/nnano.2014.308**

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# Implications for LEDs of the shift to large-diameter sapphire wafers

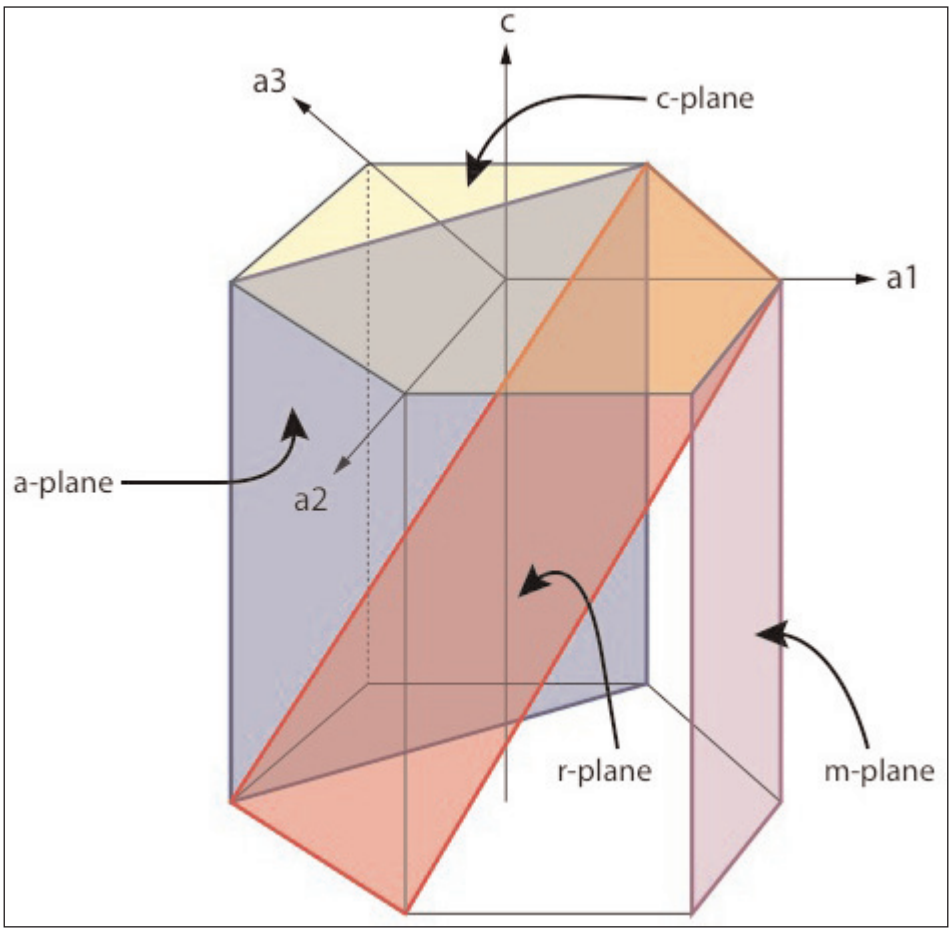
**Faisal Nabulsi, Rubicon's senior VP, operations, explains technology and market trends for sapphire wafers over the last few years, and how larger diameters and patterned sapphire substrates are impacting LED manufacturing.**

The market for sapphire LED wafers has undergone significant changes over the past two years, reflecting two significant trends: the transition to larger-diameter wafers and the transition to the purchase of patterned sapphire substrates (PSS).

The heart of the LED sapphire market has moved up from 2″ wafers to 4″ wafers. Four-inch wafers now constitute the majority of LED sapphire wafer area, while two-inch sapphire has declined to less than 20% of the wafer area used in LEDs today. All regions including China are making the move to larger diameters.

Still in the minority — but clearly the fastest-growing part of the sapphire wafer market — is 6″ sapphire. Market research firm Yole Developpement forecasted in August 2014 that the use of 6″wafers will double between 2014 and 2016, to about 25% of the LED sapphire market.

Alternative applications for sapphire, such as lens covers and smart watch faces, are absorbing much of the 2″ core in the market, although not so much as to drive up the price of cores or wafers.




**Schematic diagram showing sapphire's various crystal planes.**

During the same time frame, the purchase of patterned sapphire substrates (PSS) has also climbed rapidly. Patterned wafers provide a significant increase in light extraction efficiency. The LED chip manufacturers first developed their proprietary patterns and the capacity for patterning internally, but more recently they have been willing to outsource.

PSS now accounts for the majority of sapphire sales in dollar terms although perhaps not yet in area terms. This shift reflects both the appearance of third-party patterning companies and the growing capabilities of the sapphire producers themselves. Much of the sapphire sold as CSS (conventional sapphire substrates) is patterned by chip manufacturers themselves. Third-party patterning capability, which had originally focused on 2″ wafers, is now moving also to larger diameters.

Sapphire has a hardness of 9 on the Mohs scale, and the challenges involved in fabricating this material to very precise orientation and flatness specifications are intensified at larger diameters. Here we present an overview of these challenges and the sapphire industry's current methods for addressing them.

## Sapphire crystal growth for large-diameter wafers

By now everyone knows that the two most effective methods of growing large-diameter sapphire crystal are Kyropoulos, a bulk growth method, and EFG (edge-defined film-fed growth), which produces sapphire in sheets. There are advantages and disadvantages to either method, but both have proven to be successful in the large-diameter wafer market.

During crystal growth, stress management of material is critical, especially for large-diameter products. The Kyropoulos growth method is very natural. The boule is grown in suspension with no contact with the crucible or any other element of the system. Growth is initiated by the vertically fixed seed on a pulling shaft at the top. As the seed makes contact with the melt at the right temperature, crystallization will occur naturally. Crystallization of the molten material across the solid-liquid phase line (seed to molten) emerges as a programmed heating profile takes place. With no pulling and zero rotation, the process results in a complete and practically stress-free crystal, suspended from the seed at the top. This process is as close as it gets to the growth of sapphire as produced by nature.

One of the best advantages of the Kyropoulos method is its low defect density across the grown material indiscriminately. This attribute makes it relatively manageable for scaling up, and the uniformity of the material quality across large-diameter wafers is excellent. In addition, the Kyropoulos growth cycle encompasses an effective annealing cycle which eliminates all built-up stresses due to the cooling process at the end of the cycle. Annealing is an integral part of the growth. The single hot-zone design, which completely surrounds the entire crucible, makes the annealing process very simple, efficient and uniform. On the other hand, the EFG hot-zone design may become rather complex if annealing is required. A second heater with a separate controlling circuit must be added to achieve a low-stress sheet of sapphire.

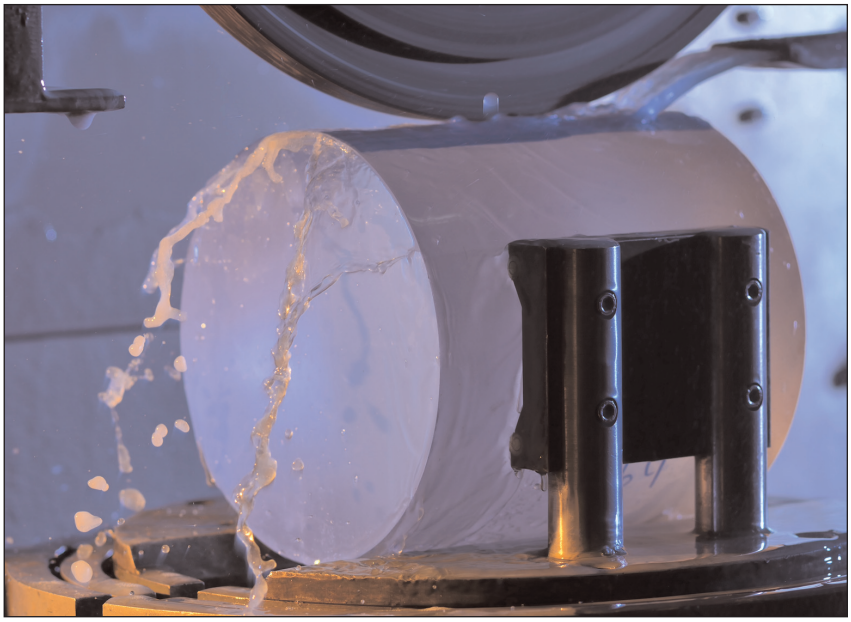
The geometric symmetry of C-plane versus R-plane makes the Kyropoulos-grown material more practical from the point of view of fabrication. The material is grown in the A-direction in a roughly cylindrical shape. The result is that the C-plane direction is only 57º apart from the R-plane along the boule's perimeter. This feature makes all grown material potentially good inventory for both C-plane of any size (2″ through 8″) and R-plane simultaneously. Inventory in boule form can therefore play a key role in responding to market needs in a timely fashion.

**Rubicon's 2″, 4″, 6″, 8″ and 12″-diameter sapphire wafers.**

## Fabrication of large-diameter cores and wafers

Drilling large-diameter cores from the bulky large Kyropoulos boules at an accurate orientation target with sub-degree tolerance has been a challenging task to master. All major LED chip manufacturers mandate a very tight orientation tolerance (as low as one tenth of one degree). The challenge has been in the handling of the massive and irregularly shaped boule to such a degree of accuracy in the x-ray alignment tool. The boule is fixed on a reference plate using two mixed bonding agents. No movements are allowed during curing of the bonding agents. The coring process, which involves a relatively harsh wet environment inside the CNC machines, must be designed to introduce no spatial or rotational movement to such a big crystal. The material must be firmly secured in the drilling machine to a great degree of stability for many hours while the drilling takes place and with the presence of high-pressure coolant.

The use of the diamond wire has been a definite advantage in slicing large-diameter sapphire. However, the main challenge in slicing 6″ ingots is twofold. The first part is anchoring the ingot in the wire saw at one tenth of one degree accuracy to guarantee the orientation spec. Holding such accuracy through the duration of slicing (which may exceed 20 hours) has been a major mechanical undertaking. However, the availability of well-designed wire saws that can handle large ingots (which may be, for example, 10-inches in length) has made it possible to achieve good results in a reasonable timeframe. The second part is the constant challenge of holding the slicing process parameters stable within a tight, sweet window to produce flat wafers. The flatter the wafers out of slicing, the easier it is to move the products through the subsequent operations with minimal process time and cost. Bow and warp values of large-diameter wafers such as 6″ are drasti-



**Core fabrication — finishing the outer diameter of the core to ensure conformance with both orientation specs and dimensional requirements.**

cally influenced by the smallest variation in the size and/or the concentration of the diamonds on the wire. Unlike Kyropoulos, EGF technology has no need for slicing. Avoiding slicing cost can be an advantage in total cost of ownership.

The next process is to flatten the large-diameter wafers further. Lapping wafers by using loose abrasive has largely been the practice in the industry. However, material grown by the EFG method requires a considerable amount of lapping to shape the parts flat, and that is largely due to the fact that EFG requires no slicing. The shape of the sheets as taken out of the EFG growth furnace is usually out of orientation and far from flat. The larger the diameter, the more difficult it is to bring the wafers into spec, especially from the flatness point of view.

The industry has suffered a great deal over this process in the past, for one simple reason: the material to be flattened, sapphire, is harder than the lapping equipment. The top and bottom metal plates on the conventional lappers are usually made of cast iron. Therefore, both plates will wear faster than the sapphire. In addition, the iron plates usually change shape during the lapping process to practically copy the shape of the incoming wafers. The plates will go out of shape even more quickly with high-warp, high-bow wafers. Conventional lapping equipment was designed and optimized for the silicon industry. This issue was manageable for sapphire in the past, when 2″ wafers were the main product for the LED industry. When the 6″ product became the driving force, this issue became quite formidable, especially for the EFG producers.

The EFG suppliers had to fix two problems in lapping. The first is to grind more material to flatten the wafers efficiently, and the second is to bring the wafers into orientation. Therefore, these producers had to develop a new grinding process to replace lapping. The solution they introduced was a fixed abrasive system, and it provided multiple advantages. The platform is built on having diamond fixed on the grinding plates in the form of either diamond pellets or pads mounted on the top and bottom plates of the conventional lappers. This design provides a high removal rate and prevents the plates from going out of shape as the sapphire is processed.

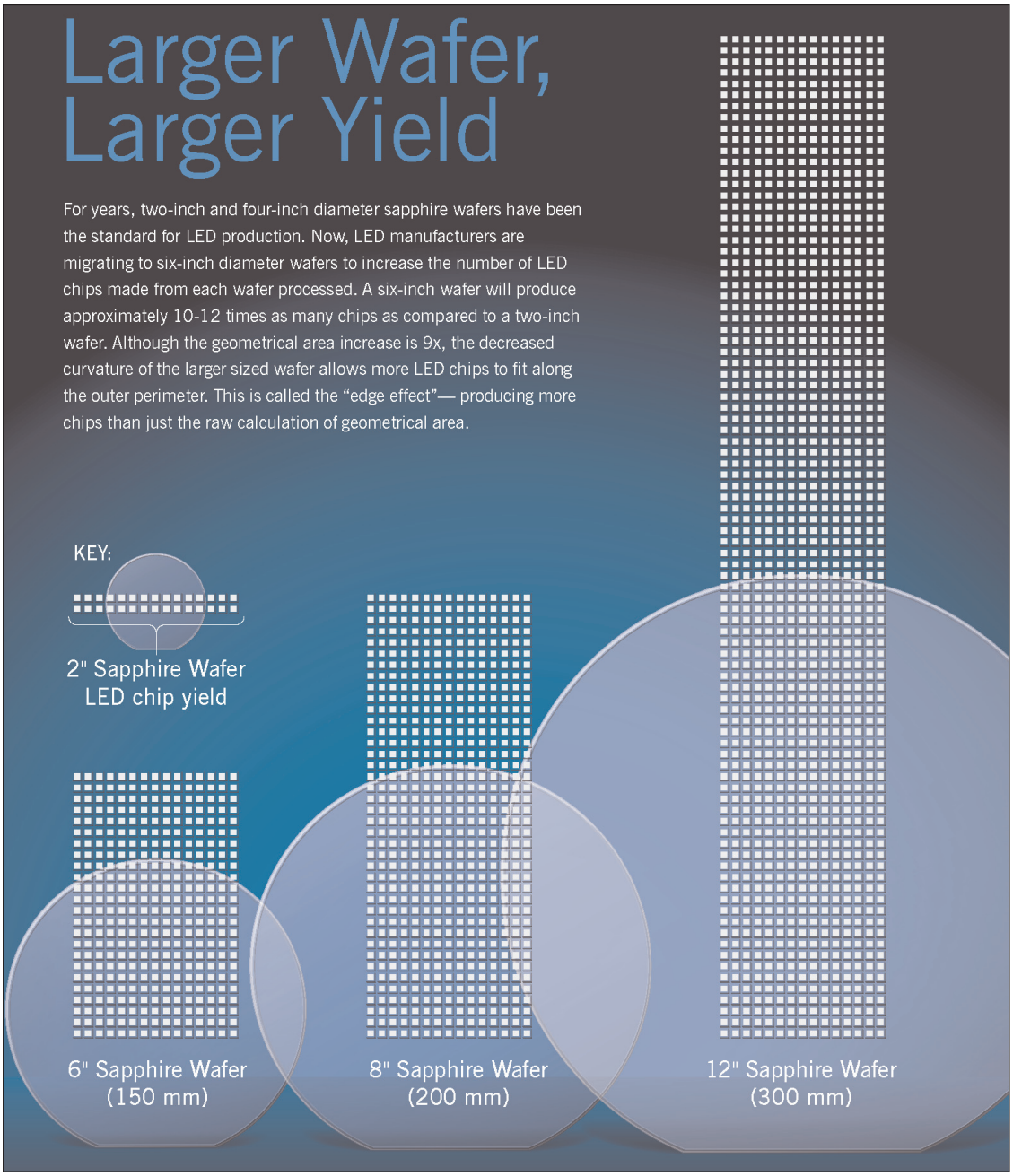
Finally, polishing large-diameter sapphire wafers brought the chemical mechanical polishing (CMP) process into a new phase. The flatness of the 6″ wafers has grown tighter year after year in an exponential fashion. The reduction of the exclusion zone, as required by the LED makers, added another dimension of complexity to the CMP process. The LED makers want to utilize every possible space on the 6″ wafers. The longer the polishing cycle, the faster the wafers go out of flatness, especially at the edges. The highest removal rate on the surface of the 6″ wafers through the CMP process is at the perimeter. Deep scratches from previous operations can be a key factor in the cycle time of the CMP and hence compromise the flatness. An effective process between grinding and CMP needed to be introduced to minimize the subsurface damage and prepare the wafers for polishing. Fine diamond grit is used to remedy this issue.

