

# semiconductor **TODAY**

C O M P O U N D S & A D V A N C E D S I L I C O N

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## Boosting performance of InGaN LEDs on sapphire



Navitas launches GaN power IC • White LEDs boosted to 210lm/W  
II-VI closes Anadigics acquisition • WIN launches opto foundry



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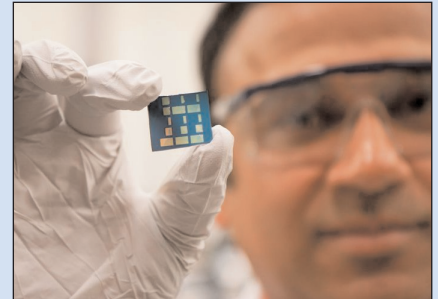
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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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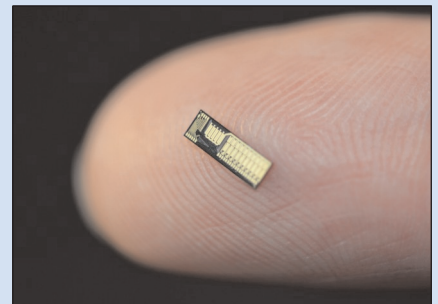
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**p19** University of Utah's Ashutosh Tiwari holds up a substrate layered with tin monoxide.



**p20** X-FAB has entered wide-bandgap semiconductor production with 6" SiC foundry.



**p67** TU/e spin off EFFECT Photonics has launched the first product family based on its optical system-on-chip.



Cover: Everlight has launched a version of its low-mid-power 5630 package series with a claimed record luminous efficiency of 210–220lm/W (at a color temperature of 5000K) as well as a tight 3SDCM ellipse binning for maximum color consistency, suitable for professional, commercial and industrial lighting applications. **p53**

## Opto boosting performance

On pages 80–86 of this issue we focus on research into improving the performance of indium gallium nitride-based LEDs on sapphire substrates. Whereas higher performance is usually obtained by using silicon carbide or gallium nitride substrates and lower cost is achieved through the economies of scale of using silicon wafers, the use of sapphire substrates in high-volume production is a trade-off between cost and performance. Here, we cover research by various teams on techniques to improve performance, including using non-standard crystal orientations (to achieve semi-polar material), modifying the standard multiple quantum well (MQW) structure, and forming gallium nitride (GaN)/zinc oxide (ZnO) heterojunctions.

Meanwhile, regarding existing commercial mass-production white LEDs, a number of manufacturers are vying for the record in luminous efficacy, as performance is pushed for mid-power LEDs, with US-based Lumileds launching 3535 form-factor LEDs approaching 200lm/W, Japan's Toyota Gosei developing 200lm/W 3030-type LEDs, Seoul Semiconductor reaching 210lm/W for its 5630-packaged LED (and 220lm/W targeted by year-end) and Taiwan's Everlight claiming 210–220lm/W for its 5630-packaged LED (see pages 52–53). In addition, Lumileds is collaborating with Australia's BluGlass Ltd to enhance its LEDs using BluGlass' patented low-temperature remote-plasma chemical vapor deposition (RPCVD) technology (which targets cost, throughput and efficiency advantages) — see page 54.

Regarding the standard metal-organic chemical vapor deposition (MOCVD) reactors used in LED mass production, the two dominant system makers Veeco and Aixtron have both reported fourth-quarter 2015 LED-related revenues impacted by push-outs in orders by Chinese LED makers (see pages 36–39). For Veeco, 'Lighting, Display & Power Electronics' (MOCVD) fell from 67% of total revenue in Q3/2015 to just 47% in Q4, while 'Advanced Packaging, MEMS & RF' rose from 10% to 20% and 'Scientific & Industrial' (including MBE) rose from 10% to 17%. Correspondingly, China fell from 58% of total sales in Q3 to 48% in Q4. Aixtron's LED-related revenue fell from 68% of full-year revenue in 2014 to just 26% in 2015 (with Asia correspondingly falling from 83% to 60% of total revenue). Despite this, total revenue still rose slightly (by 2%, to €197.8m), driven by Aixtron's diversification strategy, with optoelectronics (excluding LEDs) rising from 9% to 31%, silicon-based microelectronics from 11% to 19%, and power electronics from 7% to 17% of total revenue. This trend is evidenced by Aixtron selling an AIX G5+ C cluster system to not only UK-based Plessey (for GaN-on-silicon LED production) but also to Grenoble-based Soitec/Leti spin-off Exagan (for its ramp-up of GaN-on-Si HEMT-based power-switching electronic devices) — see pages 40–41.

Aixtron's burgeoning optoelectronics business correlates with epiwafer and substrate IQE's Photonics sales growing by 28% from 2014 to 2015 (see page 34), while substrate maker AXT's InP sales grew 50% in 2015 (to 30% of total revenue in Q4, exceeding GaAs sales) — see page 32.

Also, as well as II-VI Inc completing its acquisition of GaAs RFIC maker Anadigics — targeting its vertical-cavity surface-emitting laser (VCSEL) development (page 64) — Taiwanese GaAs RFIC foundry WIN has launched optical communications device foundry on 2–4" InP wafers (page 63). WIN gave details in late March at the Optical Fiber Communications conference (which will be covered in our next issue).

**Mark Telford, Editor**



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### Semiconductor Today covers the R&D and manufacturing of compound semiconductor and advanced silicon materials and devices

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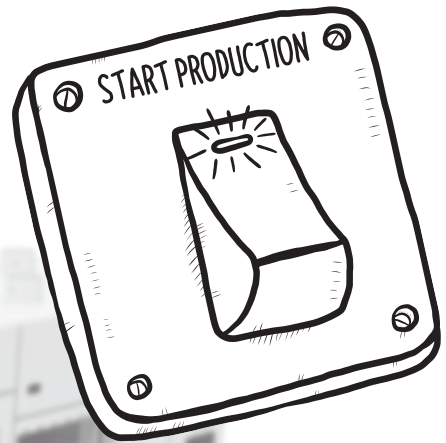
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## Chip-on-board LED market to grow at 35.5% CAGR

The global chip-on-board (COB) LED market will rise at a compound annual growth rate (CAGR) of 35.51% during 2016–2020, according to a report by market research firm Technavio.

Key COB LED vendors are listed as Citizen Electronics, Cree, Nichia, Osram Opto Semiconductors, Philips Lumileds Lighting, Samsung Electronics and Seoul Semiconductor. Other prominent vendors include Everlight Electronics, LG Innotek and Lumens.

COB is a comparatively new bare-chip technology for LED packaging in lighting applications. Multiple LED chips are placed in a small area, mounted directly on the substrate to produce an LED array, and further packed together to form a single COB LED lighting module. COB LEDs hence help to reduce costs by eliminating the complicated solder reflow assembly process.

The report 'Global Chip on Board LED Market 2016–2020' segments the market into the applications of general lighting, automotive lighting, and backlighting.

The increase in demand for smartphones will create demand for more LEDs to be used in the backlighting unit (BLU) of flat-panel displays (FPDs), positively impacting the demand for COB LEDs. The development of LED filament lamps and the development of smart lighting will also boost demand for LED lighting.

For COB LEDs in the global lighting industry, a major driving factor of demand has been the declining average selling price (ASP) of LEDs. Some of the reasons for this are economies of scale and the transition in the wafer size that is used to make LED chips. The small size of LED chips achieved by COB technology supports miniaturization of the devices and provides high efficiency.

Advantages such as better lighting effects, better color mixing, and the ability to spread light over a large area will necessitate the adoption of CoB LEDs during the estimated period. Furthermore, factors like its efficient thermal management ability, homogeneous luminosity, longer service life, high-intensity lighting, reliable output, energy efficiency, and compactness will result in substantial growth of this market until 2020.

Technavio reckons that factors such as the rising demand for energy-efficient and high-quality devices will drive market growth until 2020. In recent times, demand for energy-efficient light sources with a long lifespan has been rising rapidly. The flexible

design structure of LEDs allows lighting system controls to be used more effectively than the traditional lighting sources. Factors such as their rational design and the presence of micro-lens molding will allow these devices to avoid the defects of point and glare light, says the report.

Advantages such as its improved

color-rendering index will result in increased adoption during the forecast period, Technavio reckons.

The general lighting segment was the highest revenue-generating segment during 2015 and its revenue-generating capacity is expected to rise further due to increased utilization of the LEDs for room, ceiling and outdoor lighting applications. Advantages such as high energy efficiency, low maintenance costs, long service life, and the ability to reduce glare from the light source will necessitate the adoption of such LEDs for general lighting purposes, the report reckons. This market segment will reach a market value of more than \$8000bn by 2020.

The report forecasts that the Asia-Pacific region (APAC) will account for more than 59% of the overall market by 2020. Demand for CoB LEDs, coupled with the presence of many prominent CoB LED makers in APAC, will lead to substantial growth of this market in APAC during the forecast period.

The global CoB LED market is highly fragmented because of the presence of many global, regional and local vendors. Companies with a strong foothold in the general lighting segment are the well-established suppliers in the CoB LED market. The competitive environment in this market is expected to further intensify with an increase in product and service extensions, innovations in technology, and merger & acquisition (M&A) activities.

However, the report notes that the fluctuating economies of influential countries such as China, Russia and Brazil is posing a challenge to global COB LED makers, as it impacts the international trade of LED components and products across borders.

[www.technavio.com/report/global-embedded-systems-chip-board-led-market](http://www.technavio.com/report/global-embedded-systems-chip-board-led-market)

**The Asia-Pacific region will account for more than 59% of the overall market by 2020. Demand for CoB LEDs, coupled with the presence of many prominent CoB LED makers in APAC, will lead to substantial growth of this market in APAC during the forecast period. The fluctuating economies of influential countries such as China, Russia and Brazil is posing a challenge to global COB LED maker**

# Technavio profiles top-four vendors in packaged GaN LED market for 2016–2020

In its report 'Global Packaged Gallium Nitride (GaN) LED Market 2016–2020' — which forecasts a compound annual growth rate (CAGR) of more than 5% — market research firm Technavio has profiled the top four leading vendors (Cree of the USA, Epistar of Taiwan, Osram Opto Semiconductors of Germany, and Samsung of South Korea), as well as the six other prominent vendors (De Core Nanosemiconductors, LG Innotek, Nichia, Philips Lumileds, Seoul Semiconductor, and Soraa) that are expected to impact the market during the forecast period.

## Competitive vendor landscape

The global packaged GaN LED market is highly competitive between the key vendors Cree, Epistar, Osram Opto Semiconductors and Samsung, which are adopting new technologies to gain an edge over the other players. Cree invests in marketing activities to build its brand and expand its product offerings to position itself in both commercial and consumer lighting segments, says Technavio, whereas Samsung seeks to explore business opportunities in new areas such as health, medicine and biotechnology to enhance profitability in its organic light-emitting diode (OLED) business.

"Despite a low concentration of vendors, there is intense competition in this market due to the strong positions of the existing vendors," says Asif Gani, Technavio's research analyst for semiconductor equipment. "The highly competitive environment, rapid advances in technology and the cyclical nature of the semiconductor industry all pose a substantial risk to the vendors."

## Top four global packaged GaN LED vendors

Cree relies more on innovation and develops new products that deliver economic and competitive value to its customers, says Technavio. With R&D facilities in the USA,

India and China, the firm is aiming to constantly improve the quality and performance of its products by developing brighter and more efficient low-cost products. Cree's manufacturing units are located primarily in the USA and China. The firm also has subsidiaries in more than 10 countries, including China, Taiwan, Malaysia, Japan, South Korea and in Europe. Major corporations such as Mitsubishi Chemical, Nichia, Seoul Semiconductor, and Osram Opto Semiconductors license the company's products.

Cree offers a comprehensive range of LED components, LED chips, silicon carbide (SiC) wafers, and both LED-based and traditional lighting systems. Products are used in multiple applications such as indoor and outdoor lighting, video displays, transportation, electronic signs and signals, power supplies, inverters, and wireless systems.

Epistar is a pioneer in the design and development of high-performing packaged GaN LEDs. The firm is one of the leading LED makers in Taiwan and is engaged primarily in developing, manufacturing and selling LED chips and wafers. It specializes in supplying high-brightness LEDs and have a broad product portfolio that contains multiple LEDs. The major target segments are lighting and consumer electronics. Epistar has also developed a unique Co-Activation Service Model, through which it can work in collaboration with clients to design and develop integrated circuits.

The firm has a capacity for expansion, which has made it a leading supplier of packaged GaN LEDs. Epistar has worked jointly with brands around the world and delivered LEDs for cellphones, monitors, laptops, and TVs.

Osram Opto Semiconductors intends to expand its global presence by manufacturing and delivering multiple lighting products, solutions and services. The firm supplies sensors, LEDs and visualization solutions based on semiconductor technology for the automotive market. It also provides compact LEDs suited to pico projectors and pocket projectors for small mobile terminals. Osram Opto also supplies surface-emitting panels for applications in hotels and catering, offices and architecture. The firm also has a Black Series of LEDs for applications in trains, planes, automobiles and refrigerators.

Samsung's subsidiary Samsung LED focuses more on long-term growth than short-term profits, says Technavio. The parent company has established a new global engine, the Samsung Strategy and Innovation Centre, with an investment of \$100m, to accelerate innovation and new business creation for its device solution business.

In its nascent stage, this center is expected to focus on electronic components and subsystems to fuel innovation technologies and business models. This aims to enable Samsung LED to capitalize on its parent company's resources and gain an edge over its competitors.

Technavio summarizes that the packaged GaN LED market is highly competitive, with significant entry barriers such as intensive capital investment. This explains the intense rivalry between existing players, which is likely to continue during the forecast period.