## Patterning for large-diameter sapphire wafers

PSS technology was introduced as a solution to the constant need for more optical output. The initial GaN-on-silicon LEDs were introduced as indicator lights due to their low optical power. However, the outstanding electrical and thermal properties of the LED devices compared with all other light sources motivated the designers to aspire to much greater optical output. With sapphire substrates, high-power LED chips became a reality, but the aspiration did not stop at that point. As designers work harder to get more lumens per watt, they found a way to systematically guide the optical wave to where it is needed through the introduction of optical guiding pattern (PSS). Experiments to vary the shape, size, pitch and aspect ratio of etched patterns will continue to drive even more efficient LEDs.

There are two main contributors by which patterning affects the total optical power at the LED output facet. The first one is the geometric shape/design of the pattern. The second is the dimension tolerances of the pattern. The combinations of the shape (such as dome, pyramid or cone), in conjunction with the dimensions' tolerances, can make an astonishing difference in the coupling efficiency of the LED chips. LED

epitaxial growers continue to demand tighter tolerances of pattern dimensions. The consistency of the dimensions and their tolerances across the total area of the 6" wafers requires tight photo and etching processes. This in turn mandates precise stepper capabilities. The industry continues to drive the 6" substrate manufacturers and PSS equipment makers to achieve the best tolerances they can.




## Implications for sapphire market

The sapphire industry, like the LED industry, has been highly competitive and is characterized by under-absorbed capacity at both the crystal growth level and the wafer fabrication level. Current market trends may cause a bifurcation in sapphire supply, between highly capable large-diameter PSS providers and commodity sapphire core producers focused on components for consumer electronics. LED-focused sapphire providers will need not just proficiency but excellence at every stage of crystal growth and wafer production in order to provide the extremely precise orientation and flatness required for 6-inch wafers. We may see some consolidation, as those sapphire producers targeting the LED market seek to internalize the most effective processes and capabilities they need to be successful large-diameter suppliers. For those focused on the consumer electronics market, a low cost structure for sapphire crystal growth and core fabrication is the principal strategic imperative.

## Implications for LED market

The move to larger substrates and PSS means that instead of buying 2" wafers as a commodity product, LED chip makers at the leading edge are now buying a highly engineered custom product from a limited number of possible supply-chain partners. Other types of semiconductors grown on silicon wafers use 12- and even 18-inch wafers — an indication that this is the path to efficiency and productivity. Indeed, chip manufacturers are creating value for themselves with the move to larger wafers because they are handling fewer units. Each time the robot arm picks up a 6-inch wafer it moves more chip area by an order of magnitude compared with a 2-inch wafer.

With the increased size of sapphire wafers, LED chip companies need to be aware of the proficiency required in every operation for sapphire suppliers to maintain orientation tolerances and flatness specifications over the increased area of this very hard material. ■

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# Discrepancy in carrier density estimates for HVPE GaN templates

**Capacitance–voltage value two orders of magnitude lower than Hall measurement.**

Researchers at Raja Ramanna Centre for Advanced Technology in India have studied different techniques for measuring the electron transport properties of gallium nitride on sapphire grown by hydride vapor phase epitaxy (HVPE) and metal-organic vapor phase epitaxy (MOVPE) [Abhishek Chatterjee et al, Appl. Phys. Lett., vol106, p023509, 2015]. MOVPE templates give relatively similar estimates for carrier density in Hall and capacitance–voltage (CV) analyses. However, CV carrier density measurements on HVPE templates are two orders of magnitude lower than for Hall estimates.

Pre-grown commercial GaN templates on sapphire are commonly used to avoid tricky and time-consuming growth of thick buffer layers of the order of microns. Instead, using commercial templates, manufacturers and researchers can focus on growing the critical hetero-

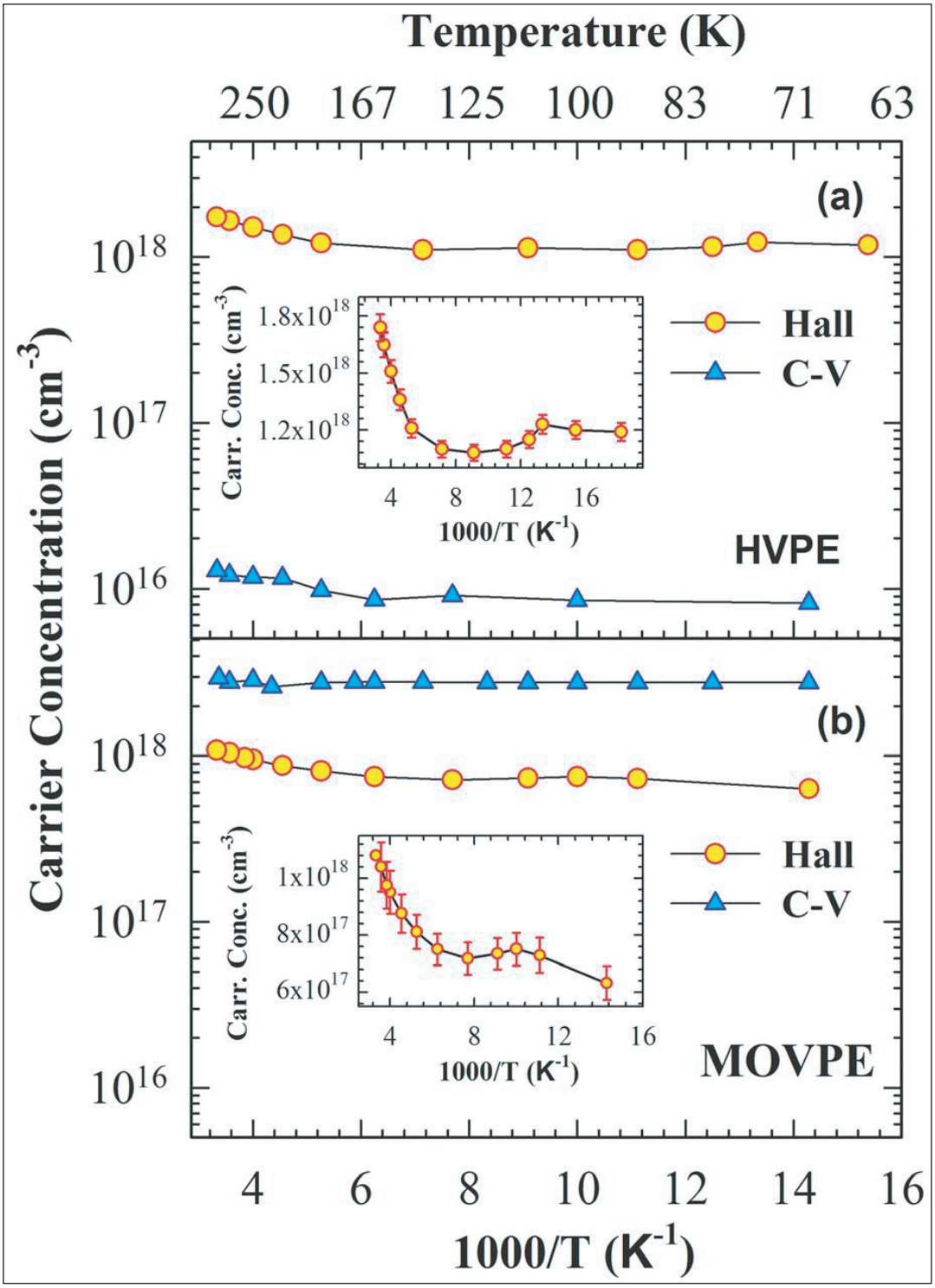


**Figure 1. Carrier concentration versus temperature recorded by Hall and C–V techniques for (a) HVPE- and (b) MOVPE-grown GaN templates. Insets: Hall concentration values plotted on linear scale with inverse temperature.**

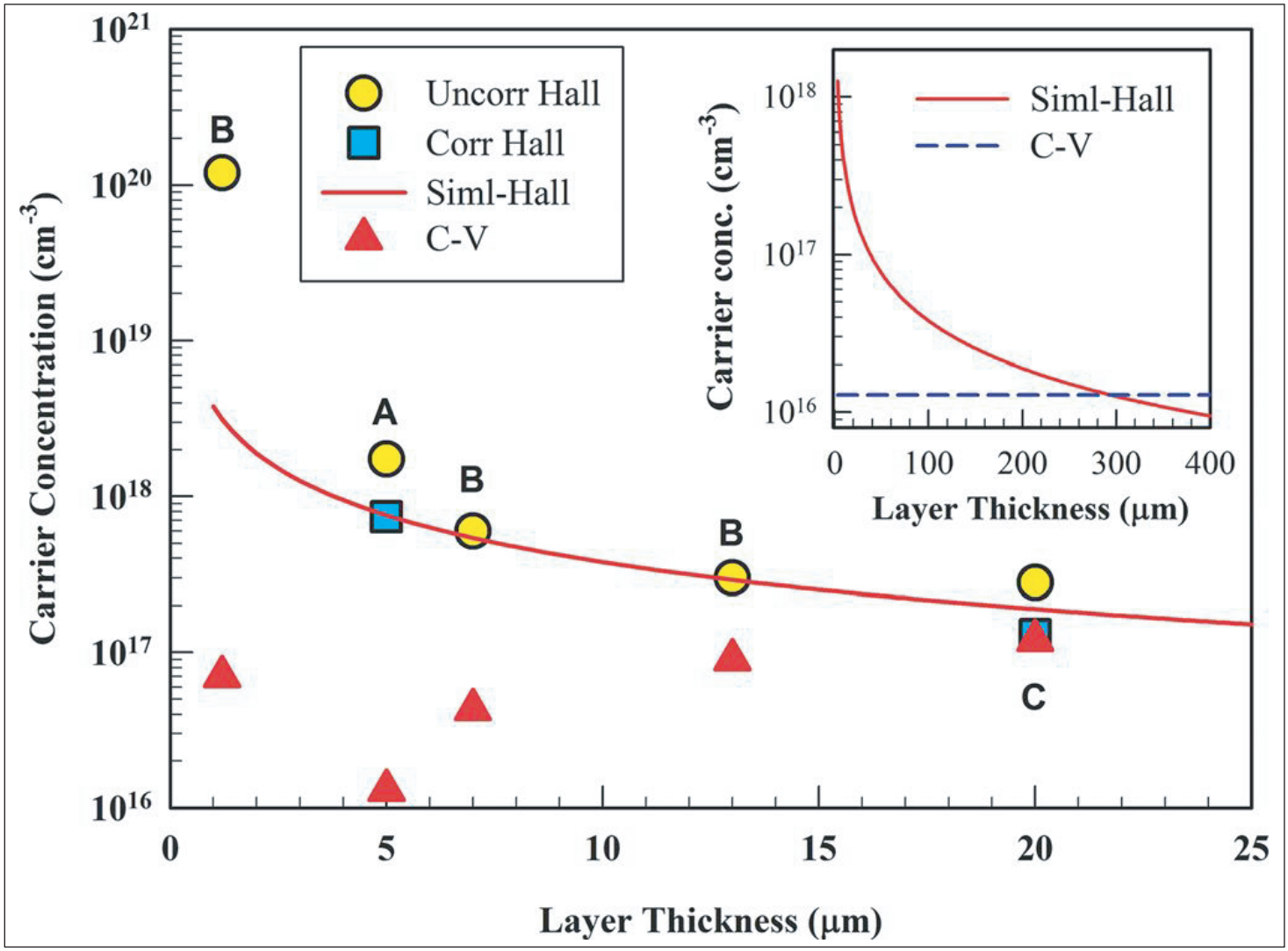


**Figure 2. Carrier concentration values obtained from conventional Hall (Uncorr-Hall), two-layer model (corr-Hall), and C–V measurements as functions of layer thickness for HVPE GaN template. Extrapolated carrier concentration curve is from two-layer model (Siml-Hall). Inset: comparison of numerically calculated Hall values with carrier concentration measured by C–V technique HVPE GaN templates.**

structure layers for optoelectronic and high-frequency/power electronic applications. HPVE has a higher growth rate than MOVPE, leading to a cost advantage.

The Raja Ramanna researchers studied commercial templates produced using HVPE and MOVPE. The researchers found that Hall and CV measurements on HVPE templates on sapphire gave radically different estimates for carrier density (Figure 1).

The researchers comment that, for the HVPE templates, "such a large difference in carrier concentration values is associated with the formation of a degenerate layer at the layer-substrate interface, which consists of a large density of threading screw and edge dislocations. Clustering of impurities around these dislocations leads to the formation of a highly conducting parallel channel for the carriers which severely affects the transport characteristics of HVPE-grown GaN templates."

The conducting channel at the sapphire/GaN layer interface could adversely affect the performance of devices using such templates. Making the GaN layer thicker reduces the parasitic effect of the interface channel, dependent on doping and dislocation density.

The researchers compared results with different thicknesses of HVPE GaN from their own and previous research (Figure 2), along with a corrected Hall value based on a two-conducting-layer model of Look and Molnar, reported in 1997 [http://dx.doi.org/10.1063/1.119176]. While the Hall measurements of the other groups line up with the two-layer Hall simulation, the CV values are still discrepant, except for Look and Molnar's result with a 20μm layer (C), due to higher doping. The Raja Ramanna researchers believe that their CV results would line up with the corrected Hall result at around 300μm layer thickness. The researchers' samples were 5μm thick (A). The (B) points were from http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=8065995&fileId=S1946427400242401.■

**http://dx.doi.org/10.1063/1.4906286**

*Author: Mike Cooke*

# Fireflies, genetics and GaN light-emitting diodes

**Nature inspires optimal surface texturing for higher light extraction.**

The researchers A Mayer and A Bay of the University of Namur in Belgium have applied a 'genetic algorithm' to the problem of finding optimal surface textures for light extraction from gallium nitride (GaN) light-emitting diodes (LEDs) [Journal of Optics, vol17, p025002, 2015].

GaN LEDs suffer from low light extraction due to the large contrast in refractive index with air, leading to reflection back into the device (killing efficiency). Compared with an extraction efficiency ($\eta$) of 3.7% for a flat GaN surface, Mayer and Bay found an optimal texturing (Figure 1, Table 1) giving 11.1% — a factor of three improvement.

The researchers also applied the genetic algorithm to samples with restricted parameters such as fixing the dielectric constant to that of a popular photoresist (2.763). It was found that a textured layer with the same dielectric constant as GaN (6.34) gave better performance.

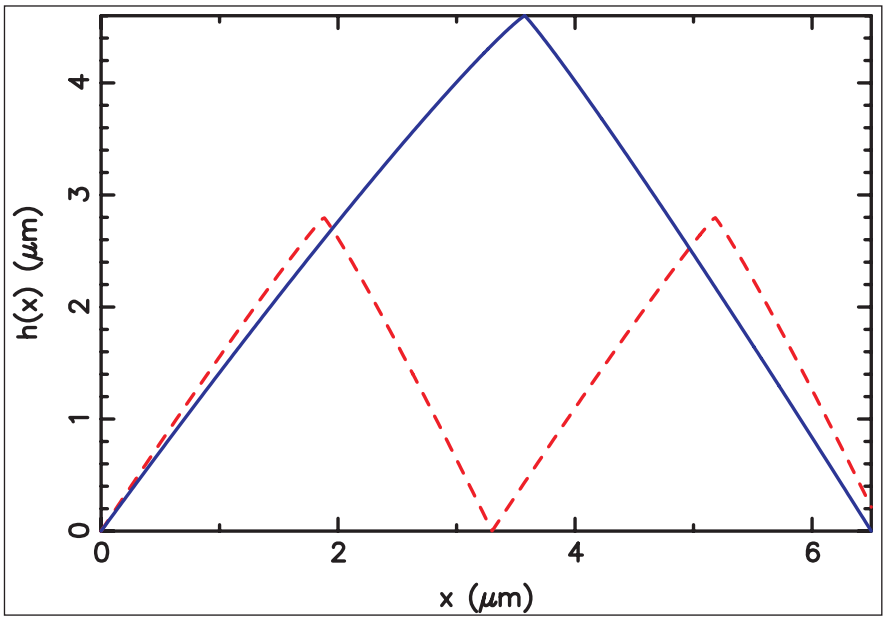


**Figure 1. Optimal shapes for surface texturing of GaN LED when optimizing on (i) P, H, c, $\alpha_{left}$ and $\alpha_{right}$ with $\varepsilon$ = 2.763 (solid), and (ii) P, H, c, $\alpha_{left}$ and $\alpha_{right}$ and $\varepsilon$ (dashed). Parameters associated with the structures are given respectively in the third and sixth lines of Table 1.**

Genetic algorithms are search techniques inspired by the process of natural selection: the parameters to be optimized are encoded as 'DNA' and a sample population with various DNA profiles is subjected to mutation and cross-over processes. The rates of mutation and cross-over have to be chosen so that the parameter space is adequately explored while at the same time the process should converge on an optimal output.

One of the researchers, Annick Bay, previously worked on light extraction from the bioluminescent organs of fireflies. Mayer and Bay comment: "This study showed that the surface of the cuticle of fireflies presents jagged scales, which turn out to increase light extraction significantly in comparison to a planar surface."

Inspired by this work, Mayer and Bay have been working on getting similar results for GaN LEDs. The researchers used a two-dimensional rigorous coupled-waves analysis to calculate the extraction efficiency of textured layers with triangular texturing. The target wavelength was 425nm. The period (P) and height (H) of the triangles were varied, along with the position of the center (c). The left and right sides of the triangles were also allowed to bend in a concave or convex sense using a power-law exponent ($\alpha$). The dielectric constant ($\varepsilon$) that controls the refractive index of the textured layer was also potentially variable.

Full variation of the six parameters with suitable steps would have needed to test some 50 trillion instances. The genetic algorithm required 2235 20-hour fitness evaluations over 60 generations. The researchers used a 'tier 1' supercomputer that allowed fitness evaluations to be carried out in parallel. The whole process took 2100 hours (3 months, 45,000 cpu hours). ■

http://dx.doi.org/10.1088/2040-8978/17/2/025002

*Author: Mike Cooke*

**Table 1. Optimal parameters for surface texturing of GaN LED with corresponding values for light-extraction efficiency. Six lines correspond to different optimizations by the GA with included parameters underlined.**

| P (μm) | H (μm) | c | $\alpha_{left}$ | $\alpha_{right}$ | $\varepsilon$ | $\eta$ |
|---|---|---|---|---|---|---|
| 6.8 | 4.8 | 0.5 | 1 | 1 | 2.763 | 7.0% |
| 5.9 | 6.1 | 1 | 1 | 1 | 2.763 | 6.1% |
| 6.5 | 4.6 | 0.55 | 1.12 | 1.07 | 2.763 | 7.1% |
| 3.5 | 2.8 | 0.5 | 1 | 1 | 6.34 | 11.0% |
| 2.7 | 2.2 | 1 | 1 | 1 | 6.34 | 7.5% |
| 3.3 | 2.8 | 0.57 | 1.07 | 1.09 | 6.34 | 11.1% |

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# Combining van der Waals technologies to make light-emitting diodes

**Heterostructures unite transition metal dichalcogenide wells, hexagonal boron nitride barriers and graphene electrodes.**

A research team including Nobel laureates Andre Geim and Konstantin Novoselov has developed light-emitting diodes (LEDs) combining transition metal dichalcogenide (TMD) wells, hexagonal boron nitride (hBN) barriers and graphene (Gr) electrodes [F.Withers et al, Nature Materials, published online 2 February 2015].

The researchers from University of Manchester and University of Sheffield in the UK and Japan's National Institute for Materials Science used a series of 'peel and lift' processes to create various heterostructures held together by van der Waals forces (Figure 1).

Peeling involves mechanical exfoliation of the source crystal layers onto a polymer double layer, dissolving the bottom polymer layer to release and float the membrane (crystal on single polymer layer), flipping and aligning with the target structure, and finally peeling off the polymer handling layer. Lifting is similar, except that the membrane is used to lift exfoliated material from a flake of crystal on a substrate for transfer to another thermally oxidized silicon wafer.

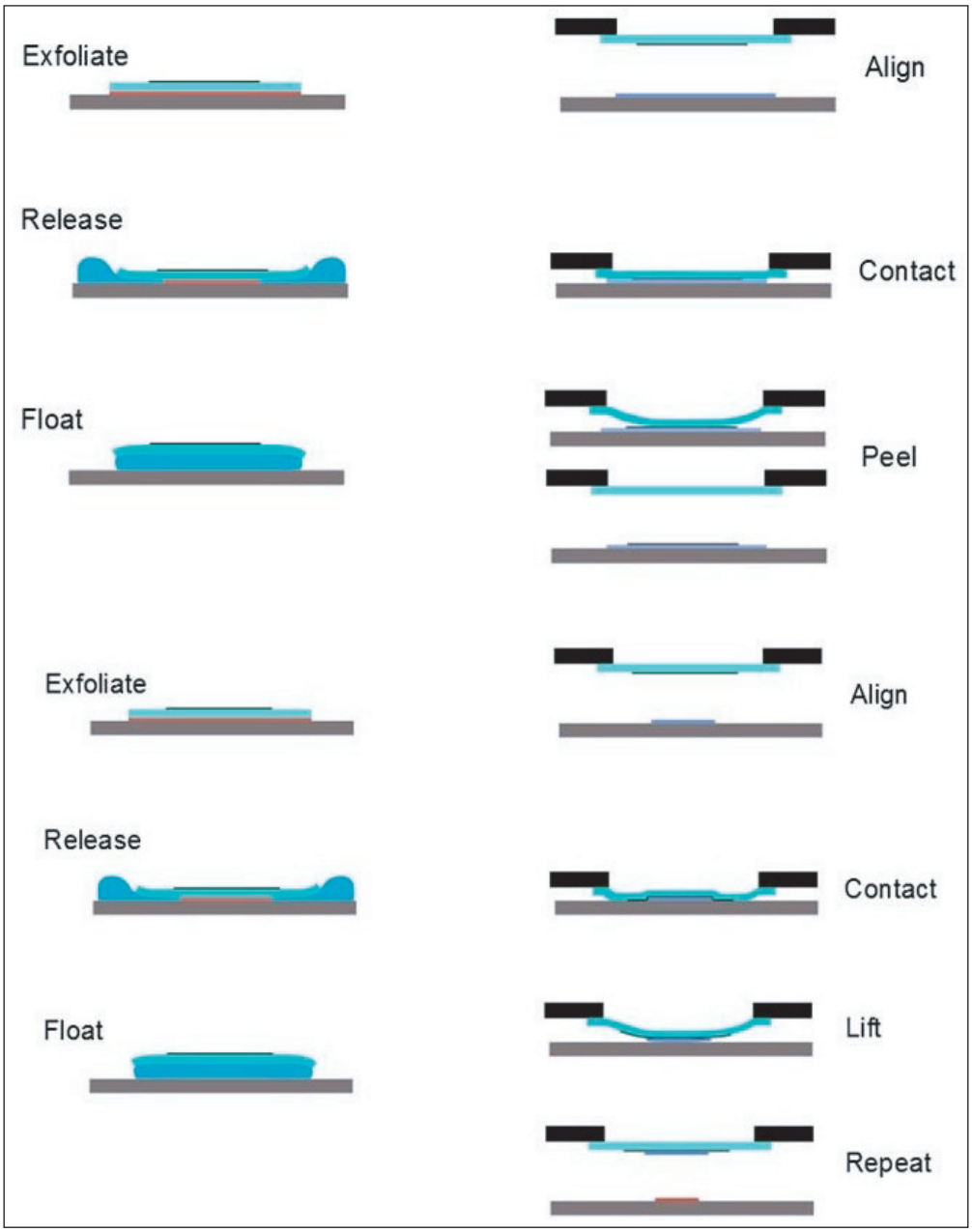


**Figure 1. Schematics of peel (top) and lift (bottom) processes.**

The LED structures consisted of molybdenum disulfide ($MoS_2$, Figure 2), or tungsten disulfide/diselenide ($W(S/Se)_2$) quantum wells separated by hBN barriers. The researchers claim 100% yield of functioning devices with strong electroluminescence "that remains unchanged after months of periodic measurements, which demonstrates the robustness of the technology and materials involved." Graphene layers were used for top and bottom electrodes in combination with chromium/gold metal contacts.

The heterostructures were analyzed by electroluminescence and photoluminescence under various

biases, along with electron microscopy and energy-dispersive x-ray spectroscopy.

Under electroluminescence (EL), the researchers estimated that a single quantum well of $MoS_2$ achieved an external quantum efficiency (EQE) of ~1% – ten times larger than for planar pn junctions of $MoS_2$ and 100x that of Schottky barrier (metal-semiconductor) emissions. The efficiency of photoluminescence (PL) was lower — the researchers comment: "Relatively low EQE found in PL indicates that the crystal quality itself requires improvement and that even higher EQE in EL may then be achieved." The line-width of these LEDs was as narrow as 18meV.

A device with three quantum wells of $MoS_2$ (Si / $SiO_2$ / hBN / GrB / 3hBN / $MoS_2$ / 3hBN / $MoS_2$ / 3hBN / $MoS_2$ / 3hBN / GrT / hBN) achieved a 6% efficiency. The turn-on current density was 1.8nA/$\mu m^2$ — nearly two orders of magnitude lower than for a single well. The voltage at this current injection was around 3.9V.

Four asymmetric quantum wells increased the efficiency to 8.4%. "This high QE is comparable to the efficiencies of the best modern-day organic LEDs," the researchers write.

An LED with mixed $WSe_2$/$MoS_2$ wells (Si / $SiO_2$ / hBN / GrB / 3hBN / $WSe_2$ / 3hBN / $MoS_2$ / 3hBN / GrT / hBN) had a QE of ~5%, an order of magnitude stronger than for the single well. The researchers suggest that this could be due to charge transfer to the well with the smallest energy gap after electron–hole generation in both wells.

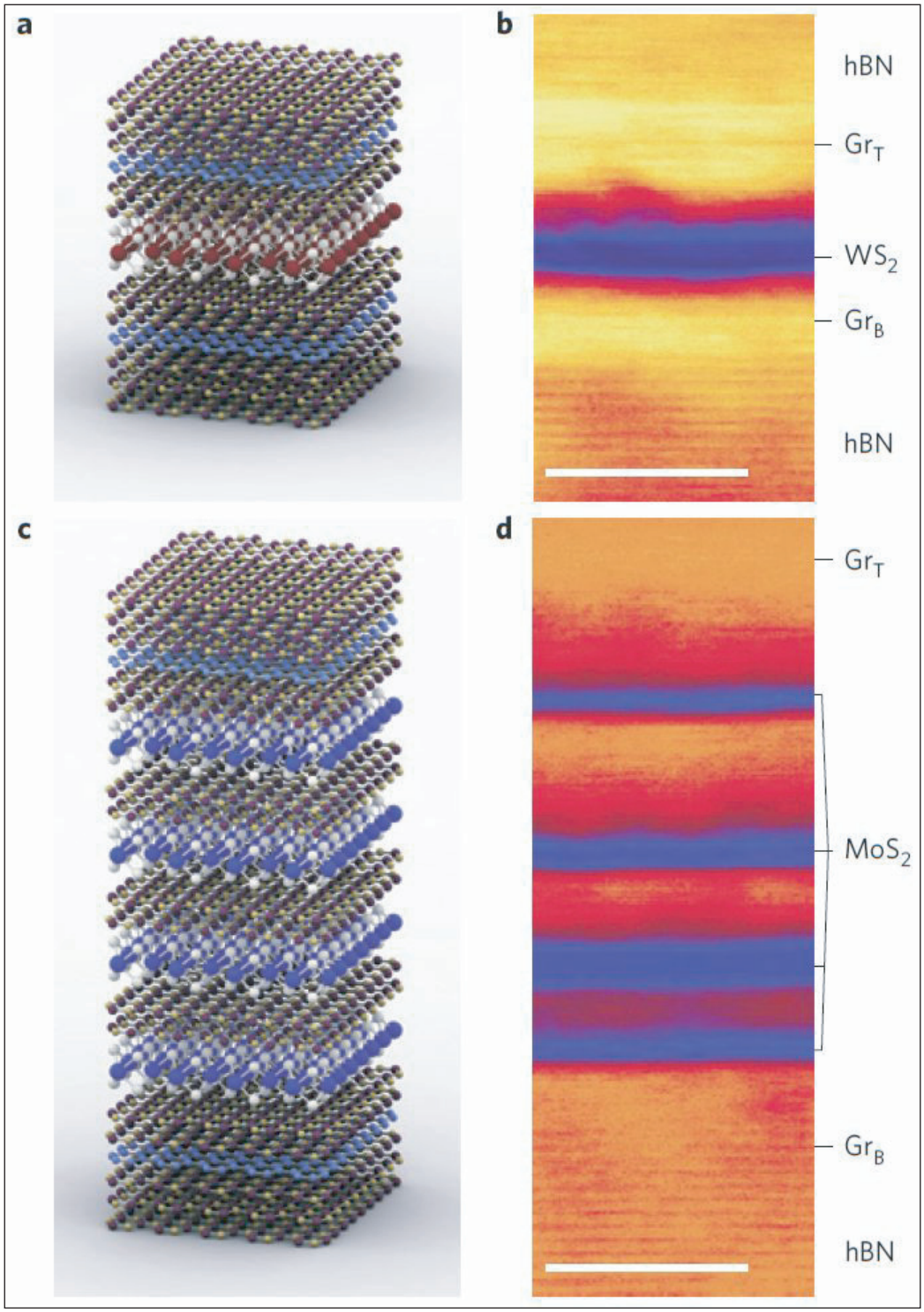


**Figure 2. a, Schematic of single quantum well structure (hBN / GrB / 2hBN / $WS_2$ / 2hBN / GrT / hBN). b, Cross-sectional bright-field STEM image of single-well heterostructure. c, d, Schematic and STEM image of the multiple quantum structure (hBN / GrB / 2hBN / $MoS_2$ / 2hBN / $MoS_2$ / 2hBN / $MoS_2$ / 2hBN / $MoS_2$ / 2hBN / GrT / hBN). The number of hBN layers between $MoS_2$ QWs in d varies from schematic. Scale bars, 5nm.**

The peak performance for the devices was at very low temperature, below 150K. At room temperature, the efficiency was around a factor of two or three lower. A single-well device assembled on a flexible polymer substrate (PET) was able to withstand bending up to 1% uniaxial strain without change in the EL spectrum.

The researchers hope that the application of chemical vapor deposition (CVD) to the preparation of such heterostructures will allow scaling up of production, as needed for commercial mass applications. ■

**http://dx.doi.org/10.1038/nmat4205**

*Author: Mike Cooke*

# Hole modulation for increased light output power from InGaN LEDs

**Researchers report 25.6% increase in light output power when last quantum barrier is partially doped with magnesium.**

Researchers based at Singapore's Nanyang Technological University and Turkey's Bilkent University have developed 'hole modulation' structures to improve hole injection into indium gallium nitride (InGaN) multiple quantum well (MQW) light-emitting diodes (LEDs) [Zi-Hui Zhang et al, Appl. Phys. Lett., vol106, p063501, 2015].