[www.technavio.com/report/global-hardware-and-semiconductor-packaged-gan-led-market](http://www.technavio.com/report/global-hardware-and-semiconductor-packaged-gan-led-market)

**Despite a low concentration of vendors... the highly competitive environment, rapid advances in technology and the cyclical nature of the semiconductor industry all pose a substantial risk to the vendors**

# GaN and SiC power semiconductor market to surpass \$1bn in 2020 then \$3.7bn in 2025

## GaN to surpass \$600m in 2025 as SiC reaches \$3bn

Energized by demand from hybrid and electric vehicles, power supplies and photovoltaic (PV) inverters, the emerging global market for silicon carbide (SiC) and gallium nitride (GaN) power semiconductors will rise from just \$210m in 2015 to more than \$1bn in five years then \$3.7bn in 2025, according to market research firm IHS Inc in its 'SiC & GaN Power Semiconductors Report'. Revenue is expected to rise with double-digit growth annually for the next decade.

SiC Schottky diodes have been on the market for more than 10 years, with SiC metal-oxide semiconductor field-effect transistors (MOSFET), junction-gate field-effect transistors (JFET) and bipolar junction transistors (BJT) appearing in recent years. SiC MOSFETs are proving very popular among manufacturers, with several companies already offering them, and more expected to in the coming year. The introduction of 900V SiC MOSFETs (priced to compete with silicon SuperJunction MOSFETs), as well as increased competition among suppliers, has

forced average prices to fall in 2015.

"Declining prices will spur faster adoption of the technology," says Richard Eden, senior market analyst for power semiconductor discretes and modules at IHS Technology. "In contrast, GaN power transistors and GaN modules have only just recently appeared in the market. GaN is a wide-bandgap material offering similar performance benefits to SiC, but with greater cost-reduction potential. This price and performance advantage is possible, because GaN power devices can be grown on silicon substrates that are larger and less expensive than SiC," he adds. "Although GaN transistors are now entering the market, the development of GaN Schottky diodes has virtually stopped."

By 2020, GaN-on-silicon devices are expected to achieve price parity with — and the same superior performance as — silicon MOSFETs and insulated-gate bipolar transistors (IGBTs). When this benchmark is reached, the GaN power market is expected to surpass \$600m in 2025. In contrast, the more estab-

lished SiC power market — mainly consisting of SiC power modules — will hit \$3bn in the same time period.

By 2025, SiC MOSFETs are forecast to generate revenue exceeding \$300m, almost catching Schottky diodes to become the second best-selling SiC discrete power device type. Meanwhile, SiC JFETs and SiC BJTs are each forecast to generate much less revenue than SiC MOSFETs, despite achieving good reliability, price and performance.

"While end-users now strongly prefer normally-off SiC MOSFETs, so SiC JFETs and BJTs look likely to remain specialized, niche products," Eden says. "However, the largest revenues are expected to come from hybrid and full-SiC power modules."

Hybrid SiC power modules (combining Si IGBTs and SiC diodes) are estimated to have generated about \$38m in sales in 2015, and full-SiC power modules are only 2–3 years behind in the ramp-up cycle. Each module type is forecast to exceed \$1bn in revenue by 2025.

<https://technology.ihs.com/521146/sic-gan-power-semiconductors-2016>

## IEEE appoints Qorvo senior fellow Chuck Campbell as Distinguished Microwave Lecturer in GaN power MMICs

Qorvo Inc says that Dr Charles (Chuck) F. Campbell, engineering senior fellow with its Infrastructure and Defense Products Division, has been selected by the Institute of Electrical and Electronic Engineers (IEEE) to serve as a lecturer for its Distinguished Lecturer program.

As engineering leaders and recognized experts in their fields, distinguished microwave lecturers are selected to serve a three-year term speaking to Microwave Theory and Techniques Society (MTT-S) chapters worldwide. Campbell has served in several roles as a fellow of IEEE, including working on the editorial

board for IEEE Transactions on Microwave Theory and Techniques; general chair for the 2015 Compound Semiconductor Integrated Circuits Symposium; and as part of the IEEE Microwave Prize selection committee.

"I am honored to have been selected to discuss the potential of GaN MMIC [monolithic microwave integrated circuits] technology," says Campbell. "I look forward to fostering university-level design research and sharing my expertise about the benefits of GaN devices combined with MMIC technology."

Campbell has authored and co-authored more than 50 journal and

conference papers as well as a chapter on MMIC power amplifier design. He received his bachelor of science, master of science and doctoral degrees in electrical engineering from Iowa State University in 1988, 1991 and 1993 respectively. From 1993 to 1998, he worked for Texas Instruments, involved with microwave module design and MMIC development. Since 1998, he has worked for TriQuint Semiconductor, where he held positions of design team leader; design engineering director; and design engineering fellow.

[www.qorvo.com](http://www.qorvo.com)



# Qorvo joins 3GPP to promote development of 5G standard

## Qorvo to support 5G roadmap under development by Radio Access Network Technical Specification Group

Qorvo Inc (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has joined 3GPP (the 3rd Generation Partnership Project) as a guest delegate to assist in the development of key aspects of 5G next-generation wireless communications standards.

3GPP is a global group of organizations responsible for developing the telecoms standards used by wireless networks worldwide, including 3G, 4G and the forthcoming 5G specifications. The 5G standard is due to be released in two phases. Phase 1 (for completion in 2018) will focus on frequencies below 6GHz and define specifications for a prioritized subset of vertical markets. Phase 2 (in 2019) will focus on frequencies above 6GHz and specs for

an expanded list of vertical markets. 3GPP has identified three high-level use cases for 5G specifications:

- Enhanced Mobile Broadband to support consumers' rapidly growing consumption of video and other data-intensive mobile applications;
- Massive Machine Type Communications for Internet of Things (IoT) applications involving very large numbers of connected devices; and
- Ultra-reliable and Low Latency Communications for situations where reliability, security and network performance are critical, such as self-driving vehicles, medical applications and industrial control systems.

Qorvo is engaging in 5G field trials with infrastructure providers and expects to leverage its new role in the development of 5G standards to broadly expand its growth

opportunities in wireless connected devices and infrastructure products.

"The 5G standard is expected to undergo significant progress in 2016 as telecommunications standards and use cases are further developed by 3GPP," notes president & CEO Bob Bruggeworth. "Partnership with 3GPP will support key aspects of the 5G roadmap under development by the RAN (Radio Access Network) Technical Specification Group, which is working on specifications for multiple elements within the telecommunications ecosystem, from base-stations to connected devices," he adds. "Qorvo is well positioned to adopt and deploy 5G solutions, given our past success in transitioning technology from 3G to 4G."

[www.3gpp.org](http://www.3gpp.org)

[www.qorvo.com/mobile](http://www.qorvo.com/mobile)

## Qorvo secures multiple mobile Wi-Fi design wins

Qorvo Inc (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has secured more than a dozen design wins at leading manufacturers of performance-tier smartphones with its rapidly expanding family of mobile Wi-Fi front-end modules (FEMs) including the RF Fusion Mobile Wi-Fi iFEM. Qorvo reckons that it is uniquely positioned to design and manufacture all the high-value components in the integrated front end, including high-performance filters, switches, low-noise amplifiers, and power amplifiers.

As Qorvo's latest RF Fusion Mobile Wi-Fi iFEM, the new QM48184 integrates a premium bulk acoustic wave (BAW) Wi-Fi coexistence filter with 5GHz and 2.4GHz power amplifiers, low-noise amplifiers, switches, a diplexer, and a coupler, in a compact 4mm x 3mm package. The QM48184 is co-designed and

tuned with a global chipset partner to provide what is claimed to be superior power output and linearity with low current consumption, helping smartphone makers to maximize data throughput while extending battery life.

The Wi-Fi coexistence filter in the QM48184 leverages Qorvo's proprietary LowDrift BAW technology to address the design challenges related to interference between Wi-Fi and the adjacent LTE bands 7, 40 and 41 in China, North America and elsewhere. The firm's coexistence filters deliver what is claimed to be superior insertion loss to enhance receive sensitivity, power-added efficiency (PAE) and power output, helping smartphone makers to extend battery life and maximize data throughput across the full 2.4GHz Wi-Fi spectrum. Qorvo says that all of its LowDrift and NoDrift premium BAW filters combine high performance and temperature stability to

solve coexistence challenges unaddressed by other technologies.

The QM48184 also employs Qorvo's proprietary wafer-level packaging (WLP) and CuFlip flip-chip technology to reduce module size and enable space savings of up to 30% versus comparable discrete solutions in 2x2 MIMO configurations.

Qorvo's Wi-Fi portfolio also includes two pairs of FEMs designed for chip-on-board implementations. The RFFM8538 and RFFM8248 provide a complete solution for premium smartphones, including 2x2 MIMO support, while the RFFM8516 and RFFM8216 are optimized for performance-tier smartphones. Each pair consists of a 2.4GHz module and a complementary 5GHz module, offering manufacturers the flexibility to implement a dual-band or single-band Wi-Fi solution.

[www.qorvo.com/rf-fusion](http://www.qorvo.com/rf-fusion)

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## Qorvo's RF Fusion recognized with GTI Award for outstanding contribution to global 4G TD-LTE ecosystem

At the Global TD-LTE Initiative's GTI Summit 2016 (a partner event at Mobile World Congress 2016) in Barcelona, Spain on 23 February, Qorvo Inc (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) says that its RF Fusion portfolio of high-band (HB) modules has received the GTI 2015 Award for 'Outstanding Contribution on Innovative Technical Product'.

The firm notes that its expanding portfolio of high-performance RF Fusion HB modules satisfies rapidly evolving customer requirements related to high-frequency LTE bands in fully integrated, compact front-end placements.

The GTI is an open global association of operators and vendors founded in 2011 to communicate and collaborate for the sake of speeding the commercialization of TD-LTE. The GTI Awards program recognizes the industry's most outstanding contributions to the LTE industry and encourage the development of innovative products, solutions and applications. The Outstanding



**Qorvo receiving GTI Award.**

Contribution award is granted to the top offering in each category.

"Qorvo is committed to working closely with the GTI to develop tightly compact, high-performance solutions that simplify design complexity and reduce form factors in mobile devices while enabling higher output power for enhanced cell coverage," says Eric Creviston, president of Qorvo's Mobile Products group. "We will continue to leverage our expanding product and technology portfolio, including our comprehensive filter technology portfolio, to help accelerate the deployment of next-generation wireless technologies," he adds.

The RF Fusion HB module portfolio addresses critical TD-LTE cellular bands while enabling FDD-LTE. The pin-to-pin compatible portfolio integrates support for bands 7, 30, 38, 40 and 41 and includes support for uplink carrier aggregation. The expanding RF Fusion high-band portfolio consists of the QM78064 with integrated band 7 duplexer and antenna switch; the QM75001 with integrated band 41 wideband filter and uplink carrier aggregation support; and the TQF6297H with integrated band 41 narrowband filter.

The QM78064 is optimized for global flagship smartphones, while the QM75001 and TQF6297H are optimized for regional and super-regional LTE devices. Each product leverages the firm's proprietary LowDrift BAW filter technology to reduce insertion loss and enable Wi-Fi coexistence. The RF Fusion portfolio roadmap will also support Class 2 output power to increase band 41 cell coverage by compensating for propagation loss.

[www.gtigroup.org](http://www.gtigroup.org)

[www.qorvo.com/rf-fusion](http://www.qorvo.com/rf-fusion)

## Qorvo's 802.11ac power amplifiers delivering higher throughput and greater range for Wi-Fi platforms

Qorvo says its recently launched RFPA55X2 Wi-Fi power amplifier (PA) family is enabling many of today's leading home and business WLAN networking devices.

The RFPA55X2 Wi-Fi PA family includes the RFPA5512, RFPA5522, RFPA5532 and RFPA5542. The PA product suite offers high power and low power consumption in a design that enables 802.11ac Wave2 features such as eight 80MHz streams, 160MHz streams and multi-user multiple-input/multiple-output (MIMO) technology supporting a variety of devices simultaneously. This allows wireless devices to connect across longer-range access points with ultra-increased

data throughput in a high-density user environment under a variety of operating conditions.

Qorvo says that home and business networking device makers turn to its power amplifiers for performance and innovative designs that reduce manufacturing costs. The RFPA5522, for example, provides power-added efficiency of 17% for 802.11ac and more than 20% for 802.11n, resulting in power-added efficiency (PAE) savings of 4–5% that significantly reduce thermal issues in MIMO applications. This reduces the need for thermal compensation devices such as fans and heat-sinks, which in turn enables smaller form factors

without a loss in performance.

"Qorvo's RFPA5522 highly efficient amplifiers deliver the high performance and power efficiency needed for our newest, dual-band 802.11ac consumer routers such as the WRT1900ACS dual-band Wi-Fi Router," comments Justin Doucette, director of product management at wireless router manufacturer Linksys.

"The RFPA5522 5GHz PA is making next-generation features a reality while helping Linksys to offer the most robust routers that allow users to connect multiple wireless products seamlessly," says James Klein, president of Qorvo's Infrastructure and Defense Products group.

# Qorvo expands RF Fusion family with low-, mid- and high-band front-end modules providing complete support for next-gen receive and transmit carrier aggregation functionality

Qorvo Inc (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has expanded its RF Fusion family with front-end modules (FEMs) that leverage the firm's RF product portfolio, advanced packaging and process technologies, and systems-level expertise to integrate all major transmit and receive RF functionality into highly integrated split-band placements.

The new RF Fusion modules showcase the firm's unique ability to tightly integrate all major RF functionality across all major frequency bands into compact, high-performance placements, claims Eric Creviston, president of Qorvo's Mobile Products group. "With RF Fusion, Qorvo is providing leading smartphone OEMs the highest level of integration and performance, helping them to simplify and accelerate the launch of their next-generation Rel-12 carrier aggregation (CA)-capable 4G smartphones and tablets," he adds.

RF Fusion solutions support all major cellular basebands and all major LTE bands to provide OEMs with a highly compact, scalable source for the entire cellular front end, while speeding an OEM's time to RF compliance under the most stringent of 3GPP standards, says the firm.

The new RF Fusion FEMs — the QM75001, QM78013 and QM78012 — are split-band placements delivering coverage of 2.3–2.7GHz, 1.7–2.1GHz and 698–915MHz, respectively. The modules are also optimized for superior performance with envelope tracking (ET) power management integrated circuits (PMICs), and provide complete support for next-generation receive and transmit carrier aggregation functionality.