Hole injection in InGaN LEDs is adversely affected by two factors: the poor doping efficiency of magnesium and use of aluminium gallium nitride (AlGaN) electron-blocking layers (EBLs). Poor doping efficiency leads to low hole density in p-GaN layers. The problem with EBLs is that, while

| | | |
|---|---|---|
| Ohmic contact | Mg-doped $p^+$-GaN | 20nm |
| Hole source | Mg-doped p-GaN | 110nm |
| EBL | Mg-doped p-$Al_{0.20}Ga_{0.80}$ | 25nm |
| MQW | 6x($In_{0.15}Ga_{0.85}N$/GaN) | 6x(3nm/12nm) |
| Contact | Si-doped n-GaN | 2µm |
| Template | Undoped n-GaN | 4µm |
| Buffer/nucleation | GaN | 20nm |
| Substrate | c-plane sapphire | |

**Figure 1. Epitaxial structure of LEDs.**

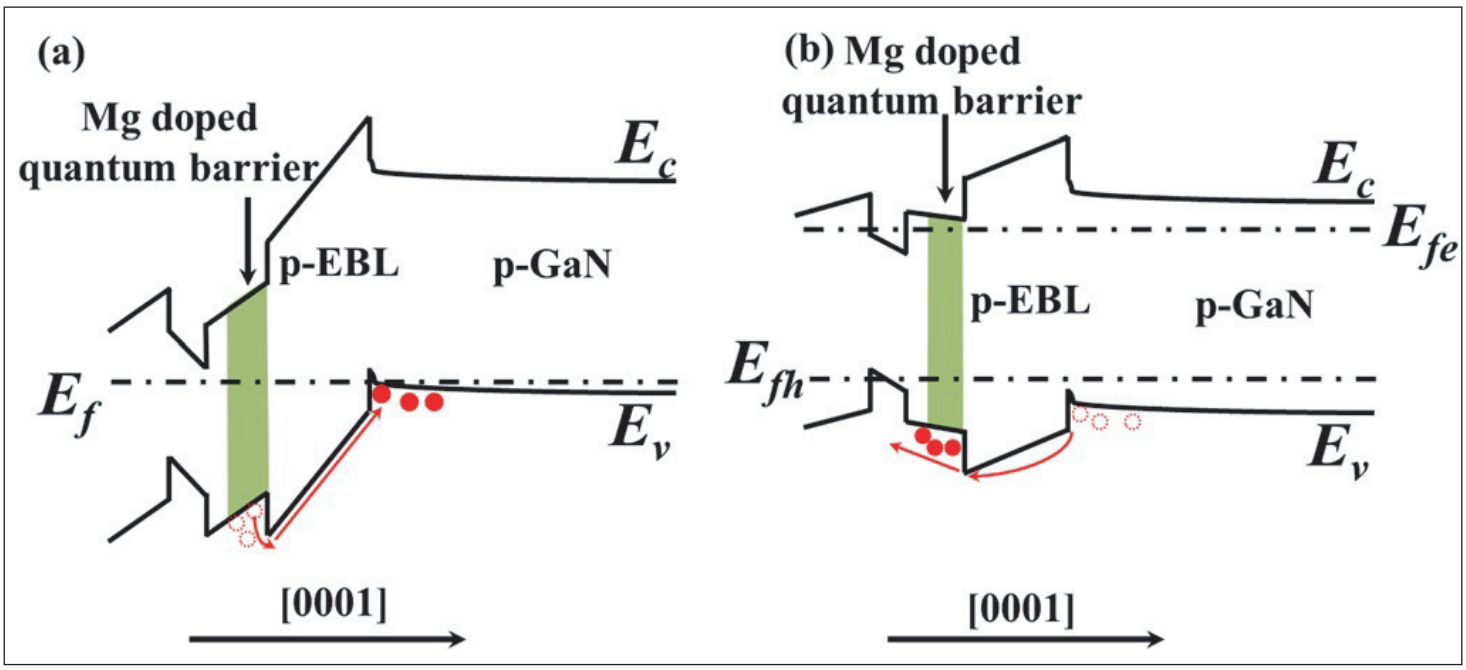


**Figure 2. Schematic energy band diagrams for InGaN/GaN MQWs, p-EBL, and p-GaN: (a) under no bias, last quantum barrier is partially p-type doped (indicated by shadow region), (b) under bias, the holes will then be injected into MQWs. $E_c$, $E_v$, $E_f$, $E_{fe}$ and $E_{fh}$ denote the conduction band, valance band, Fermi level, quasi-Fermi levels for electrons, and holes, respectively.**

they raise a barrier against electron overflow (increasing confinement of electrons in the MQW active light-emitting region), they also present a block to hole injection into the MQW.

The NTU/Bilkent technique is to partially dope the last barrier of the MQW with magnesium. The effect is to accumulate holes in the p-GaN contact layer near the EBL and to reduce the EBL barrier. The researchers report a 25.6% increase in light output power at 80A/cm$^2$ injection current density. The EBL barrier to hole injection was estimated to be 294meV, compared with 332meV for structures without last-barrier doping.

The epitaxial structures (Figure 1) were grown by metal-organic chemical vapor deposition (MOCVD) on c-plane sapphire. The last 12nm GaN barrier of the multiple quantum well structure was either undoped (LED A) or doped with magnesium in the last 6nm of growth (LED B). The structures were anneal in-situ at 720°C for 600s in nitrogen to activated the p-type magnesium doping.

The researchers performed simulations that suggested the doped last barrier would act as a 'hole modulator'. In the unbiased state (Figure 2), holes from the last barrier are depleted by the built-in electric field from charge polarization effects due to the partially ionic character of the chemical bonds in III-N compound semiconductors like GaN.

These holes accumulate in the p-GaN on the other side of the AlGaN electron-blocking layer. The hole accumulation is in a thin two-dimensional layer due to the charge-polarization-induced negative charges at the EBL/p-GaN interface.

Under bias, these holes are more easily injected into the MQW active region, compared with LED A without doping in the last barrier. Experimental determination of the hole concentration profile with capacitance–voltage measurements confirmed the picture derived from the simulations (with 'slight discrepancies').

Test LED 1mmx1mm dies were produced from the two epitaxial structures with indium bump ohmic contacts. The peak emission wavelength for LED A electroluminescence (EL) was at 454nm – LED B produced a shorter wavelength of 450nm (Figure 3). The difference was attributed to fluctuations in the conditions between the two growth runs. LED B produced stronger emission than LED A under all current density levels. At 80A/cm$^2$, the power output of LED B was 25.6% greater than for LED A.

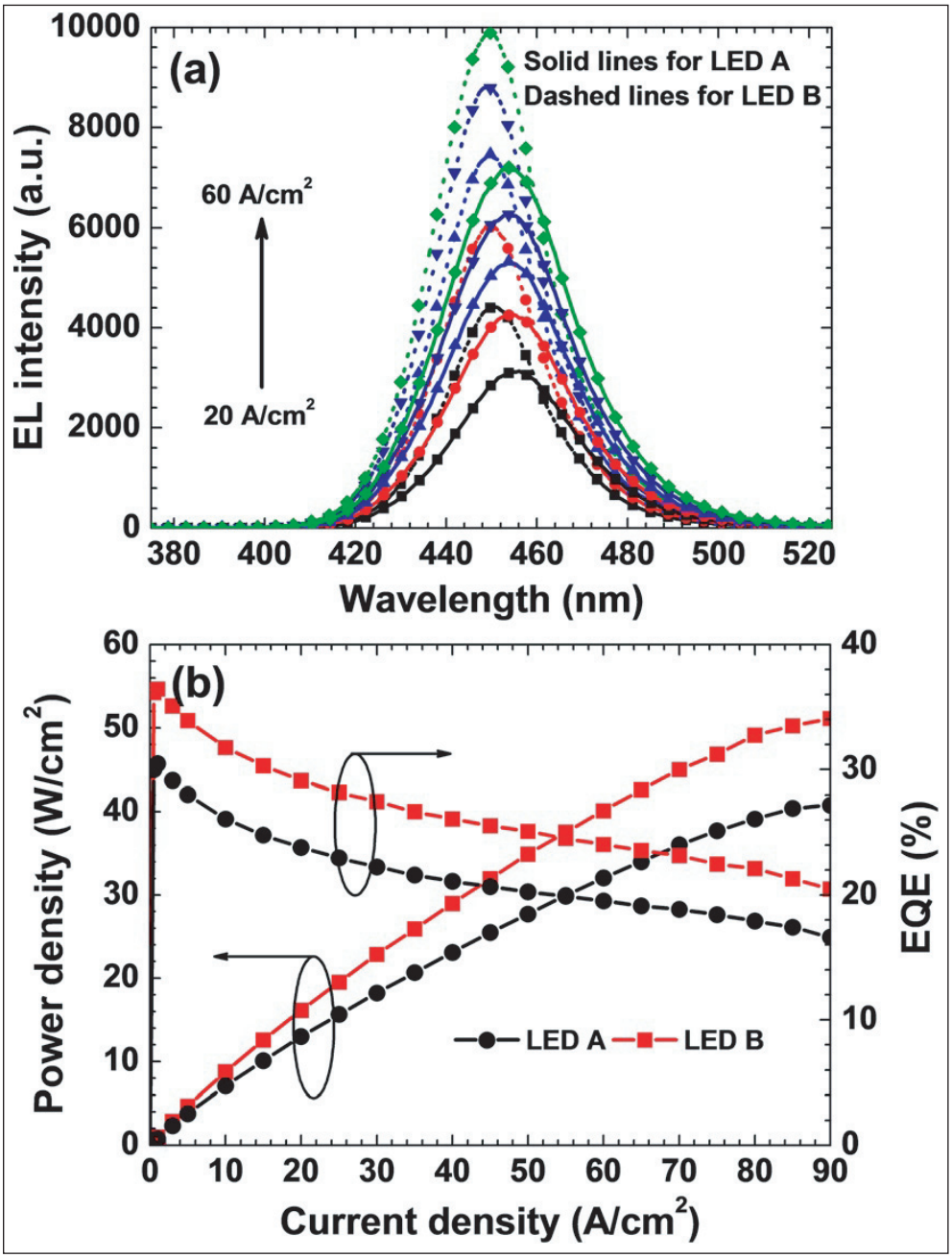


**Figure 3. Experimentally measured (a) EL spectra at 20A/cm$^2$, 30A/cm$^2$, 40A/cm$^2$, 50A/cm$^2$ and 60A/cm$^2$, solid lines and dashed lines are for LED A and LED B, respectively, and (b) optical output power density and external quantum efficiency for LEDs A and B, respectively.**

LED B also shows improved external quantum efficiency (EQE) up to 90A/cm$^2$. The presented graph cuts off at the point where the EQE peaks (for both LEDs) and one would expect the usual droop effect beyond this, although this is not mentioned in the paper. ■

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# China to comprise half of all LED epi & chip equipment spending in 2015–2016

**China growing at double the global rate, from 35% to almost 40% of capacity in 2016, according to Clark Tseng, senior manager Market Analysis with the SEMI Industry Research & Statistics Group.**

The LED industry is now fully embracing the fast-growing lighting market as (based on revenues) LED lighting has become the largest sector among LED applications, surpassing LCD backlighting in 2014, and is expected to be the major driver of the market in coming years, according to Clark Tseng of the Industry Research & Statistics Group at global industry association Semiconductor Equipment and Materials International (SEMI). Driven by robust demand forecast from lighting applications, the LED industry is geared toward another phase of capacity expansion after the previous peak observed in 2011, he adds.

According to SEMI's Opto/LED Fab Forecast report, global LED epitaxy monthly capacity reached 2.5 million (4" substrate equivalent) at the end of 2014 and will surpassed 2.9 million at the end of 2015, showing mid-teen percentage growth in both 2014 and 2015 (Figure 1).

China, however, is showing a more aggressive expansion plan, with double the growth rate compared to the worldwide growth rate throughout 2013–2016. China's LED epitaxy capacity is expected to reach 1 million (4" equivalent) per month at the end of 2015 and 1.28 million in 2016, accounting for 35% and almost 40% of global capacity, respectively.

The capacity growth is driven primarily by new metal-organic chemical vapor deposition (MOCVD) installation and partially by migration to larger substrate sizes. Specifically, new reactors have doubled the capacity compared to earlier models that were available on the market not too long ago, further boosting the capacity growth rate. Regarding the size of substrate, SEMI expects the 4" substrate to become the mainstream production size this year, surpassing 2" substrates, while 6" substrates are also gaining more share at Tier 1 and Tier 2 manufacturers. However,

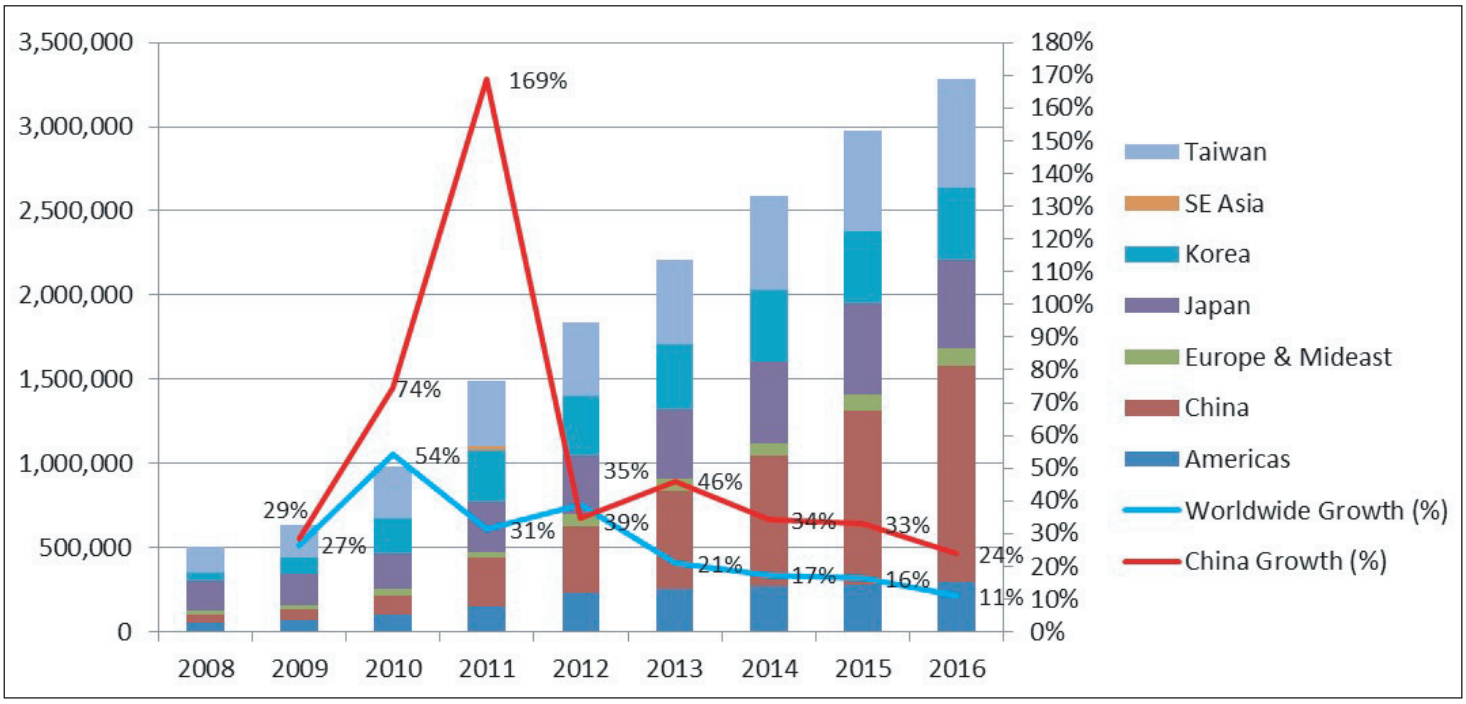



**Figure 1. Installed LED epi capacity by region (4"-equivalent per month). Source: SEMI Opto/LED Fab Forecast, April 2015.**