RF Fusion modules complement Qorvo's expanding family of RF Flex solutions, which can be mated with the firm's LowDrift and NoDrift high-performance duplexers to enable flexible and configurable front-end systems for mobile devices in emerging markets as well as emerging cellular Internet of Things (IoT) applications.

The RF Fusion family of RF front-end modules comprises the following:

**RF Fusion HB module:** QM75001 is a multimode multiband module that integrates all major transmit and receive RF functionality for high-frequency band coverage of global cellular networks while delivering what is claimed to be best-in-class performance and the industry's smallest form factor. A subset of the functional content of the QM78064 RF Fusion HB module, the QM75001 integrates multimode, multiband power amplifiers (PAs), FDD and TD-LTE capable transmit/receive switches, LowDrift filters for bands 38, 40 and 41-wide, and full support for intra-band uplink carrier aggregation, inter-band downlink carrier aggregation, advanced power tracking and envelope tracking. The highly integrated QM75001 delivers a 35% reduction in board area compared with a discrete solution, and is available in a compact 4.0mm x 3.0mm x 0.8mm multi-layer laminate substrate placement.

**RF Fusion MB module:** QM78013 is a multimode multiband module that integrates all major transmit and receive RF functionality for mid-frequency band coverage of global cellular networks while delivering what is claimed to be best-in-class performance and the industry's smallest form factor. The QM78013 integrates multimode, multiband FDD and TD-LTE PAs, mode switch-

ing, LowDrift band 25 duplexer, a LowDrift-based multiplexer capable of multi-downlink carrier aggregation for bands 1 and 3 in addition to band 4, along with an antenna switch and coupler. QM78013 PA chains can fully support intra-band uplink carrier aggregation in FDD and TD-LTE bands, such as B1 and B39 respectively, as well as inter-band downlink carrier aggregation, while operating in both advanced power tracking and envelope tracking modes. The highly integrated QM78013 delivers a 30% reduction in board area compared with a discrete solution, and is available in a compact 5.5mm x 7.7mm x 0.875mm multi-layer laminate substrate placement.

**RF Fusion LB module:** QM78012 is a multimode multiband module that integrates all major transmit and receive RF functionality for low-frequency band coverage of global cellular networks while delivering what is claimed to be best-in-class performance and the industry's smallest form factor. The QM78012 integrates a multimode, multiband FDD PA, mode switching, multiple LowDrift duplexers addressing bands 5/26, 8, 12/17, 20, 28a and 28b, receive aggregation switch, along with an antenna switch. The QM78012 is also designed to reduce harmonic radiation, allowing for improved performance in complex low-band plus mid-band carrier aggregation combinations, while operating in both advanced power tracking and envelope tracking modes. The highly integrated QM78012 delivers a 30% reduction in board area compared to a discrete solution, and is available in a compact 5.5mm x 7.2mm x 1.0mm multi-layer laminate substrate placement.

[www.qorvo.com/rf-fusion](http://www.qorvo.com/rf-fusion)

## Qorvo starts shipping RF Flex GEN-3 front-end modules to smartphone OEMs

Qorvo Inc has begun shipping its recently launched RF Flex Gen-3 family of RF front-end modules to support multiple smartphone OEMs.

RF Flex Gen-3 modules leverage Qorvo's product and technology portfolio and systems-level expertise to integrate core cellular transmit and receive functionality into multiband power amplifier (PA) modules and transmit modules. The PA modules and transmit modules are co-architected to deliver

ease of adaptability and scalability in carrier aggregation operation for performance-tier LTE smartphones in China and other emerging markets.

Qorvo's newest generation of RF Flex solutions enable carrier aggregation in flexible, scalable and cost-effective LTE architectures, says Eric Creviston, president of Qorvo's Mobile Products group. "We expect the market for performance-tier smartphones to grow quickly in 2016 as legacy 2G/3G devices

migrate to FDD/TD-LTE 4G with carrier aggregation capability," adding that Qorvo is offering products and technologies for all tiers of the 4G LTE market as the mobile industry races to achieve higher data rates and throughput.

Qorvo says RF Flex helps smartphone makers to quickly develop and ship carrier-aggregation-enabled smartphones with regional, super-regional, and global capabilities.

[www.qorvo.com/rf-flex](http://www.qorvo.com/rf-flex)

## Telephonics recognizes IDP for excellence in Supply Chain Innovation

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications) says that its IDP Infrastructure & Defense Products Group has received the Supply Chain Innovation Award from Telephonics Corp of Farmingdale, NY, USA.

Qorvo was one of 44 domestic and international suppliers invited to attend a Telephonics event in Melville, New York, for recognition in the areas of supply chain collab-

oration, innovation and execution.

Telephonics' Innovation Award recognizes key suppliers for their investments in cutting-edge supply chain technologies, commitment to stringent technical requirements, supplier performance excellence, and overall partnership collaboration.

"Telephonics is an advanced technology leader, recognized for highly sophisticated, field-proven surveillance, communications, analysis and integration solutions that help to ensure the safety and

security of military, economic and humanitarian interests around the globe," comments Roger Hall, general manager of Qorvo's defense and aerospace products.

"Collaborating successfully with our suppliers is critically important to our mission of providing high-technology products to our global customer base, and Qorvo has truly been a reliable partner as we continue to innovate new products," says Yolanda Fagundo, Telephonics' VP, supply chain.

[www.telephonics.com](http://www.telephonics.com)

## Qorvo begins high-volume shipments to support March-quarter launch of marquee Android smartphone platform

Qorvo Inc (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has been selected by a leading global smartphone manufacturer to expand its support of a marquee Android smartphone platform launching in the March quarter. Qorvo has broadly expanded its participation in this device to include RF Fusion front-end modules, diversity receive modules, power amplifier duplexers (PADs), switches, impedance tuners, low-noise amplifiers (LNAs), duplexers and filters.

"We are leveraging Qorvo's expand-

ing capabilities to introduce new enabling products and technologies, and we look forward to increasing our participation in additional marquee devices launching this year,"

**We are leveraging Qorvo's expanding capabilities to introduce new enabling products and technologies, and we look forward to increasing our participation in additional marquee devices launching this year**

says Eric Creviston, president of Qorvo's Mobile Products Group.

The RF solutions chosen to support the marquee smartphone platform launch include the QM78064 high-band RF Fusion module, the QM63001A diversity receive module, the TQQ1013 NoDrift SAW (surface acoustic wave) duplexer, the 885067 Wi-Fi coexistence filter, the TQF6260 B30 PAD, the QM14003 high-band LTE LNA, the RF1135 impedance tuner, the 885060 diplexer, and the QM13113 QM12023 and RF1646 switches for antenna control solutions.

[www.qorvo.com](http://www.qorvo.com)

# Skyworks and Sequans deliver first device optimized for LTE Category M applications

Skyworks Solutions Inc of Woburn, MA, USA (which makes analog and mixed-signal semiconductors) and Sequans Communications S.A. of Paris, France, a 4G chipmaker and provider of single-mode LTE chipsets for wireless device makers, have delivered what is claimed to be the first solution optimized for LTE Category M (Cat M) applications addressing the growing demand for embedded cellular connectivity across the Internet of Things (IoT). The device leverages Skyworks' half-duplex RF front-end module and Sequans' new Monarch LTE Cat M single chip to deliver a highly integrated, turn-key solution based on Release 13 of the 3GPP LTE standard. The Skyworks/Sequans platform, which is scalable to operator requirements worldwide, is said to simplify the design process, shorten OEM development time and accelerate the launch of next-generation LTE-based devices targeting low-data-rate, low-power applications.

"Our complete end-to-end solution, which is expected to be the dominant deployment method for LTE Cat M devices, provides customers with a powerful, cost-effective product that delivers industry-leading size and power efficiency, as well as

support for low- and mid-frequency bands," says Sequans' VP of marketing Craig Miller.

"We have focused on developing a comprehensive transmit/receive solution for the new wave of devices spanning the Internet of Things that will operate ultra-efficiently across numerous frequency bands around the world," says Skyworks' VP of marketing Carlos Bori. "OEMs will find the device easy to design and integrate into their applications."

According to market analyst firm ABI Research, cellular/wide-area Internet of Things shipments will exceed 1 billion units over the next five years. In addition, the GSMA says that cellular M2M connections could grow from around 300 million devices now to as many as 2 billion in 2020. Skyworks says that IoT developers are increasingly choosing LTE for their connectivity as they realize that technologies like Cat M meet challenging cost and power efficiency needs while providing valuable longevity through a reliable, global connectivity standard like LTE.

Sequans' Monarch LTE Cat M single-chip supports both Category M1 and M2 of the narrowband LTE user equipment categories defined in 3GPP Release 13. The Monarch chip

integrates the baseband, RF transceiver, memory and power management functionality in a small 6.5mm x 8mm package, and is optimized for half-duplex FDD with intelligent on-chip RF filtering for global band support. Combined with Skyworks' SKY68000-11 front-end module (an compact, fully integrated multi-band solution integrating all the active and passive RF front-end components), the solution provides a highly optimized LTE platforms for IoT applications.

The deployment of 3GPP Release 13 LTE networks and devices supporting Category M1 and M2 is expected to begin with trials in 2016 and commercialization in 2017. The low-cost/low-power narrowband connectivity solutions should enable low-data-rate applications and will find high usage in large-scale deployments such as smart meters, sensors and monitors for the smart city, agriculture, industrial, the environment and the smart home, consumer and health-care wearables, and ubiquitous tracking tags for vehicles, cargo, children, the elderly, pets and even luggage.

[www.sequans.com/products-solutions/streamlitel/monarch-lte-platform](http://www.sequans.com/products-solutions/streamlitel/monarch-lte-platform)  
[www.skyworksinc.com](http://www.skyworksinc.com)

## Skyworks launches SkyOne Ultra 2.0 single-unit LTE RF front-end

Skyworks has launched SkyOne Ultra 2.0, a highly integrated, single LTE SKU (stock-keeping unit) solution that solves harmonically related carrier aggregation challenges through design while delivering what is claimed to be the highest linear RF power as well as power-added efficiency.

The next-generation platform is a complete RF front-end system consisting of three LTE modules that utilize Skyworks' new SkyBlue technology in addition to a separate 2G transmitter — covering all of the functionality between the trans-

ceiver output and the antenna. The new platform not only improves performance in terms of power output and system efficiency, it also delivers this performance in the most compact size commercially available, supporting 22 bands in less than 240mm<sup>2</sup>.

"With today's high-end smartphones supporting upwards of 20 frequency bands and more than 30 carrier aggregation combinations, OEMs face tremendous challenges in managing board size and operating battery life," says Joel King, Skyworks' VP & general manager

of Advanced Mobile Solutions. "SkyOne Ultra 2.0 delivers on both fronts, providing best-in-class battery life and overall system efficiency in an industry-leading compact footprint," he adds. "Further, it enables true single-SKU platforms with flexible antenna support and a baseband-agnostic interface, giving OEMs competitive advantages and reduced times to market, it is claimed. SkyOne Ultra 2.0 also delivers enhanced output power to address emerging Class 2, high-power user equipment (HPUE) requirements."

## GlobalFoundries broadens SiGe PA portfolio, enhancing RF performance and efficiency for wireless devices

GlobalFoundries of Santa Clara, CA, USA (one of the world's largest semiconductor foundries, with more than 250 customers and operations in Singapore, Germany and the USA) has announced new radio-frequency silicon solutions, further expanding its portfolio of silicon germanium (SiGe) power amplifier (PA) technologies designed to enable performance-optimized cellular and Wi-Fi solutions in increasingly sophisticated mobile devices and hardware.

GlobalFoundries' 5PAx and 1K5PAx processes (collectively PAx) are the latest extensions to its broad family of SiGe-based PA technologies. The offerings deliver optimized PA, low-noise amplifier (LNA) and switch technology with improved power efficiency, noise figure and insertion loss, enabling more power-efficient next-generation Wi-Fi and cellular solutions for faster data access and uninterrupted connections.

"Mobile suppliers are facing mounting pressure to expand network capacity as wireless data consumption continues to increase rapidly," says Dr Bami Bastani, senior VP of GlobalFoundries' RF business unit. "Our broad portfolio of high-performance SiGe power amplifier technologies provides a distinct design, performance and cost advantage that enables our mobility customers to deliver

cost-effective solutions with faster data throughput, support wider coverage areas, and consume less power," he adds.

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) plans to use the technology to enhance both the power capability and efficiency for the next generation of mobile WLAN products and high-performance WLAN products, including access points, routers and Internet of Things (IoT) applications.

"The advances that are part of GlobalFoundries' SiGe PAx technologies enable RF front-end solutions for all levels of performance and complexity," comments Bill Vaillancourt, VP & general manager of Mobile Connectivity at Skyworks. "With these advanced features and the ability to minimize form factor by implementing multiple RF functions on a chip, GlobalFoundries' latest PAx offerings enhance the capabilities of integrated semiconductor solutions that support customers' needs for high-performance, cost-effective technologies addressing portable wireless communication devices," he adds.

There are four technologies in GlobalFoundries' SiGe PA family: SiGe 5PAe, 1KW5PAe, and now 5PAx and 1K5PAx. All four feature the firm's proven through-silicon via technology and provide

significant performance, integration functionality and cost advantages for users who are currently using gallium arsenide (GaAs)-based alternatives, it is claimed. Currently, more than 3 billion SiGe power amplifiers have been shipped worldwide using this family of technologies, and GlobalFoundries has recently invested in additional manufacturing capacity to address the anticipated growth in the mobile sector. The newest offerings, 5PAx and 1K5PAx, are optimized to meet the rigorous demands of evolving mobile standards like 802.11ac, which demands three times faster data throughput than the previous generation of standards.

For 5GHz applications, SiGe 5PAx (the follow-on to SiGe 5PAe) supports 2dB gain along with a 5% power-added efficiency (PAE) and 0.2dB LNA improvements relative to the previous generation. SiGe 1K5PAx (like its predecessor 1KW5PAe) is fabricated on a high-resistivity substrate, and is tuned for integration and higher performance. It features RF switches with about 15% better  $R_{on}-C_{off}$  compared with 1KW5PAe, and (like 1KW5PAe) enables designers to minimize form factor by implementing multiple functions (such as power amplifiers, RF switches and LNAs) on a single chip.

[www.globalfoundries.com/SiGe](http://www.globalfoundries.com/SiGe)

## Skyworks launches dual-band matched SP4T Wi-Fi switch

Skyworks Solutions has launched a dual-band single-pole four-throw (SP4T) WiFi switch with integrated GPIO interface and 50Ω match on all RF output ports.

The SKY13575-639LF is suitable for dual-band switching in Wi-Fi access points, WLAN 802.11ac and 3G/4G LTE systems and is also suitable for access points, customer-premises equipment (CPE), LTE

systems, dual-band WLAN and test & measurement equipment.

Using silicon-on-insulator (SOI) technology, the switch consumes less than 10μA of current and offers a broad frequency range, low insertion loss (0.6dB at 2.5GHz, 1.1dB at 6GHz), high isolation (40dB at 2.5GHz, 30dB at 6GHz) and integrated match.

The built-in decoders also simplify

the process for users because it limits the number of GPIO lines needed for control.

SKY13575 can operate over the temperature range -40°C to 90°C, making it suitable for a variety of applications. The switch has a small footprint, and is delivered in a 14-pin, quad-flat no-lead (QFN) 1.6mm x 1.6mm x 0.45mm package.

[www.skyworksinc.com](http://www.skyworksinc.com)

# GlobalFoundries releases 7SW silicon-on-insulator RF process design kits featuring latest Keysight Advanced Design System software

GlobalFoundries of Santa Clara, CA, USA (one of the world's largest semiconductor foundries, with over 250 customers and operations in Singapore, Germany and the USA) has announced availability of a new set of process design kits (PDKs) with an interoperable co-design flow to help chip designers improve design efficiency and deliver differentiated RF front-ends in increasingly sophisticated mobile devices.

GlobalFoundries claims that its RF silicon-on-insulator (RF SOI) technologies offer significant performance, integration and area advantages in front-end RF solutions for mobile devices and RF chips for high-frequency, high-bandwidth wireless infrastructure applications. The firm says that its most advanced 7SW SOI RF technology is optimized for multi-band RF switching in next-generation smartphones, and is poised to drive innovation in Internet of Things (IoT) applications.

The challenges of high-frequency and large-signal design in these applications have increased the need for an interoperable co-design flow,

notes GlobalFoundries. Designed for use with Keysight Technologies' Advanced Design System (ADS) electronic design automation (EDA) software, the new 7SW SOI PDKs allow designers to edit their designs in ADS using a single Si2 OpenAccess database without any interference.

The RFIC interoperability simplifies the design process by enabling the user to work from a single design database in ADS. This allows the user to edit and simulate schematic designs created in ADS. The same is true for layout where, for example, a user can open an 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.

"After releasing the first co-design PDK for our 5PAe silicon germanium (SiGe) offering, we are now extending our coverage of ADS PDK to our most advanced RF SOI technology, 7SW SOI. Our 7SW platform, with superior LNA [low-noise amplifiers], switch devices, and trap-rich sub-

strates, offers improved devices reception, interference rejection, and battery life for fewer dropped calls and longer talk time," says Peter Rabbeni, senior director of RF product marketing and business development. "Our RF SOI technology has gained significant industry traction for cellular front-end module applications, and the new RFIC interoperability feature will allow us to provide our 7SW customers additional design flexibility with a single PDK," he adds.

"GlobalFoundries customers can now access ADS' dedicated RF design flow tools based on an OpenAccess based silicon PDK," notes Volker Blaschke, Silicon RFIC product marketing manager at Keysight EEs of EDA. "The new interoperability feature facilitates the design process by using a single OpenAccess design data library, removing redundant steps of keeping the design across different EDA environments in sync."

[www.globalfoundries.com](http://www.globalfoundries.com)  
[www.keysight.com/find/eesof-ads2015.01](http://www.keysight.com/find/eesof-ads2015.01)

## Pasternack launches rack-mount variable-gain RF amplifier

Pasternack Enterprises Inc of Irvine, CA, USA (which makes both passive and active RF, microwave and millimeter-wave products) has launched a 19-inch rack-mounted variable-gain RF amplifier operating from 100MHz to 18GHz, designed for lab use and test & measurement applications. Normally, this type of test equipment commands long lead-times for delivery (often over several months), but Pasternack has made the product available from stock for immediate shipment.

The new amplifier offers broadband frequency coverage from 100MHz to 18GHz with high gain levels of 50dB minimum over

temperatures of  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ . Integrated digitally controlled attenuators have dynamic range up to 60dB with a 1dB step size. Typical performance includes 6.5dB noise figure and +14dBm output P1dB. The package design supports a front-panel LED display with manual control dial and SMA connectors, and a 9 pin D-Sub miniature connector on the rear panel. It is environmentally sealed and designed to meet a series of MIL-STD-202F test conditions.

The PE15A7000 VGA can be used on a test bench but is designed to fit into rack-mount cabinet enclosures (1U high and 10" deep). Offering control flexibility, the gain level with

precise attenuation step size over a wide frequency band can be manually controlled, or utilize the included RS-232 serial cable and Ethernet connection to link with a PC to command control for automated testing (ATE) applications that could involve production testing over temperature or R&D projects.

"This rack-mount variable gain amplifier offers designers high levels of gain and attenuation across 100MHz to 18GHz that can be command controlled via a PC for highly accurate test and measurement applications," notes Active RF Components product manager Tim Galla.

[www.pasternack.com](http://www.pasternack.com)

## GigOptix delivers E-band radio system-in-package products for point-to-point wireless back-haul

GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks) has delivered engineering samples of E-band radio system in package (SiP) products — its first E-band transmitter and receiver in a small-form-factor surface-mount package — for point-to-point (PtP) wireless back-haul applications.

The EXT7611-SSI/EXR7611-SSI and EXT8611-SSI/EXR8611-SSI are the system-in-package transceiver products for 71–76GHz (low band) and 81–86GHz (high band) frequencies, respectively.

The transmitter SiP integrates a high-performance two-chip gallium arsenide solution with 20dB of available gain, OIP3 (output third-order intercept point)

linearity of 29dBm and output power dynamic range control higher than 25dB. The transmitter SiP provides features such as envelope detector and power detector outputs for the best optimization of transmitter signal over noise and output levels.

The receiver SiP integrates a GaAs low-noise amplifier (LNA) and a silicon germanium (SiGe) BiCMOS down-converter, provides a typical noise figure of 5.5dB, excellent linearity and maximum available gain of 76dB over temperature. Baseband filters up to 750MHz and a baseband VGA (variable gain amplifier) are integrated on-chip, as optional features, and selected by a two-wire digital interface. Both the transmitter and receiver are designed to meet both FCC and ETSI requirements.

“This is the first transceiver package product of our roadmap to support the continue demand of higher data-rate in wireless applications,” says chief technology officer Andrea Betti-Berutto. “The experience gathered by our team in development of the E-band transceiver is fundamental for GigOptix’s participation in the upcoming 5G market,” he adds.

GigOptix says that the E-band radio market is entering its maturity stage, with significant volume deployment, and is on the way to becoming one of the most deployed bands for wireless back-hauling of hundreds of thousands of radios for 2016. The upcoming 5G market is expected to dramatically increase the demand for millimetre-wave radios for back-haul, front-haul, and access.

[www.gigoptix.com](http://www.gigoptix.com)

## Custom MMIC launches 2–6 GHz GaAs driver amplifier for compact high-linearity RF and microwave

Monolithic microwave integrated circuit developer Custom MMIC of Westford, MA, USA has added to its growing product line with the CMD231, a wideband (2–6GHz) gallium arsenide (GaAs) MMIC driver amplifier that offers high gain, single positive supply voltage (from +3V to +6V), low current consumption and small die size. The new device is suitable for mili-

tary/commercial communications and instrumentation applications where small size and high linearity are needed.

At 4GHz, the CMD231 delivers more than 14.5dB of gain with a corresponding P1dB (output power at 1dB compression point) of +13.5dBm and output IP3 (third-order intercept point) linearity of 23.5dBm.

The CMD231 is a 50Ω matched design, which eliminates the need for external DC blocks and RF port matching. The device also offers full passivation for increased reliability and moisture protection. The MMIC amplifier is a CMM-2 replacement (pin compatible and performance compatible).

[www.custommmic.com/CMD231DriverAmplifier](http://www.custommmic.com/CMD231DriverAmplifier)

## Custom MMIC launches 2–9GHz GaAs driver amplifier

Monolithic microwave integrated circuit developer Custom MMIC has added to its growing line of products with the CMD232, a 2–9GHz GaAs MMIC driver amplifier that offers high gain, wide bandwidth, single positive supply voltage, and a small die size.

The new device is suitable for military, space, communications

and test instrumentation systems that require small size and high linearity.

At 6GHz the CMD232 delivers more than 15dB of gain with a corresponding P1dB (output power at 1dB compression point) of +17dBm and an output IP3 (third-order intercept point) linearity of 23dBm.

The CMD232 is a 50Ω matched design, which eliminates the need for external DC blocks and RF port matching. The device also offers full passivation for increased reliability and moisture protection. The MMIC amplifier is a pin-compatible CMM-9 replacement.

[www.custommmic.com/CMD232DriverAmplifier](http://www.custommmic.com/CMD232DriverAmplifier)



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# EU's INSIGHT project to develop III-V nanowire-based CMOS on silicon system-on-chip

## €4.25m, three-year Horizon 2020 EU program funding targets millimeter-wave front-ends

Future radar imaging systems and 5G communication systems will generate improved resolution and provide higher data-transmission rates when operated at higher frequencies, but at the cost of increased power consumption. To reduce power consumption, increase performance and lower costs, the European project INSIGHT (Integration of III-V Nanowire Semiconductors for Next Generation High Performance CMOS SOC Technologies) targets the development of III-V CMOS (complementary metal-oxide-semiconductor) technology.

Aiming to establish a manufacturable III-V CMOS technology on silicon substrates in order to reduce costs and to save scarce materials, the six consortium partners include Germany's Fraunhofer Institute of Applied Solid-State Physics (IAF), France's micro/nanotechnology R&D center CEA-LETI, Sweden's Lund University, the UK's University of Glasgow, Ireland's Tyndall National Institute and Switzerland's IBM Zurich. INSIGHT has been funded with €4.25m over 36 months (from December 2015 to November 2018) under grant agreement 688784 of the H2020-ICT-2015 call of the Horizon 2020 Research and Innovation program of the European Union (EU).

INSIGHT's mission is to develop complementary functionality in compound semiconductor material (III-V CMOS), supporting both analog and digital functionality in the millimeter-wave frequency domain. III-V nanowires will be used to maintain electrostatic control, as the gate length is scaled for future technology nodes. The small nanowire cross-section further facilitates the integration onto silicon substrates using nanotechnology.

"The fabrication of high-performance III-V components on large silicon substrates using CMOS-compatible technologies opens a path for cost reduction of millimeter-wave key components with minimized usage of critical materials" says Lund University professor Lars-Erik Wernersson (INSIGHT's coordinator).

IBM foresees a growing need to push the limits of chip technology to meet the emerging demands of cognitive computers, Internet of Things and Cloud platforms, due to the enormous amount of data they are handling — 90% of which is unstructured. The new technology developed in INSIGHT offers a potential solution to scale chip technology beyond the 10nm node as well as opening up a range of new application areas.

Integrating III-V materials into silicon CMOS can enable better logic circuits with lower power consumption, and can also enable the realization of system-on-chip (SoC) products taking full advantage of III-V's RF/analog metrics.

There is a growing need for performance enhancement of key components in the millimeter-wave fre-

quency range and new consumer applications are demanding low costs. The new technology offers a potential solution, as it may provide both high-performance analog and digital functionality on the same platform where the improved manufacturability allows production on larger wafers. INSIGHT addresses the technology need with the aim to demonstrate circuits and systems by optimizing both material and device properties.

For the heterogeneous integration of III-V materials on silicon substrates using nanowires, Fraunhofer IAF will bring its III-V process and circuit design experience, and is interested in transferring the results and findings to next-generation III-V device technologies.

LETI's participation involves both the Silicon Component division and the Integrated Circuit & Embedded System division, ranging from materials to the circuit demonstration. The technology expands the LETI platform for smart devices and Internet of Things with the potential to squeeze multiple functions into a single die.

III-V CMOS technology may be particularly suitable for millimeter-wave front-ends where it will be used to detect and generate signals for communication, radar and imaging. INSIGHT's goal is to develop key technologies for both the receivers and transmitters, while exploring the limits of the transistor geometry and layout.

The expertise of the project partners spans the complete spectrum from materials, through devices, all the way to circuits and systems, allowing the consortium to take the technology further along the path to commercial products, it is reckoned.

<http://insight.eit.lth.se>

[www.iaf.fraunhofer.de/en.html](http://www.iaf.fraunhofer.de/en.html)

**INSIGHT offers a potential solution to scale chip technology beyond the 10nm node... Integrating III-V materials into silicon CMOS can enable better logic circuits with lower power consumption, and can also enable the realization of SoC products taking full advantage of III-V's RF/analog metrics**

# University of Utah develops tin monoxide as two-dimensional electronic material

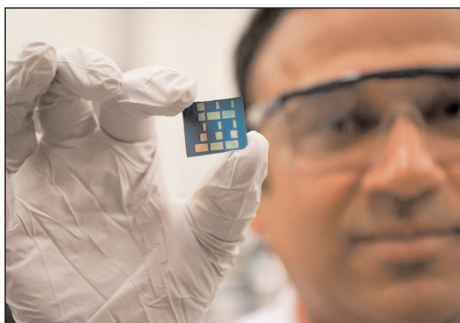
## First stable p-type 2D semiconductor material complements existing n-type 2D semiconductors

A team led by University of Utah materials science and engineering associate professor Ashutosh Tiwari claims to have discovered a new kind of two-dimensional semiconducting material for transistors that opens the door for much faster computers and smartphones that also consume much less power (K J Saji et al, '2D Tin Monoxide—An Unexplored p-Type van der Waals Semiconductor: Material Characteristics and Field Effect Transistors', *Advanced Electronic Materials*; DOI: 10.1002/aelm.201500453).