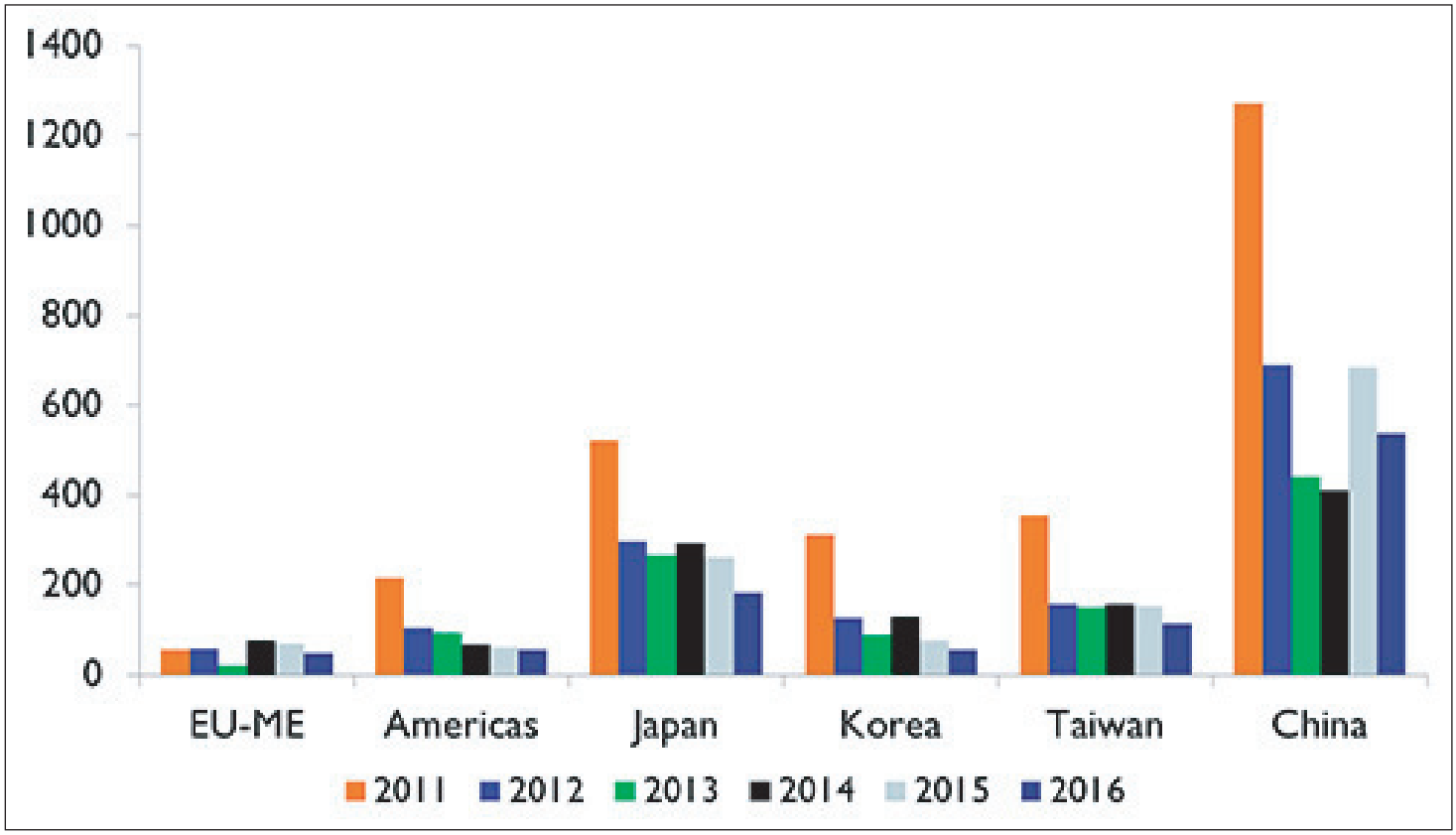



**Figure 2. LED epi/chip equipment spending by region, 2011–2016 (in millions). Source: SEMI Opto/LED Fab Forecast, April 2015.**

8" gallium nitride on silicon (GaN-on-Si) capacity will still be limited to a handful of suppliers in the foreseeable future, reckons SEMI.

Looking at the trend in LED epitaxy and chip process equipment spending (Figure 2), there is a major difference between the 2011 investment spree and 2015. Back in 2011, almost all regions were boosting their capital expenditure as they tried to seize a bigger share of the market. Overall investment into LED front-end facilities reached a staggering $2.7bn worldwide in 2011, with China representing about 46% of that. However, that also resulted in oversupply and consequently a slowdown in the LED equipment market afterwards. In contrast, the investment recovery in 2015 seems much more disciplined, with only China expecting to see big growth over 2014, says SEMI. Total equipment spending is forecasted to reach $1.35bn in 2015, followed by a correction in 2016 to $1bn. China will contribute over half of worldwide investment in 2015 and 2016. Sanan Opto, Elec-Tech, HC SemiTek, Aucksun and Changelight are among the few to see bigger investment in SEMI's forecast. Some of the expansions in China are also from Taiwanese LED suppliers.

**Further consolidation at epi/chip suppliers will gradually help bring healthier supply/demand dynamics going forward**

On the other hand, other regions are showing a slowdown in investment. Leading players will still spend on capacity expansion and technologies but at a more disciplined pace. Japan and Taiwan are the two regions that remain committed to investing and adding new capacity. SEMI expects major investment to come from leading players like Nichia, Toshiba, Epistar and Lextar.

China's LED industry is still supported by government subsidies, even though they are now more subdued. SEMI forecasts that the LED lighting market is big enough to consume all the new capacity coming online. It is more concerned about the mounting pressure of price erosion on LED component suppliers. With the rise of mid-power LED chips which are applicable to many of the lighting solutions, Chinese LED suppliers will be able to gain a sizable share of the LED lighting market, it is reckoned. That could drive out some of the value of high-power LED components, which is the sector that leading suppliers still dominate.

Overall, the scale of investment in 2015 and 2016 is still within the range of market acceptance, given the even faster LED lighting growth forecast, says SEMI. The concern regarding oversupply could be eased somewhat, considering that real utilization rates at some of the older fabs are not particularly high. "We expect further consolidation at epi/chip suppliers will gradually help bring healthier supply/demand dynamics going forward," concludes the report. ■

**www.semi.org/en/Store/MarketInformation/OptoLEDFabForecast**

# GaN MOCVD reactor installations to total 220 in 2015

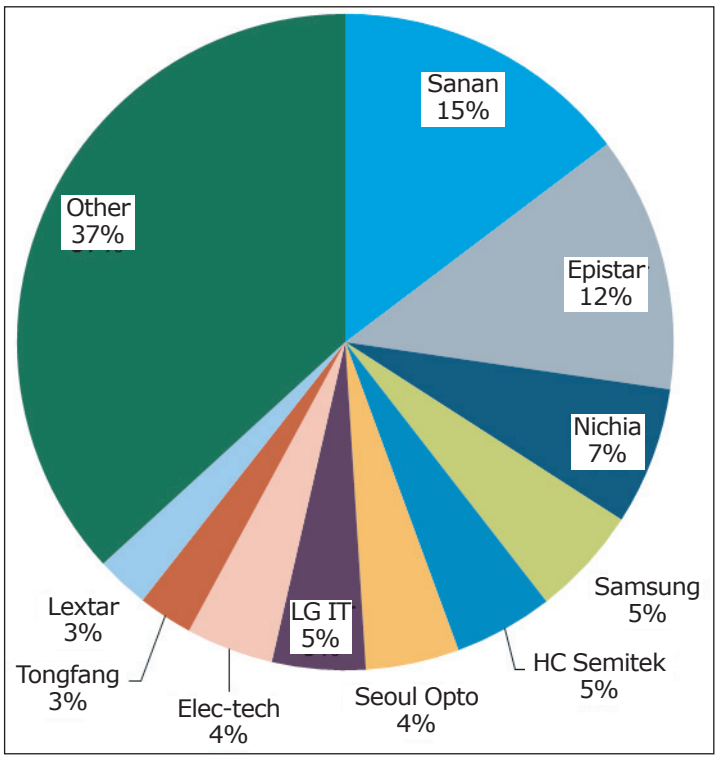
## Three largest Chinese firms to take 27% of installations, reckons IHS.

Due to the major aggressive expansion plans of some Chinese LED firms, 220 gallium nitride metal-organic chemical vapour deposition (MOCVD) reactors will be installed in 2015, according to the latest data from the IHS LED Intelligence Service. This large number of MOCVD tool shipments will result in a 28% increase in the level of excess supply in the LED industry, forecasts market research firm IHS.

The new capacity expansion is slightly different from what happened several years ago, when large numbers of LED companies in China purchased government-subsidized tools, notes IHS.

The firm forecasts that this year only large and publicly traded companies will purchase MOCVD systems. The bar chart above shows the largest 20 MOCVD customers by the end of 2014: eight are Chinese companies and three of those — Sanan, HC Semitek and Aucksun — have announced expansion plans for 2015.

Most of the new reactors purchased in 2015 will be new-generation tools, which provide double the capacity per reactor. By the end of 2015, Sanan is projected to lead in 2-inch-equivalent wafer capacity share, although Epistar will still own the largest number of MOCVD tools. The three largest Chinese firms will achieve a combined market share of 27% in 2015, concludes IHS. ■




**2"-equivalent GaN LED wafer capacity by end 2015.**

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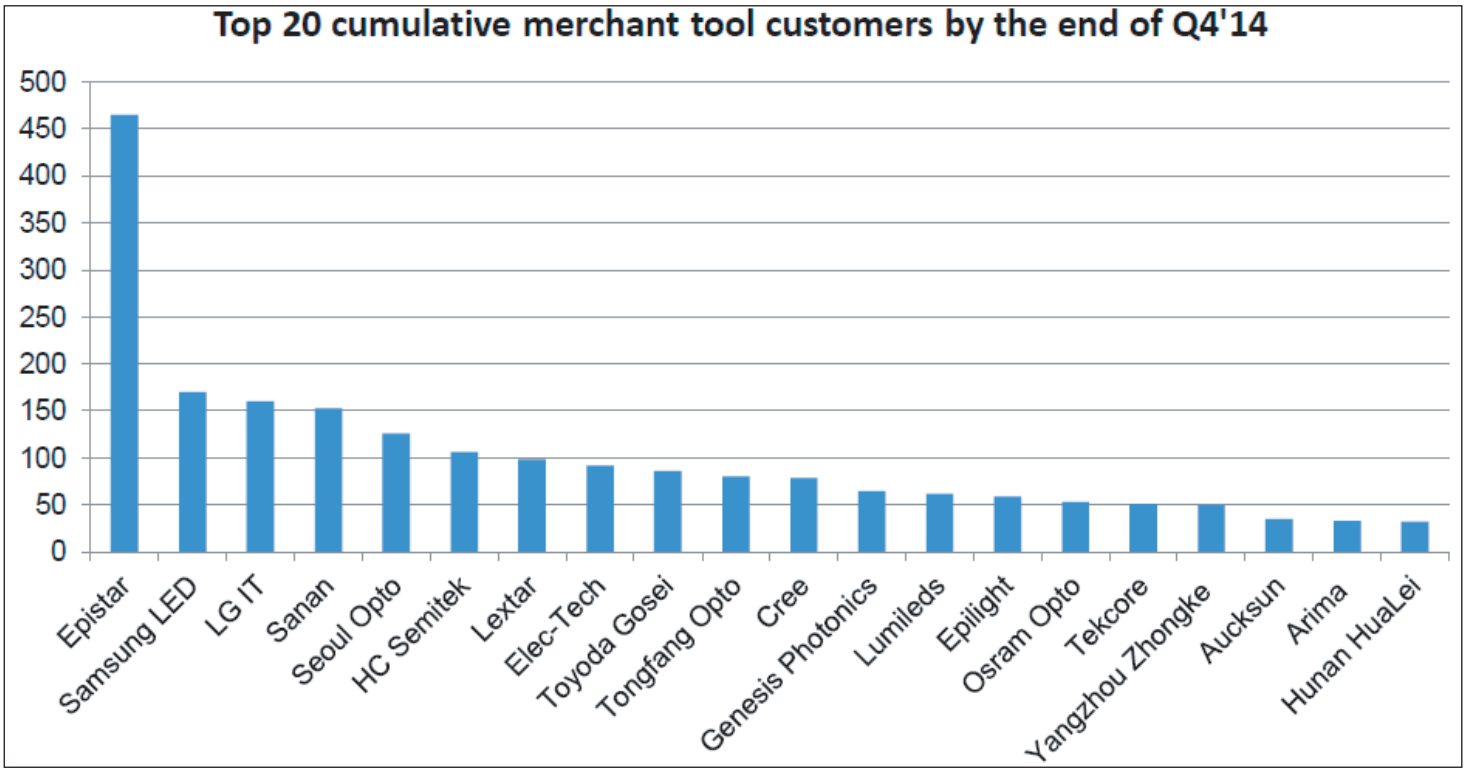


# SiC and GaN power semiconductor market to grow 17-fold to $2.5bn in 2023

## Price and performance parity with silicon MOSFETs, IGBTs and rectifiers expected in 2020, forecasts IHS.

Energized by growing demand for power supplies, hybrid and electric vehicles, photovoltaic (PV) inverters and other established applications, the emerging global market for silicon carbide and gallium nitride power semiconductors will grow by a factor of 17 over the 10 years from 2013 (just $150m) to 2023 ($2.5bn), forecasts market research firm IHS Inc in the report 'The World Market for SiC & GaN Power Semiconductors — 2014 Edition'.

SiC and GaN power semiconductors have been trying to establish themselves in key applications for a few years now. However, about 15% of the eventual market could consist of new applications using these device technologies that are currently still two or three years away from production. In addition to the market for hybrid and electric vehicles themselves, it is now apparent that the electric vehicle charging infrastructure market — including battery charging stations for plug-in hybrid and battery-electric vehicles — is also a potentially interesting sector for SiC and GaN power devices.

There is no agreed global standard for hybrid-electric vehicle (HEV) charging infrastructure, so there are various competing standards describing the various levels or modes for AC and DC charging. All of the assorted AC levels can be considered to be for electro-mechanical systems, which require few, if any, power semiconductors. The IHS report therefore only considers DC or 'fast charging' systems, because these are AC–DC power supplies, converting power from the mains (typically three-phase) into very high currents of up to 125–400A at direct-current voltages up to 480–600$V_{DC}$ (delivering a maximum power of 240kW).

Wireless power charges battery-powered appliances by transmitting power through the air instead of through power cables. Although proximity within a specified range is required, this technology is gaining in popularity in mobile phones, game controllers, laptop computers, tablets, electric vehicles, and other commodity products. The adoption of SiC and GaN power semiconductors will be negligible in inductive charging solutions, which are designed to comply with the Wireless Power Consortium (WPC) Qi or Power Matters Alliance (PMA) standards, because silicon metal-oxide-semiconductor field-effect transistors (MOSFETs) are adequate for the low frequencies involved. In contrast, the fast-switching capabilities of SiC and GaN power semiconductors are ideal for magnetic-resonance power-transfer applications, which perform well at the higher frequencies of the Alliance for Wireless Power (A4WP) standard.

As numerous consumer electronics applications use fairly low voltages, they will be more suitable for GaN devices. The only area of this application thought suitable for SiC power devices is wirelessly charging battery-powered electric vehicles, such as plug-in hybrid vehicles (PHEVs) etc.

Two more applications that could potentially use SiC power modules are wind turbines and traction. In both cases the biggest barriers to adoption are their high cost, unproven reliability, and a lack of availability of high-current-rated modules, in general, and of full SiC modules in particular. Both applications typically require 1700V modules, a voltage at which few SiC transistors have already been developed. Trials are underway, but commercial production is not expected to start until 2016 or 2017.

For high-voltage SiC technologies, there are many new medical applications and other potential industrial applications. For low-voltage GaN devices, the new applications include many emerging technologies that are expected to drive significant growth in the future, such as wireless envelope tracking, light detection and ranging (LIDAR), Class-B audio amplifiers, and medical devices.

IHS says that the key factor determining market growth will be how quickly SiC and GaN devices can achieve price parity with — and equivalent performance of — silicon MOSFETs, insulated-gate bipolar transistors (IGBTs) or rectifiers. Price and performance parity is forecast to occur in 2020, and the SiC and GaN power market is subsequently expected to experience tremendous growth through 2023. ■

**https://technology.ihs.com/489338/sic-gan-power-semiconductors-2014**

# Meeting manufacturing challenges for GaN-on-Si power IC devices

**Veeco's chief technology officer and its senior director, MOCVD Technology discuss how systems with single-wafer chambers can address the transition of gallium nitride on silicon power devices from R&D to volume production.**

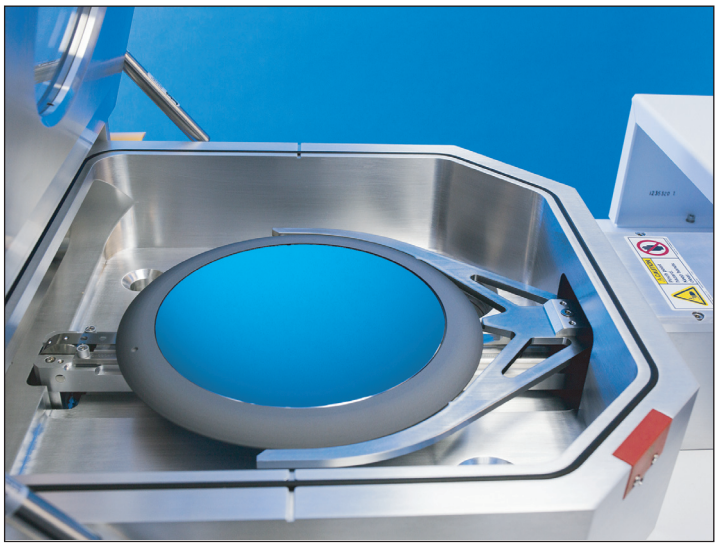
The research and development efforts put into growing gallium nitride (GaN) layers on silicon wafer substrates (GaN-on-Si) over the past five years are beginning to pay off with the introduction of some exciting new products. While much of the discussion has centered on the introduction of LED chips grown on silicon wafers to help reduce the cost of solid-state lighting, breakthroughs are also occurring in power IC markets thanks to the technology's potential to deliver more cost-effective and energy-efficient devices. This is especially true for the power-switching device market. If current product development efforts stay on track, we should see increasing device shipments in 2016, targeting higher-end, less price-sensitive applications.

As production ramps and costs fall, GaN-on-Si device power ICs are being targeted for a broad range of applications such as consumer electronics, solar and wind power, power supplies and automotive applications. Various industry analyst firms, such as IHS Research, are predicting a compound annual growth rate (CAGR) of 90% between 2015 and 2020.

The power-switching market today is largely served by silicon IC devices. The promise of devices fabricated on GaN layers is a smaller form factor with better thermal properties and greater efficiency — ideal for applications such as IT servers, where heat generation is a growing problem as server banks become larger and where heat management and energy efficiency are increasingly important factors.

## Market still in initial stages of product development

While GaN-on-Si power devices are showing great promise, they are currently still in development. A few 200V GaN-on-Si devices are starting to appear. One or two OEMs have introduced long-anticipated 600V GaN high-electron-mobility transistors (HEMTs) to the market, but these products are still considered to be in their infancy. Current data indicates that products such as servers and white-box goods using these GaN power ICs have yet to ship. OEMs are currently perfecting device architectures and developing manufacturing processes.



**Wafer in Veeco's Propel PowerGaN MOCVD system.**

To help speed the development of GaN-on-Si power devices, Veeco has developed the Propel PowerGaN single-wafer manufacturing system, based on the core metal-organic chemical vapor deposition (MOCVD) technologies used in its multi-wafer TurboDisc EPIK700 and MaxBright batch systems. A 200mm-wafer-capable system, Propel allows power-device OEMs to leverage Veeco's years of MOCVD technical experience and market expertise. Significant orders are anticipated in 2015 as OEMs rush to finish GaN IC development, which should allow adoption of these devices in 2016 – for IT servers initially, with white-box applications shipping in 2017.

The Propel system is designed to assist users in solving product development issues for GaN-on-Si devices. The three key challenges are to deliver a device that has:

1. low ON-state resistance (enabling the device to produce less heat and be more energy efficient);
2. low current leakage; and
3. high breakdown voltage.

"The GaN material system offers great potential for the future of power electronics," says Karl Knieriem, senior epitaxial engineer with Toshiba America Electronic Components. "The capability to grow GaN material on silicon grants access to existing power electronic silicon fabs—allowing for easy adoption," he adds. "The Veeco Propel system provides capabilities for GaN-on-Si growth that go beyond what can be achieved using other systems in existence today."

Because the Propel system is a single-wafer tool, it can deliver very high film uniformity across the wafer and can demonstrate wafer-to-wafer repeatability. Uniformity is key to the device's ultimate performance and reliability. For instance, a film thickness variance of just ±1nm can result in threshold voltage variance of ±0.5V across the wafer, which will significantly impact device performance. Also, since Propel is a single-chamber system (rather than a batch MOCVD tool), it can offer very tight chamber temperature control utilizing Veeco's proprietary SymmHeat technology. This precise thermal control provides excellent thickness and compositional uniformity. The single-chamber architecture also permits faster heat-up and cool-down times. For product development, this translates to short cycle times and a broad process window, giving OEMs greater flexibility to help speed architectural design, testing and recipe development.

Also important to device development is flexibility in the IC stack design and doping process of specific layers. Here, again, uniformity is a critical aspect — both for the aluminum (Al) containing layers, which contribute to threshold voltages, and for the doping layers, which are critical to device performance. When the Al and doped layers are uniform, device performance is uniform.

## Transition from R&D to volume production

Market analyst firm Yole Développement predicts that, as the manufacturing costs for GaN power devices come down, market demand will rise rapidly. If 600V devices are as successful as anticipated, this will open a broad range of applications that will culminate in a market size of $600m by 2020 (see 'GaN: Primed for Power', Compound Semiconductor, Issue VI 2014).

As device OEMs transition from R&D to volume production, throughput will become a critical issue for reducing costs. Single-wafer tools can create a severe fab bottleneck. To address this problem, Veeco designed the Propel system so that multiple single-wafer chambers can be attached to a single backbone, creating a cluster tool capable of achieving much faster throughput while maintaining the same uniformity and reliability performance. While traditional batch MOCVD tools such as Veeco's K465i and MaxBright have been used for R&D, customer feedback has consistently stressed the need for single-wafer-like performance to meet device performance and production yield targets.

Veeco anticipates that Propel will enable its customers to enter volume production and meet the burgeoning market demand.

Of further benefit to device OEMs, Veeco's MOCVD system architecture provides inherent system-level advantages over systems that typically use a close-coupled showerhead (CCS) or vertical reactor design. First, Veeco's technology provides OEMs greater flexibility. The unique reactor design gives manufacturers easy scalability of flow, pressure and disc rotation speed, and enhanced thermal control within the reactor chamber. Second, the approach is far cleaner. Cleaner operation permits greater system up-times, since the frequency of maintenance cycles is reduced, thereby improving overall system throughput.

## Conclusion

During any new technology adoption process, there are many challenges to be overcome and, often, surprising lessons to be learned as the technology moves from the laboratory to the fab floor. This will be no less true for the transition of GaN-on-Si technology into volume production. The industry is currently at this stage in adopting GaN-on-Si for power-switching devices. The greater the flexibility of the manufacturing systems that device OEMs have to work with, the shorter the time to market.

Veeco is working with customers to utilize proven technologies integrated with a flexible platform — a platform optimized for development but also adaptable to volume production while seamlessly transitioning the recipe and manufacturing processes. With this approach, we hope to both speed product development and assist with the cost-reduction challenges of volume production.

*Authors: Ajit Paranjpe, chief technology officer, and George Papasouliotis, senior director, MOCVD Technology, Veeco Instruments*

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# Direct growth of indium gallium nitride on silicon substrate

**Low-temperature plasma-assisted molecular beam epitaxy produces layers with an indium composition spanning the range from GaN to InN.**

Researchers in Europe have developed a low-temperature plasma-assisted molecular beam epitaxy (PAMBE) process for direct growth of indium gallium nitride (InGaN) on silicon (Si) substrates [Pavel Aseev et al, Appl. Phys. Lett., vol106, p072102, 2015]. Silicon is an attractive substrate with a view to low-cost production and integration with silicon CMOS electronics.

GaN on silicon has been developed recently for high-power switching and high-frequency amplifier applications. Some work has also been performed on InGaN-based light-emitting devices using GaN templates on silicon. However, a direct growth on InGaN could open the way to a wider range of wavelengths and applications such as solar cells.

The low-temperature PAMBE deposition was able to produce InGaN layers across the range of compositions, including near-infrared, as used in 1.3μm and 1.55μm optical communications. The work was carried out at Universidad Politécnica de Madrid and Universidad de Cádiz in Spain, Max Planck Institute of Microstructure Physics and Carl von Ossietzky Universität Oldenburg in Germany, and Universitá di Milano-Bicocca in Italy.

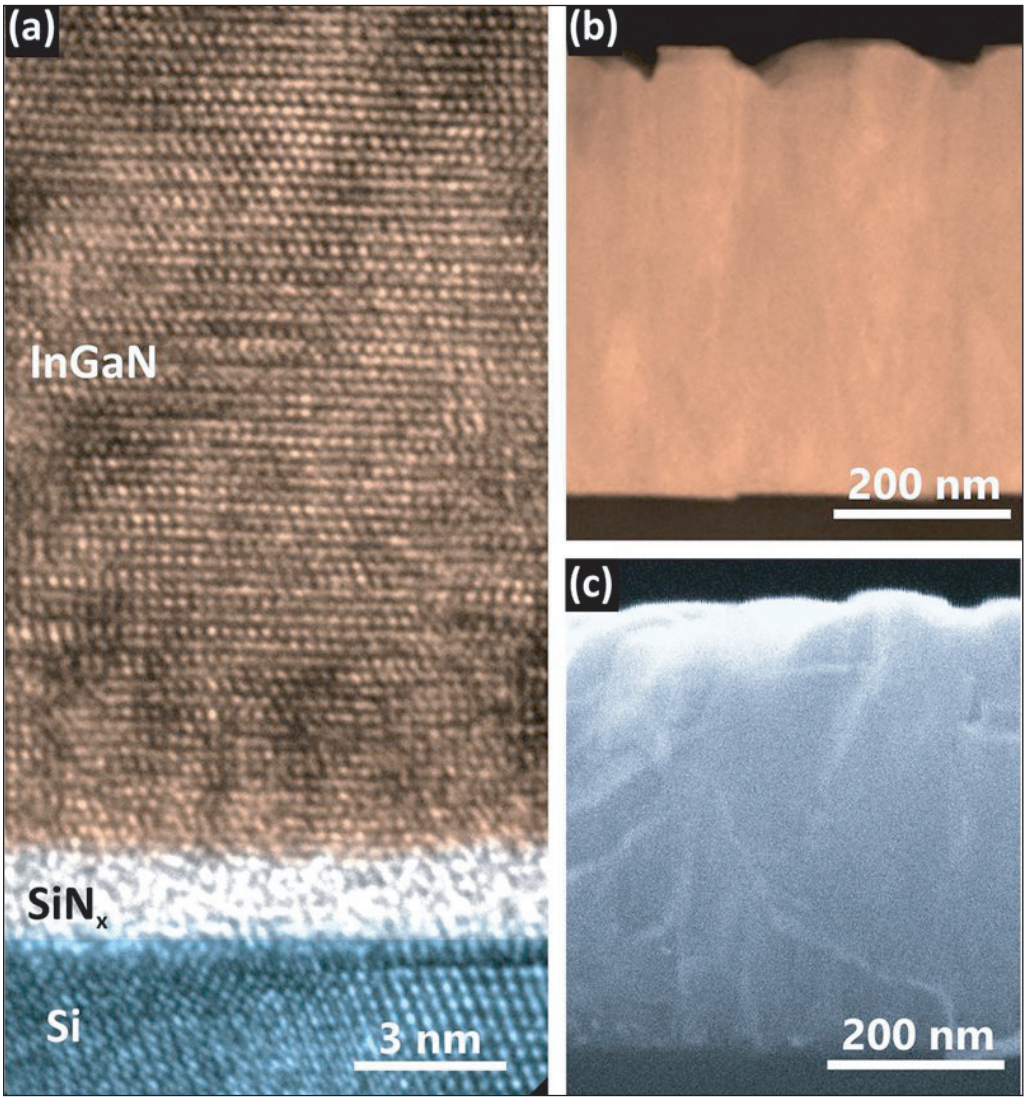


**Figure 1. (a) HRTEM image of 480nm-thick $In_{0.73}Ga_{0.27}N$/SiNx/Si interface and (b) HAADF image of the InGaN layer, both taken along the [11$\bar{2}$0] III-N zone axis. (c) Corresponding SEM image.**

The InGaN was grown on p-type silicon (111) substrates. Before deposition, the substrates were degassed at 850°C for 30 minutes and exposed to a nitrogen flux for 5 minutes to create a 2–3nm silicon nitride layer. Such nitridation has previously been found to improve strain relaxation and crystal quality for GaN growth on silicon.

The InGaN growth at 450°C lasted an hour. The growth temperature is low, even for MBE — GaN MBE is typically carried out at 700–800°C. The aim of the low temperature was to avoid indium desorption.

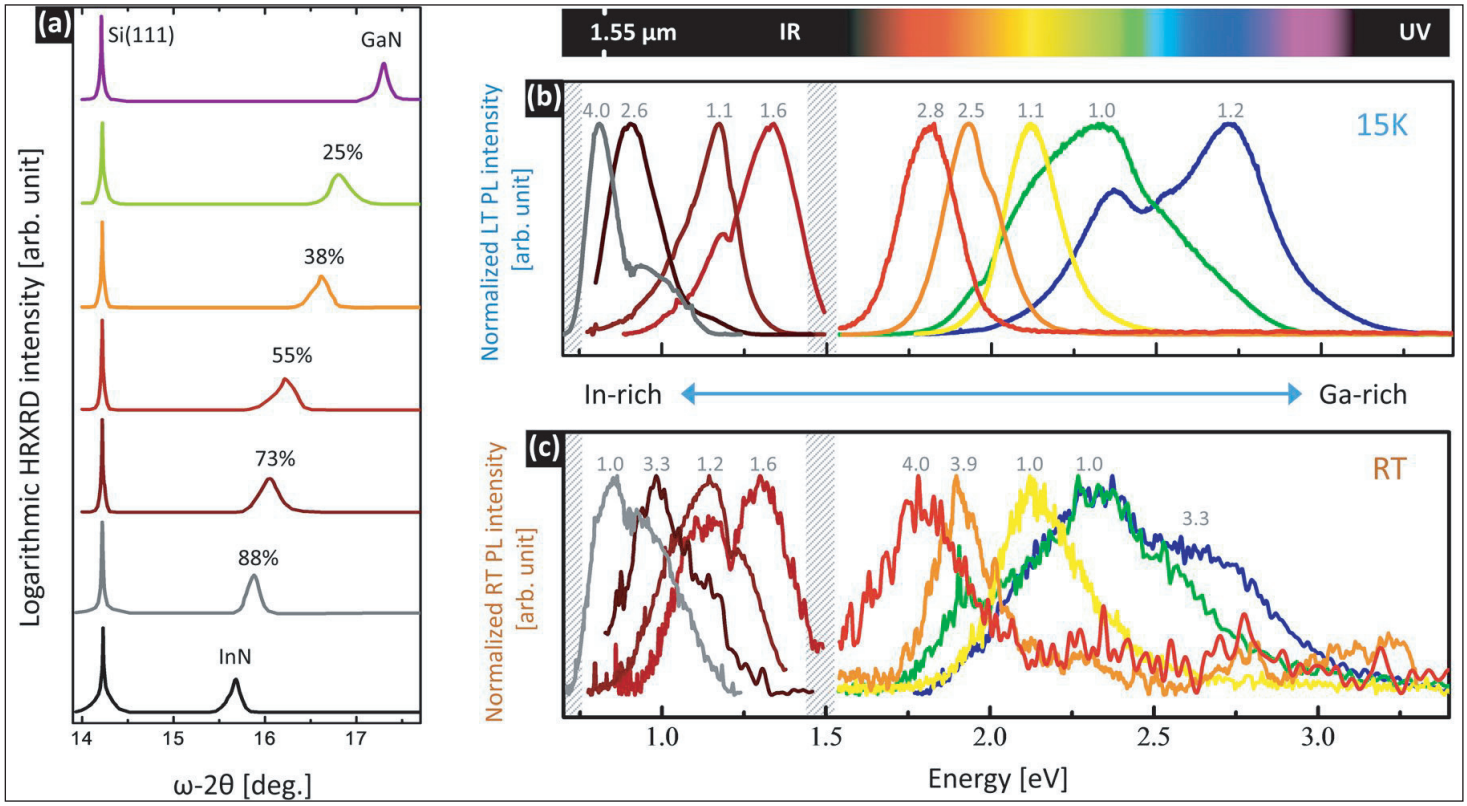


**Figure 2. (a) High-resolution x-ray diffraction spectra recorded around symmetric InGaN(0002)/Si(111) Bragg reflection. Normalized photoluminescence spectra of InGaN layers taken at (b) 15K and (c) room temperature. Relative intensity scaling factors indicated. Low- and room-temperature intensities scale 95:1.**

The growth conditions were slightly nitrogen-rich. The balance between the group-III metals (In, Ga) and nitrogen was important to avoid metallic droplet (metal-rich) or nanocolumn (nitrogen-rich) formation.