The paper was co-authored by University of Utah materials science and engineering doctoral students K. J. Saji and Kun Tian, and Michael Snure of Wright-Patterson Air Force Research Lab near Dayton, Ohio.

The tin monoxide (SnO) is a layer of 2D material only one atom thick, allowing electrical charges to move through it much more quickly than conventional 3D materials like silicon.

While researchers have recently discovered new types of 2D material such as graphene, molybdenum



**Ashutosh Tiwari holds up a substrate layered with tin monoxide. Photo: Dan Hixson/ University of Utah College of Engineering.**

disulfide and borophene, they have been n-type materials that only allow the movement of negative charge carriers (electrons). But to create an electronic device you need semiconductor material that allows the movement of both negative charge carriers (electrons) and positive charge carriers (holes). The tin monoxide material is reckoned to be the first stable p-type 2D semiconductor material.

"Now we have everything — we have p-type 2D semiconductors and

n-type 2D semiconductors," he says. "Now things will move forward much more quickly."

It is reckoned that the new 2D tin monoxide material could lead to the manufacturing of transistors that are even smaller and faster than those in use currently. Such transistors could lead to computers and smartphones that are more than 100 times faster than regular devices. Also, because the electrons move through just one layer, there will be less resistance, so the microprocessors will not get as hot as normal computer chips. They also will require much less power to run (crucial for mobile electronics that operate from battery power). Tiwari says this could be especially important for medical devices such as electronic implants that will run longer on a single battery charge. "In two or three years we should see at least some prototype device," Tiwari forecasts.

<http://onlinelibrary.wiley.com/doi/10.1002/aelm.201500453/full>  
[www.nmrl.mse.utah.edu](http://www.nmrl.mse.utah.edu)

## CVD Equipment industrial partnership with Penn State University steps up 2D crystal development

CVD Equipment Corp of Central Islip, NY, USA (a designer and maker of chemical vapor deposition, gas control, and other equipment for developing and manufacturing materials and coatings) has announced the next phase in its industrial partnership formed in March 2015 with Penn State University (PSU) to advance 2D crystal device development.

"We are pleased to continue to benefit from the industrial perspective and specialized equipment manufacturing expertise that CVD Equipment Corporation brings as

part of our ongoing collaboration," comments Joan Redwing, Professor of Materials Science and Engineering, Chemical Engineering and Electrical Engineering. Redwing will lead the consortium with a goal to advance the state-of-the-art in crystal growth of 2D materials on the wafer scale.

The National Science Foundation's Materials Innovation Platform (MIP) recently awarded \$17.8m over five years to fund a national user facility, based at Penn State's Materials Research Institute, for developing new materials for next-generation electronics.

CVD will contribute through the supply and development of equipment required for synthesizing 2D materials at the wafer scale. The firm says the promise of emerging 2D materials (including graphene, boron nitride and transition metal dichalcogenides) for revolutionizing the semiconductor and electronic device industries is reinforced by this platform award from the NSF. The PSU user facility aims to synthesize 2D crystals for faster, more energy-efficient, flexible electronics.

[www.mrsec.psu.edu](http://www.mrsec.psu.edu)  
[www.cvdequipment.com](http://www.cvdequipment.com)

## X-FAB offers high-volume 6-inch SiC foundry production

X-FAB Silicon Foundries of Erfurt, Germany — a mixed-signal IC, sensor and micro-electro-mechanical systems (MEMS) foundry — has entered wide-bandgap semiconductor production by announcing the availability of silicon carbide (SiC) foundry from its wafer fabrication plant in Lubbock, Texas.

The firm says that, due to major internal investments in the conversion of capital equipment (as well as the support provided by the Power-America Institute at North Carolina State University), X-FAB Texas has heavily upgraded its manufacturing resources in order to be 'SiC-ready'. Among the tools now added are a high-temperature anneal furnace, backgrind equipment for thinning SiC wafers, backside metal sputter and backside laser anneal tools. A high-temperature implanter is scheduled for installation later this year. X-FAB can hence now fully leverage the economies of scale that are already available in its established 30,000 wafer per month



**A 6-inch SiC wafer at X-FAB.**

silicon line, presenting the market with the means to produce large volumes of SiC devices on 6" wafers.

X-FAB says that, as well as its 6-inch wafer capabilities, other key differentiators include higher yields and accelerated ramp-up to full-scale production, plus decades of experience in manufacturing semiconductor devices that adhere to the most stringent quality standards (such as those for automotive applications). The firm will not only supply fabless semiconductor vendors but also act as a second source for integrated device manufacturers

(IDMs) with their own SiC production.

"Current SiC offerings are either IDMs creating their own products or relatively small foundry operations using 4-inch production facilities," says Andy Wilson, X-FAB's director of strategic business development. "X-FAB is bringing something different to the market, with a SiC capacity of 5000 wafers/month ready to utilize and potential to raise this further," he adds. "We can thus offer a scalable, high-quality, secure platform that will enable customers to cost-effectively obtain discrete devices on SiC substrates and also safely apply vital differentiation."

In 2015, SiC diode and MOSFET supplier Monolith Semiconductor Inc of Ithaca, NY, USA relocated its headquarters from Ithaca, NY, to Round Rock, Texas, following a strategic partnership announced in 2014 for the manufacture of its SiC switches in X-FAB Texas' high-volume 150mm silicon production line.

[www.xfab.com](http://www.xfab.com)

## UK's Cobham and Korea's RFHIC to co-develop GaN high-power amplifier modules

UK-based Cobham plc (which designs and manufactures equipment, specialized systems and components for the aerospace, defense, energy and electronics industries) has established a strategic partnership to incorporate the GaN technology of South Korea's RFHIC Corp into its next-generation RF products.

Cobham and RFHIC will jointly develop GaN high-power amplifier (HPA) modules for integration into a prototype 175kW solid-state transmitter. Development activities will be executed by Cobham Integrated Electronics Solutions, a business unit of Cobham Advanced Electronic Solutions (CAES) at its site in Exeter, NH, USA that brings together RF technology and motion control solutions for the integration of high-performance systems.

"GaN-based solid-state transmitter technology is affordable, reliable and scalable, and has a number of advantages over traditional vacuum electronic devices (VED) used in current transmitter designs," notes Bob McArthur, business area VP for Cobham Integrated Electronic Solutions. "Benefits include a significant increase in mean time between critical failure (MTBCF), substantial decreases in operational and sustainability costs, and graceful degradation in the event of hardware failure, as opposed to single point of failure or instantaneous shutdown," he adds.

"Cobham is revolutionizing radar, communication, and EW [electronic warfare] markets with its proprietary solid-state transmitter, using RFHIC's GaN amplifier technology," says RFHIC founder & chairman Dr Samuel Cho.

Cobham has developed a 35kW prototype S-band solid-state transmitter for air-traffic control and weather radar applications. RFHIC has a comprehensive product portfolio ranging from discrete components to integrated high-power amplifiers. The firms reckon their combined expertise will enable further exploration of domestic and international civil and military radar applications for GaN-based solid-state technologies. Additionally, the partnership may help provide offset obligations between Korean military and US Navy contracts. RFHIC has an ITAR-registered and ISO 9001-certified facility in Morrisville, NC, USA to support US military/aerospace customers.

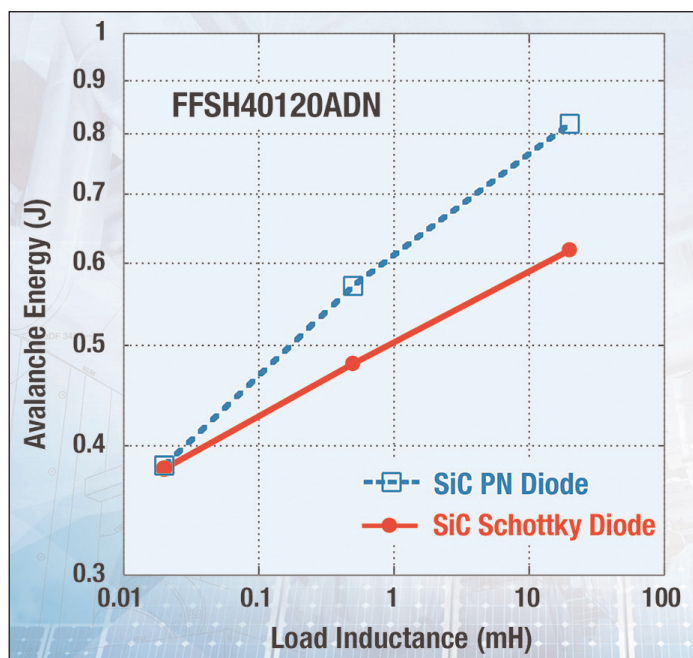
[www.rfhic.com](http://www.rfhic.com)

[www.cobham.com](http://www.cobham.com)

## Fairchild launches its first 1200V SiC diode, targeting high-speed solar inverters & rugged industrial applications

Fairchild Semiconductor of San Jose CA, USA has launched its first 1200V silicon carbide (SiC) diode, the FFSH40120ADN, in its series of upcoming SiC solutions. The 1200V diode's combination of switching performance, reliability and low electromagnetic interference (EMI) make it suitable for next-generation solar inverters, industrial motor controls and welders, which are all increasingly required to be more energy efficient at higher power densities.

"The combination of market trends and tightening industry standards is driving the need for more energy-efficient products, and our new 1200V SiC diode is designed specifically to help manufacturers achieve these ever-greater efficiency requirements and with better reliability, ruggedness and cost efficiency," says Jin Zhao, VP & general manager of Fairchild's High Power Industrial division. "We based this diode on silicon carbide due to the material's considerable advantages over silicon, and we will add additional SiC-based semicon-



ductors as we build a comprehensive family of SiC solutions."

The FFSH40120ADN diode has what is claimed to be the best leakage current performance in its class, leaking far less current at temperatures up to 175°C. Key benefits include fast switching and no reverse recovery current, which reduces switching losses compared

to silicon and results in superior energy efficiency. Faster switching also allows manufacturers to reduce the size of their products' magnetic coils and associated passive components, which improves packaging efficiency, reduces system weight, and can reduce bill-of-materials (BOM) costs.

The diode's ability to switch stably over a wide tem-

perature range is another factor contributing to its performance, as is its zero recovery voltage which eliminates voltage overshoots.

Fairchild demonstrated the performance of the 1200V SiC diode at the Applied Power Electronics Conference and Exposition (APEC) in Long Beach, CA (20–24 March).

[www.fairchildsemi.com/sic](http://www.fairchildsemi.com/sic)

## Monolith demonstrates fast-switching SiC MOSFETs

At the Applied Power Electronics Conference & Exposition (APEC 2016) in Long Beach, CA, USA (20–24 March), Monolith Semiconductor Inc of Round Rock, TX, USA demonstrated its fast-switching silicon carbide (SiC) metal-oxide semiconductor field-effect transistors (MOSFETs).

The in-booth demonstration illustrated the capabilities of Monolith's SiC technology by operating a 5kW buck converter with 675V nominal input and 350V nominal output at high frequencies (~200kHz) and high-efficiency (>98%) converter performance that cannot be achieved with silicon insulated-gate bipolar transistors (IGBTs).

Monolith says that its SiC technol-

ogy also allows for reductions in device size and weight (as a result of the higher frequency capabilities) and power consumption (due to reduced power losses) in applications like data-center uninterruptible power systems (UPS).

In 2015, Monolith formed a strategic partnership with Littelfuse Inc of Chicago, IL, USA (which provides circuit protection technologies) to develop power semiconductors for industrial and automotive markets. "We are excited for the opportunity this offers to increase our customer reach dramatically, gain access to global channels, and benefit from their sales and marketing depth and expertise," says Monolith's CEO Sujit Banerjee PhD. Littelfuse has

committed to add to its investment as Monolith achieves specific technological milestones.

Monolith also has a strategic manufacturing partnership with the CMOS fabrication facility of X-FAB Silicon Foundries in Lubbock, Texas, to produce Monolith's 150mm SiC wafers in high volumes. By producing SiC power diodes and MOSFETs in a facility typically used for silicon, Monolith aims to lower the cost, improve the reliability, and expand the availability of SiC devices. The objective is to make their adoption economically feasible for a wider range of high-performance, high-efficiency power electronics systems.

[www.monolithsemi.com](http://www.monolithsemi.com)

# GE Aviation receives \$2.1m US Army contract to develop SiC power electronics

## 18-month development program to demo GE's SiC MOSFETs combined with GaN devices in 15kW, 28V<sub>DC</sub>/600V<sub>DC</sub> bi-directional converter

GE Aviation (an operating unit of GE) has been awarded a \$2.1m contract from the US Army to develop and demonstrate silicon carbide (SiC)-based power electronics supporting high-voltage next-generation ground vehicle electrical power architecture. GE's Global Research Center is developing silicon carbide MOSFET technology across multiple industries including aviation, healthcare and energy.

"The US Army's implementation of silicon carbide technology for high-voltage, more-electric ground vehicles, facilitates significant improvements in size, weight and power for high-temperature applications," says Vic Bonneau, president of Electrical Power Systems for

GE Aviation. "We have multiple SiC-based power conversion products in development and continue to invest in this area," he adds.

"Successes to date have led to this new application that will enable the US Army to better manage on-board power and simplify the vehicle cooling architecture. Ultimately, this product will increase mission capability for the warfighter."

The \$2.1m contract consists of an 18-month development program to demonstrate the benefits of GE's silicon carbide MOSFET technology combined with gallium nitride (GaN) devices in a 15kW, 28V<sub>DC</sub>/600V<sub>DC</sub> bi-directional converter. The hardware should provide twice the power in less than half the volume of pres-

ent silicon-based power electronics. In addition, the converters will be able to operate in parallel and be CANbus programmable.

The contract is in support of the US Army's Tank Automotive Research, Development and Engineering Center (TARDEC) next-generation vehicle electrical power architecture leap-ahead technology development. It will result in a technology demonstration in mid-2017.

The contracting agent for US Army TARDEC is DCS Corp, which develops advanced technology solutions and provides acquisition management expertise for US Army aviation, ground vehicle, soldier systems and missile systems.

[www.ge.com/aviation](http://www.ge.com/aviation)

# Navitas launches first gallium nitride power ICs

## 'AllGaN' monolithic integration of power FETs with drive and logic enables 10–100x higher frequency than silicon ICs

Navitas Semiconductor Inc of El Segundo, CA, USA has launched its first products, which are claimed to be the industry's first gallium nitride (GaN) power ICs.

Navitas was founded in 2013, and in 2014 investment firm MalibuIQ licensed the GaN power electronics technology from HRL Laboratories LLC. Navitas raised \$15.1m in equity financing in July 2015.

Using a proprietary 'AllGaN' process design kit (PDK) to monolithically integrate 650V GaN power field-effect transistors (FETs) and GaN logic and driver circuits enables 10–100x higher switching frequency than existing silicon circuits, making power electronics smaller, lighter and lower cost, says Navitas. A new generation of high-frequency, energy-efficient converters is hence being enabled for smartphone and laptop chargers, OLED TVs, LED

lighting, solar inverters, wireless charging devices and datacenters.

"GaN has tremendous potential to displace silicon in the power electronics market given its inherent high-speed, high-efficiency capabilities as a power FET," says chief technology officer & chief operating officer Dan Kinzer. "Previously, that potential was limited by the lack of equally high-performance circuits to drive the GaN FETs quickly and cost effectively. Navitas has solved this remaining challenge to unlock the full potential of the power GaN market. With monolithic integration of GaN drive and logic circuits with GaN power FETs, the industry now has a path to cost-effective, easy-to-use, high-frequency power system designs," he adds.

"The last time power electronics experienced a dramatic improvement in density, efficiency and cost was in

the late 70s when silicon MOSFETs replaced bipolar transistors, enabling a transition from linear regulators to switching regulators," says CEO Gene Sheridan. "A 10x improvement in density, 3x reduction in power losses and 3x lower cost resulted a short time thereafter. A similar market disruption is about to occur in which GaN power ICs will enable low-frequency, silicon-based power systems to be replaced by high-frequency GaN with dramatic improvements in density, efficiency and cost."

Navitas introduced its AllGaN platform and GaN Power ICs in a keynote presentation 'Breaking Speed Limits with GaN Power ICs' on 21 March at the Applied Power Electronics Conference (APEC 2016) in Long Beach, CA, USA.

[www.navitassemi.com](http://www.navitassemi.com)

[www.apec-conf.org/conference/](http://www.apec-conf.org/conference/)

## Wolfspeed ships GaN RF devices surpassing 1.3GW output while maintaining FIT rate of 5-per-billion device

Wolfspeed of Research Triangle Park, NC, USA — a Cree Company that makes silicon carbide (SiC) and gallium nitride (GaN) wide-bandgap semiconductor devices — says that, as of the end of 2015, it had shipped gallium nitride on silicon carbide (GaN-on-SiC) RF power transistors with a combined RF output power of over 1.3GW. Wolfspeed achieved this while maintaining a failure-in-time (FIT) rate of 5-per-billion device hours.

“Wolfspeed’s achievement, exceeding 100 billion total hours of field operation for GaN-on-SiC devices, is the largest known body of fielded data accumulated by any domestic GaN supplier to date, and includes not only discrete transistors, but complex multi-stage GaN MMICs as well,” says RF & microwave director Jim Milligan. “Our production numbers reflect the increasingly widespread adoption of GaN-on-SiC RF technology in military and

aerospace systems, telecom base-stations, wideband test equipment, civil radar, and medical applications,” he adds.

For comparison, 1.3GW is the same power output as the energy required to power all of the LED street lights in Los Angeles for 22 years, or enough to power more than 124,900 USA residential homes for a year.

[www.wolfspeed.com/RF](http://www.wolfspeed.com/RF)

[www.wolfspeed.com/power/products](http://www.wolfspeed.com/power/products)

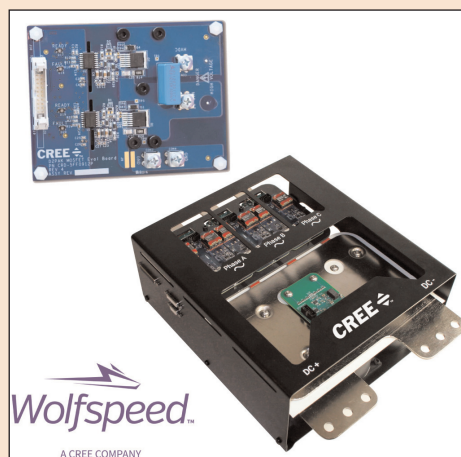
## Wolfspeed exhibits SiC power portfolio at APEC

Wolfspeed showcased its solutions at the Applied Power Electronics Conference and Exposition (APEC 2016) in Long Beach, CA (20–24 March). In addition, as part of the conference program, Wolfspeed engineers presented new research and leading application panels.

Wolfspeed demonstrated an evaluation board that enables power electronics design engineers to quickly implement the firm’s 900V SiC MOSFETs (claimed to be the industry’s first 900V SiC MOSFET portfolio, including exclusive SiC-optimized surface-mount packaged devices) and an evaluation unit utilizing high-performance SiC power modules for three-phase inverter applications.

“Our latest evaluation board allows design engineers to quickly and easily evaluate the quality and performance of these MOSFETs for themselves,” says Guy Moxey, senior director of power products.

Wolfspeed showcased its portfolio of 900V SiC MOSFETs in the surface-mount 7L-D2PAK package, and demonstrate a pre-assembled PCB evaluation board that allows design engineers to evaluate SiC MOSFET switching waveforms, gate driver performance, and circuit protection features to quickly prototype a SiC power converter. The evaluation board (available



through authorized distributors) contains two 900V C3M MOSFETs with separate Kelvin sources configured in a flexible half-bridge circuit capable of prototyping a synchronous buck or boost inverter. This represents an optimal board layout, short-circuit protection, and thermal management using an isolated heat-sink to evaluate any 7L-D2PAK 900V Wolfspeed MOSFET.

The firm also demonstrated a new high-performance three-phase power evaluation unit that reduces the development time required to implement SiC power modules in a three-phase inverter. Using Wolfspeed’s soon-to-be released CAS300M12HM2 SiC power module and gate drivers, the evaluation unit provides a modular, configurable circuit

design using standard components to rapidly optimize three-phase SiC power module designs for performance, efficiency, thermal management, and circuit protection.

Conference presentations

Business development & program manager Jeffrey Casady presented what is claimed to be industry-first performance via the paper ‘Record-Low 10mΩ 900V SiC MOSFET in TO-247’ authored by Casady, Vipindas Pala, Gangyao Wang, Brett Hull, and Scott Allen. Presented as part of APEC’s ‘Advances in Wide Bandgap Devices’ session, the presentation describes how Wolfspeed’s 900V SiC MOSFET achieves what is claimed to be record-low specific ON-resistance and  $R_{DS(on)}$  temperature coefficient, which enable the development of discrete switching devices that far exceed the current densities of super-junction MOSFETs.

In addition, chief technology officer John Palmour co-chaired the technical session ‘Power Semiconductors Enabling Next-Generation Applications’, consisting of a series of presentations designed to showcase the potential for advanced wide-bandgap power semiconductors in power electronics applications.

[www.apec-conf.org](http://www.apec-conf.org)

# EPC publishes reliability report documenting over 1.7bn field-device hours with very low failure rate

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 announced its Phase Seven Reliability Report, showing the distribution of over 17 billion accumulated field-device hours and detailing test data from more than 7 million equivalent device-hours under stress.

The stress tests included intermittent operating life (IOL), early life failure rate (ELFR), humidity with bias, temperature cycling, and electrostatic discharge. The study reports a composite 0.24 FIT rate

for products in the field, which is consistent with all of EPC's in situ evaluations to date and validates the readiness of eGaN FETs to supplant silicon for commercial power switching applications, reckons the firm.

"Demonstration of the reliability of new technology is a major challenge," says CEO & co-founder Dr Alex Lidow. "The results of this study show that EPC gallium nitride products have the requisite reliability to displace silicon as the technology of choice for semiconductors."

For this report, EPC's eGaN FETs were subjected to a wide variety of stress tests under typical conditions

for silicon-based power MOSFETs. The eGaN FETs were stressed to meet the latest JEDEC standards, when possible. The tests included: high-temperature reverse bias (HTRB), high-temperature gate bias (HTGB), temperature cycling (TC), high-temperature high-humidity bias (H3TRB), early life failure rate (ELFR) HTRB, and intermittent operating life (IOL).

EPC says that its extensive reliability testing continues to show that the devices are both intrinsically and environmentally reliable. All seven phases of the reliability test program are available on EPC's web-site.

[www.epc-co.com](http://www.epc-co.com)

## EPC presents applications using eGaN technology at APEC

At the 31st IEEE Applied Power Electronics Conference and Exposition (APEC 2016) in Long Beach (20–24 March), EPC exhibited more than 20 demonstrations showing GaN technology's performance.

Featuring its latest eGaN FETs and integrated circuits as well as customers' end-products enabled by eGaN technology, demonstrations included wireless power systems that span the full power range of Qi and AirFuel standards and a multi-mode solution, a single-

stage 48V–1V DC–DC converter, 3D real-time LiDAR imaging camera, and an LTE-compatible envelope tracking supply.

Also, in the conference, EPC's experts presented the following six technical presentations on GaN FETs and ICs:

- Educational Seminar: '48V to Load Voltage: Improving Low Voltage DC-DC Converter Performance with GaN Transistors' by Alex Lidow, David Reusch and John Glaser;
- 'Introducing eGaN IC Targeting Highly Resonant Wireless Power'

by Michael de Rooij;

- 'Thermal Evaluation of Chip-Scale Packaged Gallium Nitride Transistors' by David Reusch;

- 'GaN: Changing the Way We Live' by Alex Lidow;

- 'GaN vs Silicon — Overcoming Barriers to the Rise of GaN' by Alex Lidow (Power Semiconductors Enabling Next Generation Applications; Session IS16); and

- 'Envelope Tracking – GaN Power Supply for 4G Cell Phone Base Stations' by Yuanzhe Zhang.

[www.apec-conf.org](http://www.apec-conf.org)

## EPC launches 100W, 92%-efficient eGaN FET development board for 6.78MHz AirFuel wireless power standard

EPC has launched the EPC9065, a development board that can serve as the amplifier stage for AirFuel Alliance Class 4 and Class 5 wireless power transfer applications. The board is a zero voltage switching (ZVS) differential-mode class-D amplifier development board configured at, but not limited to, 6.78MHz (lowest ISM band).

The EPC9065 includes all the critical components, including two

screw-mounted heat-sinks for increased power capability. It can be easily connected into an existing system to speed end-product time to market.

The development board features the EPC2007C and the EPC8010, which are 100V-rated enhancement-mode gallium nitride FETs. The EPC2007C is used in the class-D amplifier while the EPC8010 is used as a synchronous bootstrap FET.

The amplifier can be set to operate in either differential or single-ended mode and includes the gate drivers, a 6.78MHz oscillator, and a separate heat-sink for each Class-D section.

The EPC9065 is priced at \$414 each and is available now from distributor Digi-Key Corp. Quick Start Guides, containing set-up procedures, circuit diagram, bill of material and Gerber files for the boards, are provided on-line.

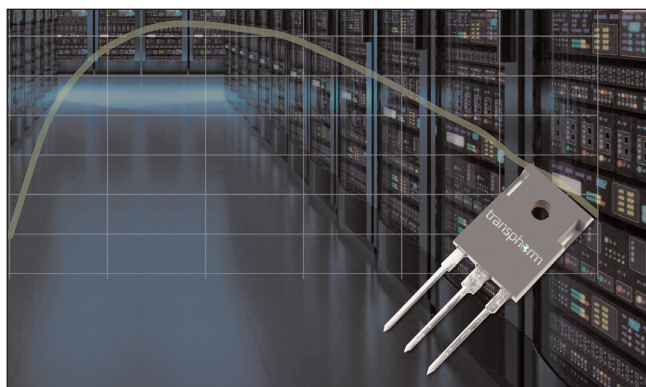


# Transphorm introduces only fully qualified 650V GaN FET, with lowest on-resistance in TO-247 package

## Lowest $R_{on}$ of 41m $\Omega$ and ultra-low $Q_{rr}$ of 175nC increase power density and boost efficiencies over range of power levels

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC-qualified 650V gallium nitride (GaN)-based devices for high-voltage power conversion applications — has launched the TPH3207WS GaN field-effect transistor (FET), which has what is claimed to be the lowest on-resistance ( $R_{on}=41m\Omega$ ) in a TO-247 package, reducing system volume as much as 50% without sacrificing efficiency. Transphorm says that the device's low  $R_{ds(on)}$  and ultra-low reverse-recovery charge ( $Q_{rr}$ ) of 175nC bring the benefits of GaN to applications that previously relied on silicon, enabling engineers to achieve power-dense solutions with reduced component count and improved reliability in high-voltage power conversion applications.

The TPH3207 is said to improve system reliability, performance and



power density in an easy-to-handle cascode configuration (EZ-GaN) that can be easily driven with off-the-shelf drivers. Also, the device's TO-247 industry-standard packaging allows for ease of design and development and low electromagnetic interference (EMI). Also, faster switching speeds from low capacitances and gate charge enable designers to double the power density, reducing the overall system costs.

These advantages are being realized in hard-switched bridges and the continuous conduction mode (CCM) bridgeless totem-pole power factor correction (PFC) designs (reducing overall power supply losses by as much as 40% while achieving up to 99% effi-

ciency) in on-board chargers, solar inverters, telecom power supplies and other power conversion applications.

TPH3207WS samples are available to purchase now, priced at \$22.69 for 1000-unit quantities.

Transphorm's GaN FET portfolio is also strengthened with the introduction of the TPH3208 family (130m $\Omega$ ) in industry-standard TO-220 and PQFN packages.