High-resolution transmission electron microscope (HRTEM) study of an $In_{0.73}Ga_{0.27}N$ sample (Figure 1) showed "clear projections of atomic columns" apart from "occasional localized defects". High-angle annular dark-field (HAADF) imaging showed some slight variations in contrast from threading dislocations (TDs) or differences in sample thickness.

The researchers comment: "It is difficult to quantitatively deduce the density of the TDs as they are accumulated locally. Still, their density is lower or similar to that in other III-N layers grown on buffered silicon or sapphire substrates."

The team estimates the standard deviation for indium content at less than 2.5% on the basis of energy-dispersive x-ray (EDX) spectroscopy. The chemical homogeneity is attributed to the low growth temperature that suppresses compositional fluctuations and phase separation. One possible drawback of the low temperature was an undulating surface that is not seen with higher temperatures of more than 500°C.

The researchers point out that undulating surfaces can also be advantageous for many low-cost mass production applications "such as light-emitting diodes, solar cells, water splitting, and photodetectors".

Photoluminescence analysis at 10K of data from a near-field scanning optical microscope (NSOM) showed homogeneous peak intensity emission with ~15% standard deviation. The peak energy was around 1.24eV (near-infrared, 1µm wavelength). Intensity variation was attributed to differences in crystal quality rather than indium composition.

Samples with varying indium content were produced covering the whole range from GaN to InN. Photoluminescence intensity varied by a factor of four among the samples (Figure 2).

The electrical characteristics of the InGaN/p-Si junction were also measured. Above 50% indium content, the InGaN layer had an n-type majority carrier with defects acting as electron donors. This allowed an ohmic contact to be formed with titanium/aluminium/nickel/gold top contacts. The bottom contact was silver paste applied to the back-side of the silicon substrate.

The resulting structure gave 'near-ideal ohmic' current–voltage behavior for n-$In_{0.53}Ga_{0.47}N$/p-Si heterointerfaces, according to the researchers. Above 50% indium content, n-InGaN/p-Si junctions are expected to be ohmic due to alignment of the p-Si valence band and n-InGaN conduction band.

A structure with $In_{0.37}Ga_{0.63}N$/p-Si gave a rectifying behavior. The junction with the top metal contact was found to be still ohmic, but more resistive, due to the lower n-type carrier density. ■

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# High-mobility channels and moving beyond silicon

**A number of significant changes are seemingly converging on 7nm — lithography, III-V NMOS, Ge PMOS? Here we focus on InGaAs NMOS research.**

Reports from February's 2015 IEEE International Solid-State Circuits Conference (ISSCC) in San Francisco suggest that Intel plans to move away from silicon transistors at the 7nm technology node, which is expected to begin around 2018. Intel's existing leading-edge technology is 14nm, producing the 'Broadwell' micro-architecture. The next step will be 10nm, around 2016–17, implemented with more silicon technology.

The question is what does "moving away from silicon" mean? It is widely expected to involve III-V materials and indium gallium arsenide (InGaAs) in particular. These materials have higher mobility — meaning that the carrier drift velocity is higher for a given applied field. The aim of applying high-mobility materials is to achieve denser, faster ICs consuming less power.

InGaAs channels cover the n-channel side of complementary metal-oxide-semiconductor (CMOS) transistors circuits. However, the p-side may be some form of germanium that is chemically related to silicon in the group IV of the periodic table. Suggested alternatives include tin–germanium (IV–IV) or indium gallium antimonide (III–V) alloys. Using two different materials increases complexity and cost, risking development delays.

It is a matter of pride for Intel to stay on the 'Moore's Law' course of shrinking devices by 0.7x every two years — this would give the sequence 14nm–10nm–7nm corresponding to the years 2014–2016–2018. However, the path in recent years has not been simple — Intel delayed its 14nm introduction for several months as a result of reported "manufacturing issues".

Apparently one of these issues was an increase in the number of masks used in photo-lithographic processing, reducing the 'learning rate' in development toward higher yield. This is presumably related to the problem of using 193nm ultraviolet radiation to image deep-subwavelength 14nm features. Over the years, subwavelength lithography has developed various work-arounds to improve resolution, such as optical proximity correction, phase-change masks, immersion in high-refractive-index liquids, and multiple exposures (the cause of the increase in mask number?).

Although extreme ultraviolet lithography (EUVL, with an expected wavelength of ~13nm) has been in development since before 2000, it has been delayed from its initial target of imaging 100nm devices (~2004) and is now not expected to be implemented before the 7nm node. The main problem seems to be with light source power, but there are also infrastructure concerns arising from the different ways that EUVL masks work.

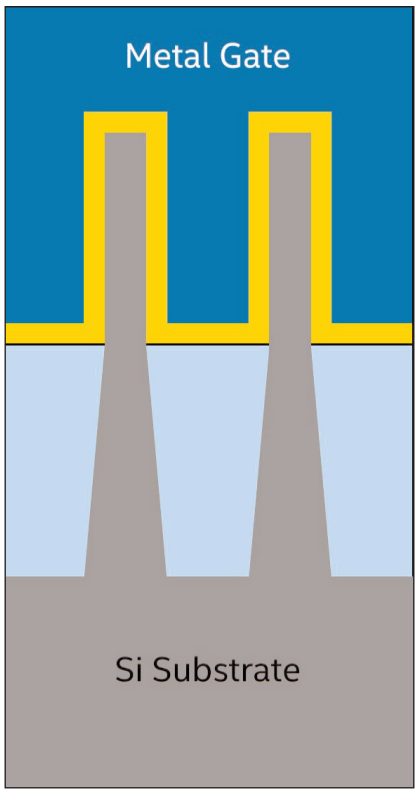



**Figure 1. Schematic of Intel 14nm finFET.**

Despite the problems, Intel claims that its 14nm technology resulted in a better-than-the-trend drop in cost per transistor. Pilot 10nm devices are reported to be 50% faster than 14nm devices, and the company does not expect any delays.

At first sight it may seem strange that 14nm was delayed, since it is Intel's second generation of tri-gate fin field-effect transistor (finFET, Figure 1). These devices use a series of fins to allow the gate electrode to wrap around the channels, giving increased electrostatic control over traditional planar structures with the applied field coming from just one side.

Intel's first-generation tri-gate was 22nm for the 'Ivy Bridge'/'Haswell' micro-architectures (2012–13). Other companies are due to move to the tri-gate structure at 14nm (Figure 2).

The introduction of InGaAs or some other III–V material channels poses a number of challenges. The first is producing a workable technique for creating InGaAs on 300mm substrates — which are vital for mass production, and this means silicon (since there is no other crystal material available at these diameters).

In 2013, nanoelectronics R&D center Imec of Leuven, Belgium produced InGaAs finFETs on 300mm silicon

wafers with a view to 7nm production. The Imec technique uses wafers with silicon fins that are replaced with InGaAs/InP fins. The European research center has also developed a similar germanium fin-replacement process.

Other groups are working on techniques where InGaAs is grown on much smaller indium phosphide substrates (up to 100mm diameter) and transferred to 300mm silicon by direct wafer bonding. However, this adds process complexity and, hence, cost.

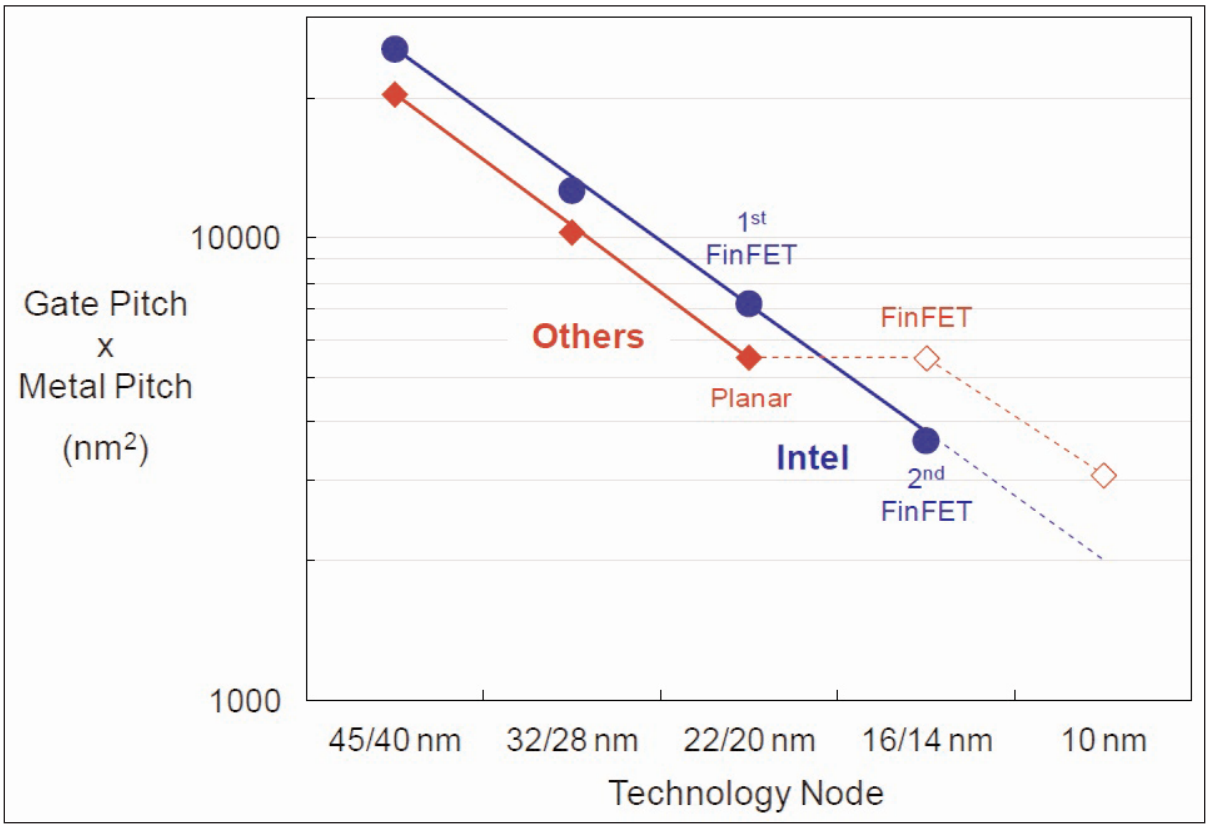



**Figure 2. Intel's assessment of transistor scaling for the recent past and near future.**

Further aspects of InGaAs transistor fabrication also need work, such as the source/drain contacts of many experimental devices being too large for 7nm and using materials not suitable for a silicon environment.

## Boosting swing and transconductance

Researchers based in USA and South Korea have claimed a record combination of subthreshold swing (82mV/decade, 0.5V drain bias), transconductance (1800μS/μm) and on-current (0.41mA/μm) for a tri-gate quantum well InGaAs MOSFET [Tae-Woo Kim et al, IEEE Electron Device Letters, published online 20 January 2015]. The team was based at Sematech Inc in the USA, KANC in South Korea, and GLOBALFOUNDRIES in the USA.

The III-V epitaxial structure was grown on semi-insulating indium phosphide by molecular beam epitaxy (MBE) — see Figure 3. A multi-layer cap was used to control the side spacing, $L_{side}$, in the combined wet/dry recess etch (Figure 4). Patterning consisted of two electron-beam lithography processes to achieve the desired fin width and gate length. The fin width and height were 30nm and 20nm, respectively.

The 80nm gate length was determined by an opening in a silicon dioxide ($SiO_2$) layer. The gate insulation consisted of 0.7nm aluminium oxide ($Al_2O_3$) and 2nm hafnium dioxide ($HfO_2$) deposited by atomic layer deposition (ALD).

The authors present a benchmark chart of transconductance ($g_{m,max}$) versus subthreshold swing (S) to support their record claim (Figure 5).

## Buried yttrium oxide insulator

Korea Institute of Science and Technology has presented what it says is the first demonstration of InGaAs-on-insulator ($In_{0.53}Ga_{0.47}As$-OI) transistors with buried yttrium oxide ($Y_2O_3$ BOX) layer [SangHyeon Kim

| | | |
|---|---|---|
| Cap | $n^+$-$In_{0.53}Ga_{0.47}As$ | 20nm |
| Cap | InP | 2nm |
| Cap | $n^+$-$In_{0.53}Ga_{0.47}As$ | 20nm |
| Barrier | InP | 1nm |
| Channel | $In_{0.53}Ga_{0.47}As$ | 20nm |
| Back barrier/buffer | $In_{0.52}Al_{0.48}As$ | 300nm |
| Substrate | InP | |

**Figure 3. Epitaxial structure for InGaAs MOSFET.**

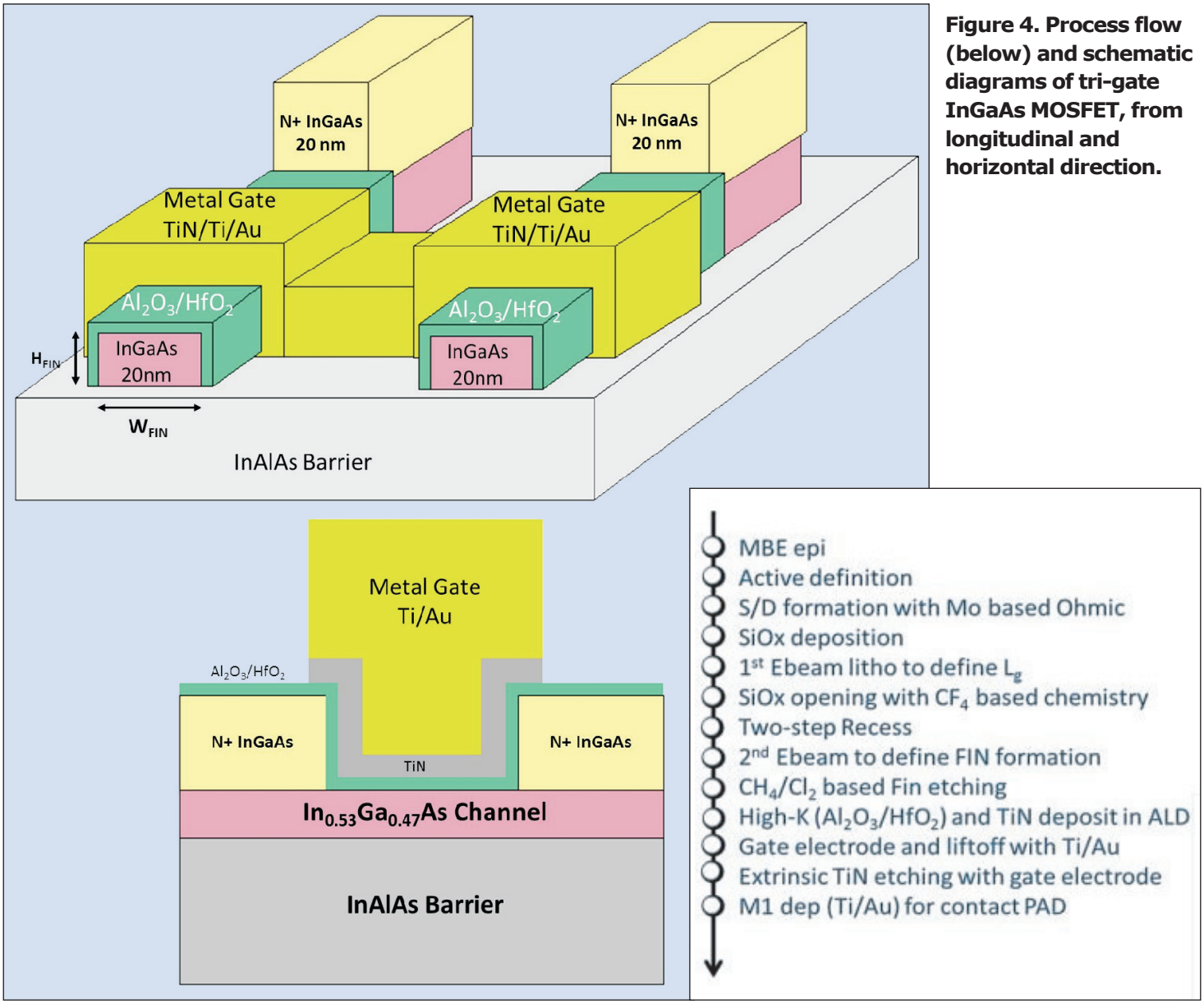
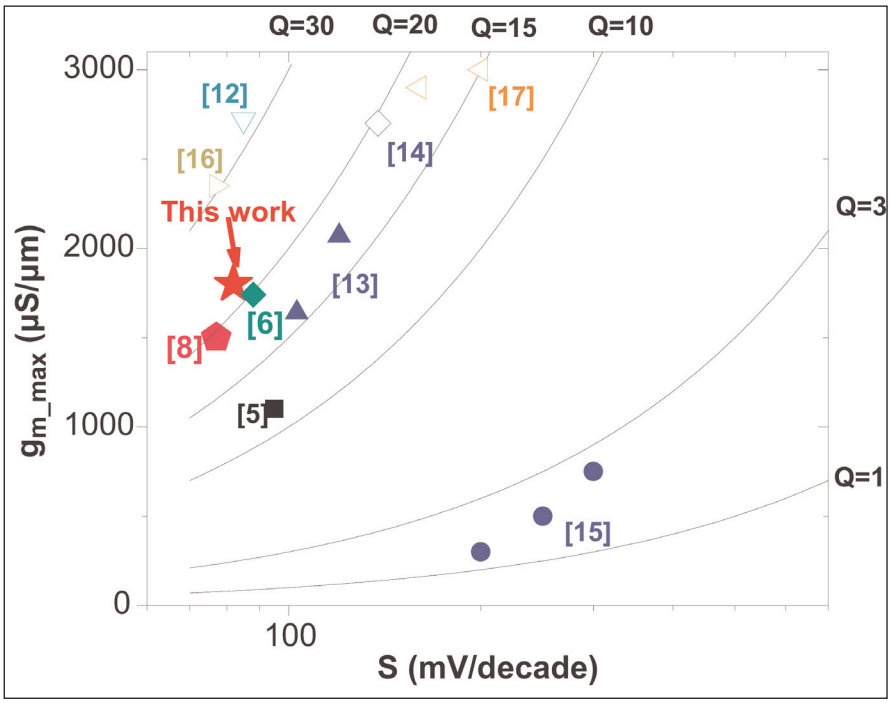