[www.transphormusa.com/products](http://www.transphormusa.com/products)

## Transphorm demonstrates key applications at APEC

At the Applied Power Electronics Conference (APEC 2016) in Long Beach, CA, USA (20–24 March), Transphorm exhibited the following live demonstrations:

- high-power 3.5kW bridgeless totem-pole PFC with 99% efficiency;
- a single-phase 4.5kW inverter that exceeds 99% efficiency; and

- an end-customer (Sumolight) high-power LED lighting system that is an order of magnitude smaller and lighter than a silicon-based approach.

Also at APEC, Jason Cuadra, Transphorm's director of Power Electronics Applications, participated in the following speaker events:

- PSMA/PELS workshop: 'Power Magnetics @ High Frequency — Solving the Black Magic';
- Industry Session presentation (IS04): 'GaN Takes Server Power Supplies' Power Density to New Heights'.

[www.pasma.com/technical-forums/magnetics/workshop](http://www.pasma.com/technical-forums/magnetics/workshop)

## Transphorm adds Richardson Electronics as global distributor and A/D Sales as Northeast sales rep

Transphorm has added global distributor Richardson Electronics and the Northeast representative A/D Sales to support growing design activity for its GaN power transistors and modules.

"The power electronics industry is waking up to the realization that

Transphorm GaN is enabling the most compact, highest-efficiency solar inverters, on-board electric vehicle chargers, power supplies and other high-power-density applications," says Michael White, senior VP, sales & marketing. "Our new channel partners bring

both knowledge and access to the design engineering community to facilitate the integration of Transphorm GaN devices into these applications," he adds.

[www.rell.com](http://www.rell.com)

[www.ad-salesinc.com](http://www.ad-salesinc.com)

[www.transphormusa.com](http://www.transphormusa.com)

# MACOM debuts new GaN power transistors for macro base-stations among expanded wireless infrastructure

At the Mobile World Congress (MWC 2016) in Barcelona, Spain (22–25 February), 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) debuted a newly expanded portfolio of wireless infrastructure semiconductor solutions which — optimized to meet the most demanding bandwidth, performance and efficiency needs — target new standards for integration, ease of use and cost effectiveness.

MACOM's technology and wireless application experience enables mobile network operators worldwide to keep pace with burgeoning bandwidth demands while minimizing capital and operating expenses, says Preet Virk, MACOM's senior VP & general manager, Carrier Networks. "Addressing the needs of 4G, 4.5G and 5G wireless infrastructure, with the proven ability to support high-frequency backhaul and access technologies, MACOM provides a one-stop shop for high-performance RF, microwave, millimetre-wave and optical components," he adds.

Solutions and technologies for wireless network infrastructure that MACOM exhibited include the following:

- The new MAGb series of GaN power transistors for macro base-stations (debuted at MWC) produce GaN performance at what is claimed to be LDMOS-like cost

structures at scaled volume production levels. MAGb power transistors target all major cellular bands within the 1.8–3.8GHz frequency range, and support peak output power up to 700W.

- MACOM's small-signal solutions for base-station receivers span from discrete high-power switch, low-noise amplifier (LNA), digital step attenuators, variable voltage attenuators and control components to semi- and fully integrated front-end modules that combine these devices with optional bias and matching capabilities. These highly integrated modules are ultra-compact and easy to use, and provide a wide range of customization and scalability options.

- The newest entries in MACOM's family of gallium arsenide (GaAs) microwave power amplifiers (PAs) for wireless backhaul applications enable full frequency-band coverage from 7GHz to 86GHz, with both narrow- and wideband PA options to ensure deployment flexibility.

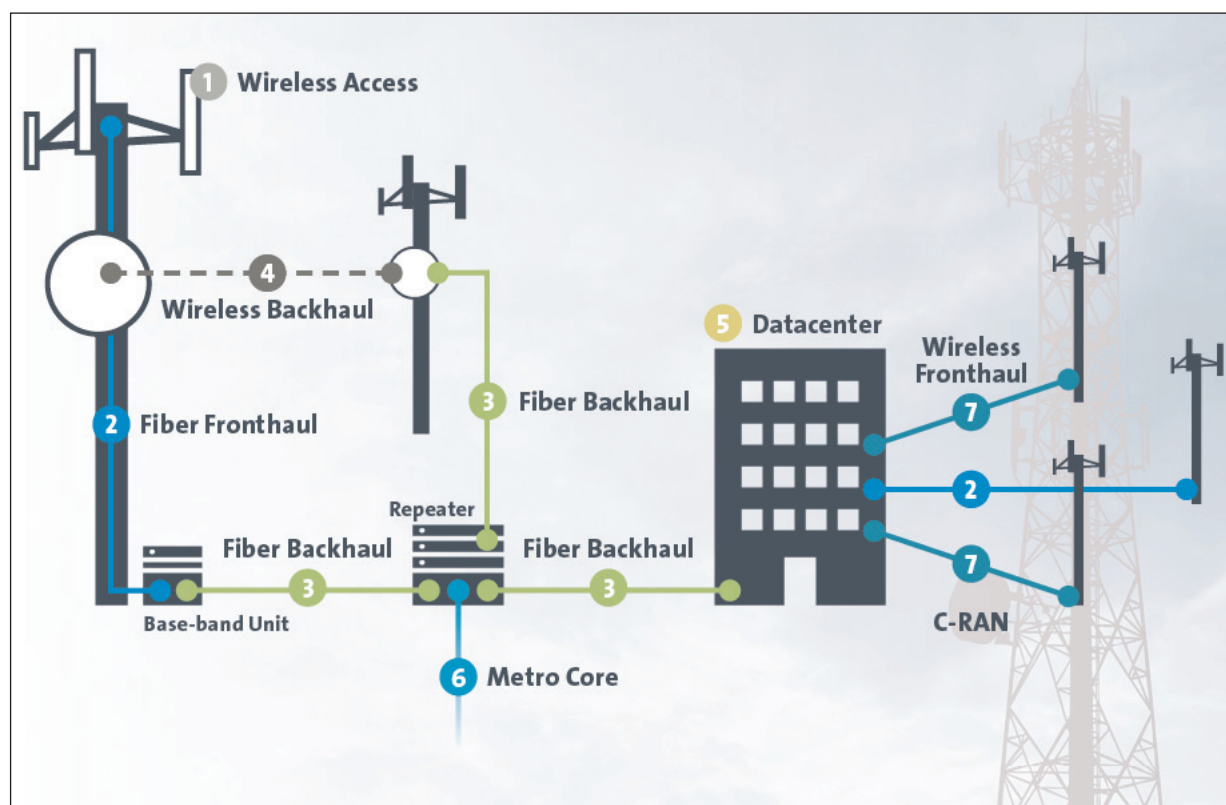
- MACOM's family of E-band PAs

and integrated modules help to accelerate the evolution to higher-capacity wireless backhaul, while its surface-mountable E-band Tx and Rx modules simplify the design and manufacturing of low-cost E-band point-to-point radios.

- MACOM is aiding the development of next-generation 5G and MIMO demonstration systems, through its decades of experience in mmWave and expertise from the circuit level to the device packaging level, as well as phased array technologies. Providing the ability to integrate multiple components into ultra-compact front-end modules, MACOM says that it can help to facilitate the design of large antennae arrays supporting advanced 5G beam-forming capabilities.

- Regarding optical transport components, MACOM also offers a portfolio of optical front-haul (CPRI) and optical back-haul (GPON) lasers and chipsets to complement its RF and microwave product portfolio for wireless infrastructure.

[www.macom.com/wirelessinfra](http://www.macom.com/wirelessinfra)



# MACOM launches Gen4-based family of GaN power transistors for wireless basestations

At the Mobile World Congress (MWC 2016) in Barcelona, Spain (22–25 February), 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) launched its MAGb series of GaN power transistors for use in wireless macro base-stations.

Leveraging MACOM's Gen4 GaN technology, the new MAGb series is claimed to be the industry's first commercial basestation-optimized family of GaN transistors to achieve leadership efficiency, bandwidth and power gain with LDMOS-like linearity and cost structure, and a path to better-than-LDMOS cost at scaled volume production levels.

The MAGb series of power transistors targets all cellular bands within the 1.8–3.8GHz frequency range. Initial entries in the product series include single-ended transistors providing up to 400W peak power in small packages, dual-transistors and single-package Doherty configuration providing up to 700W peak power in both symmetric and asymmetric power options. The new product series delivers power efficiency improvement of up to 10% and package size reduction greater than 15% over legacy LDMOS offerings, it is reckoned. Based on linear Gen 4 technology, the MAGb is easy to linearize and correct with digital-pre-distortion (DPD) schemes compared with other GaN technologies, the firm claims.

The power transistors in the MAGb family cover much wider bandwidth than LDMOS, reducing the number of parts needed to cover the major

**MAGb Series of GaN Power Transistors**  
Delivers Size, Efficiency  
& Broadband Advantages

**Gen4 GaN**

**The new product series delivers power efficiency improvement of up to 10% and package size reduction greater than 15% over legacy LDMOS offerings.**

cellular bands. The new product family delivers these advantages while simplifying the Doherty implementation over LDMOS-based transistors and maintaining over 200MHz of video bandwidth.

The MAGB-101822-120B0S is the first product in this family and covers 500MHz of RF bandwidth between 1.7GHz to 2.2GHz. It is housed in a small AC-400 ceramic package and delivers over 160W of peak power and a peak efficiency of 74% with fundamental tuning only and linear gain over 19dB across the 500MHz band.

Second in the series is the MAGB-101822-240B0S, which has double the output power of the MAGB-101822-120B0S with peak power over 320W, 19dB of linear gain and peak efficiency over 72% with fundamental tuning only across the 500MHz RF bandwidth, housed in the AC-780 ceramic package.

The peak efficiency of both new products can be further improved to well above 80% when the devices are presented with the proper harmonic terminations.

MACOM says that, by unleashing the efficiency, size and broadband advantages of its Gen4 GaN technology, the new series enables wireless carriers to deploy the

latest LTE releases and significantly reduce operating expenses at highly competitive price points, with a scalable supply chain combined with MACOM's applications and design support team.

"Gen4 GaN positions MACOM at the vanguard of a transformative evolution in basestation power amplifiers, enabling a price/performance breakthrough that cannot be achieved with alternative semiconductor technologies," reckons Preet Virk, senior VP & general manager, Carrier Networks, at MACOM. "We anticipate that the wireless application expertise and commercial manufacturing scalability that MACOM brings to this domain via the MAGb product platform will vault GaN-based PAs into the mainstream, unlocking a host of benefits for the next generation of wireless base-stations."

As well as giving private demonstrations of MAGb products at the Mobile World Congress in February, MACOM will also be demonstrating the technology at the International Microwave Symposium (IMS 2016) in San Francisco (22–27 May).

Select products in the new MAGb series of GaN power transistors are sampling to qualified customers now.

[www.macom.com/wirelessinfra](http://www.macom.com/wirelessinfra)



# GaN Systems' transistors used in winning inverter design for \$1m Google Little Box Challenge

GaN Systems Inc of Ottawa, Ontario, Canada, a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications, says that its GS66508P gallium nitride power transistors were instrumental in the winning design of the Google 'Little Box Challenge'.

Google and the IEEE Power Electronics Society awarded the \$1m prize to 'Red Electrical Devils' (named after Belgium's national soccer team), a team from CE+T Power of Wandre, Belgium, for designing, building and demonstrating an inverter with the highest power density and smallest volume. The competition included more than 2000 registered teams, from which 18 finalists were selected. After 4 months of testing the finalists' designs, the \$1m prize winner was announced at the ARPA-E Energy Innovation Summit in Washington DC.

Global demand for more power is unsustainable without using fewer manufacturing materials and consuming less energy to operate the burgeoning number of electronic devices, says GaN Systems. Inverters convert direct current (DC)



**GaN Systems' GS6650P transistor used in winning design for Google Little Box Challenge.**

from solar panels or batteries into the alternating current (AC). The Little Box Challenge organizers tasked engineers to "Figure out how to shrink an inverter down to something smaller than a small laptop (a reduction of >10x in volume)."

The key goal was to reach an inverter power density in excess of 50W/cubic inch in a volume of under 40 cubic inches. The Red Electrical Devils presented their entry at the National Renewable Energy Laboratory (NREL) in Golden, CO, USA, and passed exhaustive testing. Their winning inverter design produced a power density of 143W/cubic inch in 14 cubic inches, outperforming the Little Box Challenge power density goal by nearly a factor of 3, which,

according to Google, "is 10 times more compact than commercially available inverters."

"The use of GaN technology enabled our team to reach a power density of ~145W/in<sup>2</sup> for the 2kVA inverter designed for this project," says Olivier Bomboir, VP of product management & new business at CE+T Power. "The reduced gate drive and switching losses of GaN Systems' GS66508P were critical to our thermal and power density goals. Additionally, we were highly impressed at how reliably the devices performed over the months of rigorous, real-world testing by the NREL team," he adds.

"This achievement is added confirmation that gallium nitride semiconductors are instrumental in helping power design engineers respond to the ever increasing need to develop more efficient power conversion solutions," comments GaN Systems' CEO Jim Witham. "GaN technology clearly paves the way toward more powerful, compact and efficient inverter designs."

[www.littleboxchallenge.com](http://www.littleboxchallenge.com)  
[www.cet-power.com](http://www.cet-power.com)  
[www.gansystems.com](http://www.gansystems.com)  
[www.nrel.gov](http://www.nrel.gov)

## Advantech Wireless opens new US headquarters

Advantech Wireless Inc of Montreal, Canada (which manufactures satellite, RF equipment and microwave systems) has opened its new US headquarters in Buford, Georgia.

The new office will provide customer service and support as well as sales, training and finished goods inventory for fast deliveries to Advantech Wireless' US customers.

"The improvement in Advantech Wireless' ability to serve our fast-growing US customer base is consistent with meeting the increasing demand for our satellite network solutions and award-winning sec-

ond-generation GaN-based SSPA [solid-state power amplifier] systems," says Bob Petrucelli, VP of US sales. "This location will allow us to respond to new and existing customers with dedicated staff in a timely manner," he adds. "It is strategically located in Buford, GA, near several key US customers and the Atlanta International Airport, offering convenient air transportation and shipping to the entire United States."