**Figure 4. Process flow (below) and schematic diagrams of tri-gate InGaAs MOSFET, from longitudinal and horizontal direction.**




et al, IEEE Electron Device Letters, published online 31 March 2015].

The researchers see InGaAs-OI as a promising alternative to more complicated tri-gate devices. The use of $Y_2O_3$ should enable reduced equivalent oxide thickness (EOT) compared with aluminium oxide, on the basis of a higher dielectric constant (16 versus 9–12). Reduced EOT brings the gate effectively closer to the channel, improving electrostatic control.

A simple MOS back-gate stack transistor was constructed by layer transfer of InGaAs

**Figure 5. Maximum transconductance versus subthreshold swing, comparing with other reports. Q is $g_{m,max}/S$. Filled symbols are for III-V non-planar MOSFETs and open symbols are for planar MOSFETs. In all cases, the drain bias is 0.5V.**

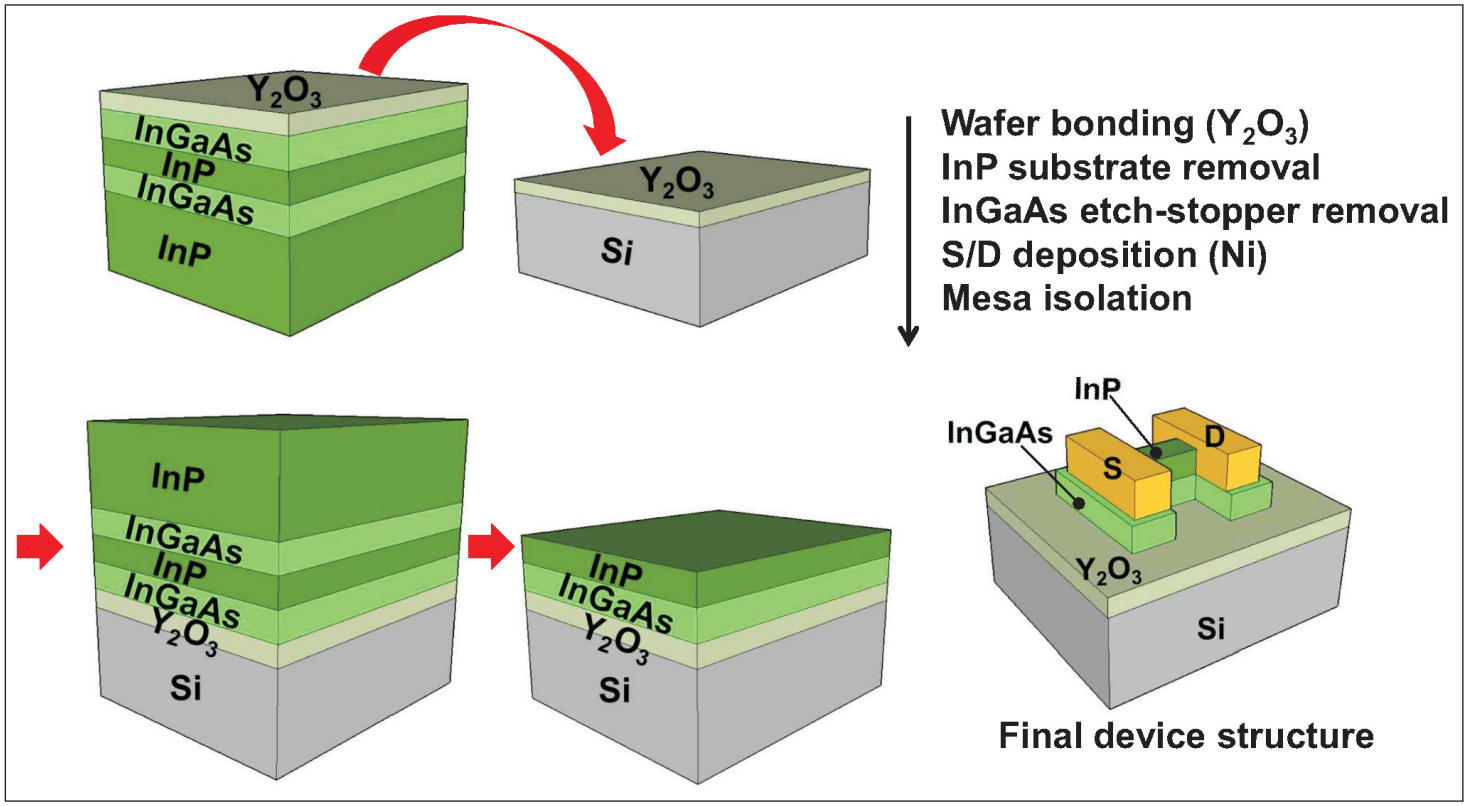



**Figure 6. Fabrication process for InGaAs-OI on Si wafer by direct wafer bonding and schematic of final device.**

from its InP growth substrate to silicon with a $Y_2O_3$ buried layer (Figure 6). The InGaAs surface was prepared by native oxide removal and passivation with acetone, ammonium hydroxide and ammonium sulfide solutions. The clean surface was covered with 10nm of $Y_2O_3$ produced through electron-beam evaporation. The silicon target substrate was also covered with 10nm of $Y_2O_3$, after cleaning with hydrofluoric acid.

The wafer bonding was achieved with hand pressure in air. The InP growth substrate and an InGaAs sacrificial layer were removed with hydrochloric and phosphoric acid wet etching. Nickel/gold was used for the source and drain electrodes. An InP etch-stop layer was selectively removed from the source and drain areas, but left in place over the channel region to reduce surface effects, which can impact effective mobility.

The final device was subjected to rapid thermal annealing (RTA) at 300ºC. The gate length was 2μm and the body (channel) thickness was 10nm. The subthreshold swing was 90mV/decade, described by the researchers as "very low" in view of the relatively large EOT.

The effective mobility was enhanced by a factor 2.5x over the value for silicon-based devices, even without annealing (Figure 7). Annealing at 300ºC increased the effective mobility to 2000cm$^2$/V-s. These first results should be improvable with process optimization, say the researchers.

The interface trap density extracted from the subthreshold behavior was 1.1x10$^{12}$/eV-cm$^2$, comparable with values from MOS capacitor measurements. These capacitor structures were produced on InGaAs/InP substrates with 10nm $Y_2O_3$ dielectric, and top and bottom electrodes of platinum/gold and nickel/germanium/gold, respectively. Post-metal annealing at 350ºC reduced interface trap densities to as low as 4x10$^{12}$/eV-cm$^2$ near the conduction-band edge, according to capacitance–voltage measurements. The hysteresis was 15mV. ■

*Author:*
*Mike Cooke*

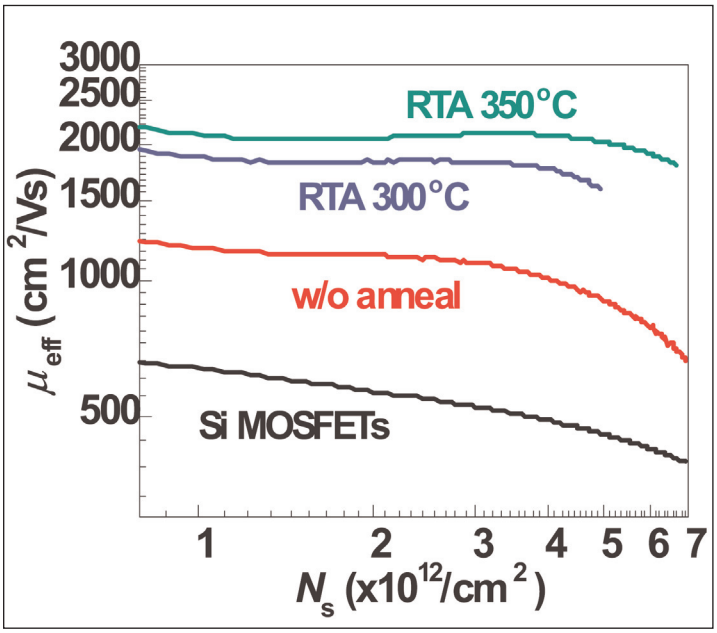



**Figure 7. Effective mobility ($\mu_{eff}$) characteristics of InGaAs-OI transistors produced with various annealing temperatures.**

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# event calendar

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**17–22 May 2015**
**Microwave Week 2015, incorporating:**
**IEEE MTT-S International Microwave Symposium (IMS 2015)**
**IEEE Radio Frequency Integrated Circuits Symposium (RFIC 2015)**
**85th Automatic RF Techniques Group (ARFTG) Microwave Measurement Conference**
Hyatt Regency Hotel, Phoenix, AZ, USA
**E-mail**: Nannette@mpassociates.com
**www.ims2015.org**

**18 May 2015**
**2015 ROCS: Reliability of Compound Semiconductors Workshop**
Hyatt Regency Scottsdale Resort, AZ, USA
**E-mail**: Peter.Ersland@macomtech.com
**www.jedec.org/home/gaas**

**18–21 May 2015**
**CS MANTECH 2015:**
**International Conference on Compound Semiconductor Manufacturing Technology**
Hyatt Regency Scottsdale Resort, AZ, USA
**E-mail**: conferencechairman@gaasmantech.org
**www.csmantech.org**

**26–28 May 2015**
**International SIC Power Electronics Applications Workshop (ISiCPEAW 2015)**
Radisson Blu Royal Park Hotel, Stockholm, Sweden
**E-mail**: brita.backstrom@swerea.se
**www.b2match.eu/isicpeaw2015**

**7–10 June 2015**
**EW MOVPE 2015:**
**16th European Workshop on Metalorganic Vapour Phase Epitaxy**
Lund, Sweden
**E-mail**: ewmovpe2015@ftf.lth.se
**www.nano.lth.se/ewmovpe2015**

**15–19 June 2015**
**2015 Symposia on VLSI Technology and Circuits**
Rihga Royal Hotel, Kyoto, Japan
**E-mail**: vlsi@vlsisymposium.org
**www.vlsisymposium.org**

**16–18 June 2015**
**SEMICON Russia 2015**
Moscow, Russia
**E-mail**: eweller@semi.org
**www.semiconrussia.org/en**

**23–24 June 2015**
**Imec Technology Forum Brussels 2015**
SQUARE, Brussels Meeting Centre, Brussels, Belgium
**E-mail**: Olfa.Marzouk@imec.be
**www.itf2015.be/ITF-Brussels/Homepage/page.aspx/1790**

**8–10 July 2015**
**SEMICON West 2015**
Moscone Center, San Francisco, CA, USA
**E-mail**: semiconwest@semi.org
**www.semiconwest.org**

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**13–16 July 2015**
**Intersolar North America 2015**
Moscone Center West Hall and InterContinental Hotel
San Francisco, CA, USA
**E-mail**: brade@intersolar.us
**www.intersolar.us**

**9–13 August 2015**
**SPIE Optics + Photonics 2015**
San Diego Convention Center, CA, USA
**E-mail**: customerservice@spie.org
**http://spie.org/optics-photonics1**

**26–28 August 2015**
**GFP-2015:**
**IEEE Photonics Society's 12th International Conference on Group IV Photonics**
Vancouver, British Columbia, Canada
**E-mail**: m.figueroa@ieee.org
**www.gfp-ieee.org**

**2–4 September 2015**
**SEMICON Taiwan 2015**
Taipei World Trade Center (TWTC), Taiwan
**E-mail**: staiwan2@semi.org
**www.semicontaiwan.org**

**2–5 September 2015**
**17th China International Optoelectronic Expo (CIOE 2015)**
Shenzhen, China
**E-mail**: cioe@cioe.cn
**www.cioe.cn/EN**

**3 September 2015**
**1st International Forum on Sapphire Market & Technologies**
Shenzhen, China
**E-mail**: veyrier@yole.fr
**www.i-micronews.com/yole-events/eventdetail/40/-/1st-int-forum-on-sapphire-market-technology.html**

**21–24 September 2015**
**SPIE Remote Sensing 2015**
Centre de Congrès Pierre Baudis, Toulouse, France
**E-mail**: info@spieeurope.org
**http://spie.org/spieremotesensing**

**27 September – 1 October 2015**
**ECOC 2015:**
**European Conference on Optical Communication**
Feria Valencia, Spain
**E-mail**: ecoc2015@viajeseci.es
**www.ecoc2015.org**

**4–8 October 2015**
**IPC 2015:**
**28th IEEE Photonics Conference**
Reston, VI, USA
**E-mail**: c.c.scott@ieee.org
**www.ipc-ieee.org**

**6–8 October 2015**
**SEMICON Europa 2015**
Dresden, Germany
**E-mail**: semiconeuropa@semi.org
**www.semiconeuropa.org**

**12–15 October 2015**
**SPIE Optifab 2015**
Joseph A. Floreano Rochester Convention Center, Rochester, NY, USA
**E-mail**: customerservice@spie.org
**http://spie.org/spieoptifab**

**20–22 October 2015**
**SEMICON Europa 2015**
Messe Dresden, Germany
**E-mail**: eweller@semi.org
**www.semiconeuropa.org**

**26–29 October 2015**
**IMAPS 2015:**
**48th International Symposium on Microelectronics**
Orlando, FL, USA
**E-mail**: blamm@imaps.org
**www.imaps.org**

**26–29 October 2015**
**2015 IEEE International Topical Meeting on Microwave Photonics**
Paphos, Cyprus
**E-mail**: info@cyprusconferences.org
**www.mwp2015.org**

**3–5 November 2015**
**Global Summit on Electronics and Electrical Engineering**
Valencia, Spain
**E-mail**: electricalengineering@conferenceseries.net
**http://electricalengineering.global-summit.com**

**4–6 November 2015**
**Successful Semiconductor Fabless 2015: Technology & supply chain challenges for fabless semiconductor companies**
Paris, France
**E-mail**: veyrier@yole.fr
**www.i-micronews.com/trade-shows-conferences.html**

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