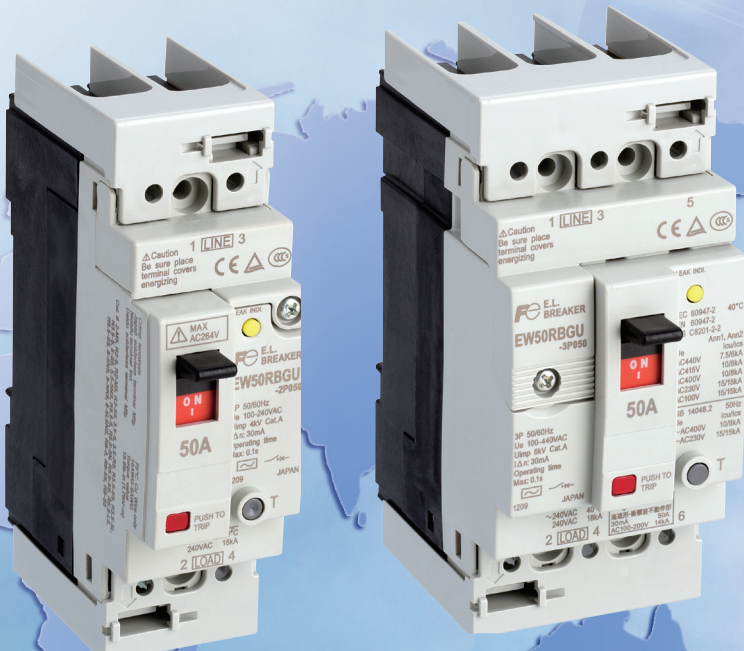
Advantech Wireless exhibited at the Satellite 2016 Conference and Exhibition (7-10 March) in National Harbor, MD, USA.

● Advantech Wireless has appointed Gregory Litinsky as regional VP for sales for Russia and the Commonwealth of Independent States (CIS).

Litinsky has over 25 years of experience in international sales for Israeli and North American high-tech firms. Prior to being regional VP, Eurasia, for Gilat Satellite Networks, he was director, strategic accounts & market channels Russia & CIS for Ceragon Networks. He also has experience in penetrating and developing sales in emerging markets, particularly in Russia and CIS.

[www.advantechwireless.com](http://www.advantechwireless.com)

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## Multitest launches mmWave Contactor interface for high-frequency testing in high-volume production

Multitest elektronische Systeme GmbH of Rosenheim, Germany (a company of Xcerra Corp of Norwood, MA, USA that makes material handling equipment and interfaces for testing and calibrating semiconductors and sensors) has introduced a contacting solution for testing extremely high-frequency semiconductors in high-volume production. The mmWave Contactor offers field-proven electrical performance while maintaining mechanical characteristics, says the firm.

Multitest has developed a hybrid contacting solution that combines traditional spring probe architecture for low-frequency and power I/Os while incorporating a cantilever solution for the peripheral high-frequency transceiver I/Os. By combining spring probe and cantilever technologies, Multitest has extended the reach of volume-production contactors to the extremely high-frequency ranges needed by automotive radar, WiGig, and 5G backhaul devices.

By keeping the interface from test equipment to the device as short as possible while minimizing the number of transitions, Multitest is able to minimize the loss and maintain broadband performance from DC to 81GHz ( $<-10$ dB return loss and 4dB to 6dB insertion loss typical at 81GHz).

The mmWave contactor addresses the mechanical requirements of high-volume production by incorporating high-compliance, robust spring probes and materials and on-site replacement compatibility. The contactor assembly can be fully serviced onsite without incurring delays due to shipping lead times or RMA queues. The entire contacting solution is mechanically assembled and each component can be removed and replaced on-site.

The mmWave contactor solution from Xcerra is a field-proven solution for high-volume semiconductor test that has overcome the challenge of using of metal transmission lines for extremely high-frequency applications.

"With the advent of production volumes of extremely high-frequency semiconductors, it begs the question, 'How will you test it?'" says Jason Mroczkowski, director RF product development & marketing. "The experts at Multitest have considered all factors, ranging from impedance discontinuities to stackup tolerances and their impact on RF performance at mmWave frequencies," he adds. "Xcerra is the only supplier offering a complete test cell solution for volume production of automotive radar devices up to 81GHz. This test cell includes the tester, handler and interface components required for a true high-volume production test of mmWave devices. A critical component of this hardware is the Multitest mmWave Contactor. To date there are many lab and low-volume solutions for extremely high-frequency semiconductor test, but none exist for true high-volume production test of mmWave devices. Until now."

[www.multitest.com/mmWave](http://www.multitest.com/mmWave)

## EVG's executive technology director Paul Lindner receives European SEMI Award

At the SEMI Industry Strategy Symposium Europe 2016 conference in Nice, France (6-8 March), Paul Lindner, executive technology director at EV Group of St Florian, Austria (a supplier of wafer bonding and lithography equipment for MEMS, nanotechnology and semiconductor applications), received the 2015 European SEMI Award.

Established in 1989, the European SEMI Award recognizes individuals and teams that have made a significant contribution to the European semiconductor and related industries.

Paul Lindner was nominated and selected by his peers within the international semiconductor com-

munity in recognition of his outstanding contributions in the field of wafer processing equipment. Lindner is honoured for leading exceptional innovations in wafer bonding technologies at EVG. The process separation between wafer alignment and wafer bonding (developed in 1990) revolutionized wafer bonding technology and has since become an industry standard. Lindner is said to have changed the way the industry builds semiconductors, exemplifying EVG's ongoing effort of "being the first" in exploring new techniques and serving next-generation applications of micro- and nano-fabrication technologies, the citation adds.

"We are very proud of SEMI Member EVG's achievements in wafer bonding technologies and the contributions that Paul Lindner and his team have made to the semiconductor community," commented SEMI Europe president Laith Altimime.

Lindner heads the R&D, product and project management, quality management, business development and process technology departments at EVG. He joined the firm in 1988 as a mechanical design engineer and has since pioneered semiconductor and MEMS processing systems, which have set industry standards.

[www.EVGroup.com](http://www.EVGroup.com)

<http://regions.semi.org/eu/node/8501>



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# AXT's Q4/2015 revenue hit by gallium pricing, but indium phosphide annual revenue up 50%

## Indium phosphide substrates now over 30% of revenue

For fourth-quarter 2015, AXT Inc of Fremont, CA, USA — which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials — has reported revenue of \$18.1m, down 1.6% on \$18.4m last quarter and 7.6% on \$19.6m a year ago but above the expected \$17–18m. Full-year 2015 revenue was \$77.5m, down 7.2% on 2014's \$83.5m.

Of total Q4 revenue, 66% came from Asia Pacific, 24% from Europe and 9% from North America. Only one customer generated more than 10% of revenue, and the top five generated 42% of total revenue (down from 45% last quarter), reflecting diversification of both products and customers.

After growing more than 50% from the prior year, InP substrates now represent AXT's single largest product category (nearly 30% of total revenue in Q4), driven mainly by demand for optoelectronic devices (specifically fiber-optic communications and telecommunications and passive optical networks). "For these InP-based devices, performance is a much larger driver than price. This contributed to a better substrate margin profile and pricing stability than we see today in gallium arsenide," says CEO Dr Morris Young.

"The most significant near-term headwind in our business is raw materials, which were down meaningfully in Q4 as a result of both price and volume decline," notes Young. In particular, gallium pricing has continued to reach historic lows (taking a very severe hit, starting in October–November) due largely to oversupply, resulting in a one-time charge at one of AXT's joint ventures to write-down inventory to market-level pricing. "At the beginning of 2015 we thought gallium prices had hit the bottom [about \$200/kg], but now gallium pricing is quoted somewhere

around \$140/kg," adds Young. Germanium pricing has also dropped significantly in recent months, leading to AXT's germanium joint venture incurring a loss.

Gross margin has fallen from 25.4% a year ago and 25.1% last quarter to 17.1%, but this includes the write-down charge from AXT's gallium raw material subsidiary (reducing consolidated gross margin by about three percentage points). In addition, the historically low gallium pricing currently also affected gross margin on consolidated sales from the firm's gallium subsidiaries (an additional hit to consolidated gross margin of about 2.5%). The balance of the difference compared to last quarter (2.5%) is related to product mix. Despite Q4, full-year gross margin was 21.7%, up from 20.6% for 2014.

"During 2015, our semi-insulating GaAs substrate revenue reached a relatively stable level, having weathered a major technology

**Gallium pricing has continued to reach historic lows (taking a very severe hit, starting in October–November) due largely to oversupply, resulting in a one-time charge at one of AXT's joint ventures to write-down inventory to market-level pricing. At the beginning of 2015 we thought gallium prices had hit the bottom [about \$200/kg], but now gallium pricing is quoted somewhere around \$140/kg**

transition in previous years," says Young. "This area of our business now requires comparatively modest ongoing investment that holds upside potential to qualify with meeting customers' demands in RF device markets," he adds.

Operating expenses have been from \$5.6m a year ago and \$5.3m last quarter to \$4.8m in Q4, led by a reduced level of R&D spending in one of the raw material subsidiaries. Operating loss has risen from \$0.7m last quarter to \$1.7m, due to the impact of gallium pricing.

Compared with net income of \$42,000 last quarter (\$0.00 per share), net loss was \$1.2m (\$0.04 per share, slightly worse than the expected \$0.01–0.03 per share due to the raw material write-downs). Full-year net loss was \$2.2m (\$0.07 per share), up from \$1.4m (\$0.04 per share) for 2014.

In Q4, depreciation and amortization was \$1.3m. Capital expenditure (CapEx) was just \$0.5m (down from \$1.4m last quarter). AXT also used a small amount of cash to repurchase stock (taking the total for full-year 2015 to \$2.3m). Altogether, during the quarter, cash and investments hence fell from \$45.4m to \$44m (down on \$48.9m a year ago).

"2015 was a year of transformation for AXT as we continued to realign our business with the trends that are driving growth in compound semiconductor substrates," says Young. "This process began in earnest two years ago following the significant customer consolidation and technology transition in our industry. As we began to pivot our business in 2014, we made meaningful improvements in our cost structure and began to see a positive shift in our revenue mix," he adds.

"With our recent purchase of the production equipment for GaAs wafer processing and handling for Hitachi Metals, we believe we can improve our manufacturing capability



► for quality and consistency and enhance our ability to pursue growth opportunities,” says Young. “With semiconducting GaAs we continue to play modestly. We are pursuing higher-end applications such as backlighting, signage and automotive; we have made a conscious decision not to participate in certain lower-end applications as a result of the serious competitive landscape and corresponding pricing environment,” he adds.

“In 2015, we focused on strategic investments in our technology and manufacturing capabilities that will position AXT to benefit from the growth in InP and will improve us in driving improved consistency and

efficiency across our substrate portfolio,” continues Young. “We are pleased with these investments, and in the early results of our efforts,” he adds.

For first-quarter 2016, AXT expects the continued weakness from near-term trends to yield flat revenue of \$17.5–18.5m and a loss of \$0.03–0.05 per share. “However, the longer-term shift in our business towards InP, coupled with the potential new opportunities across our portfolio, gives us confidence in our renewed growth this year,” says chief financial officer Gary Fischer.

“Although raw material pricing is providing a near-term headwind, we expect to continue to see a pos-

itive shift in our revenue mix in 2016 driven by InP, providing the potential for both revenue and margin expansion,” says Young. “AXT is the market leader [in InP] and we’re now clearly in the early stages of increased market adoption.”

“Further, we continue to focus on helping our customers optimize the benefit of indium phosphide and we are actively in development of the industry’s first 6-inch InP substrates,” notes Young. “We are confident that we will be able to drive continued growth in indium phosphide sales and an increasing shift in our revenue mix towards this emerging material.”

[www.axt.com](http://www.axt.com)

## Keysight’s new InP chip-sets to enable record-bandwidth 100GHz+ oscilloscopes

Keysight Technologies Inc of Santa Rosa, CA, USA (which provides electronic measurement instruments, systems and related software used in the design, development, manufacture, installation, deployment and operation of electronic equipment) has announced the turn-on of chip-sets based on its indium phosphide (InP) technology that will enable it to deliver (in 2017) real-time and equivalent-time oscilloscopes offering record bandwidths of greater than 100GHz with significantly better noise floors than what is currently on the market.

The real-time oscilloscopes will also include a new 10-bit analog-to-digital converter (ADC) that allows higher vertical resolution of signals captured at ultra-high bandwidth, and more than one maximum bandwidth input channel per oscilloscope to enable tight channel synchronization. Keysight attributes the results to its expertise in microwave semiconductor design and packaging, oscilloscope architecture and in-house fabrication technology.

“Our expertise in microwave semiconductor technology has allowed us to deliver the next-generation

indium phosphide process to create a breakthrough in real-time and equivalent-time oscilloscope performance, and it will enable significant advancements in other Keysight products over time as well,” says senior VP & chief technology officer Jay Alexander.

Engineers working with next-generation, high-speed interfaces such as the upcoming IEEE P802.3bs 400G, as well as terabit coherent optical modulation, will need oscilloscopes for electrical parametric measurements, notes Keysight. These technologies and others will play a key role in validating fifth-generation wireless (5G) designs. Also, these interfaces will drive the need for high-performance, real-time and equivalent-time signal analysis capabilities to 100GHz and beyond, add the firm. As data rates continue to extend beyond 56Gb/s NRZ and 56GBaud multi-level signaling, engineers will need not only higher bandwidth but also higher vertical resolution and lower noise floors to address their validation challenges, and the new chip-sets have been designed with this in mind.

Six years ago, Keysight released

its first oscilloscope with chip-sets fabricated using the firm’s proprietary InP process, and it is still the only company that produces oscilloscopes made with InP chip-sets. Investing in the next-generation InP process has allowed Keysight to scale the transistor switching frequencies beyond the 300GHz level, enabling higher bandwidths in both the chips and the end products.

“Keysight is investing in a completely new technology chain to meet the next-generation measurement needs,” says Dave Cipriani, VP & general manager of Keysight’s oscilloscope business. “Our goal is to move multiple performance parameters ahead simultaneously. The next-generation oscilloscopes deliver bandwidths starting at 80GHz and going beyond 100GHz. They will have a lower noise density, providing higher-resolution measurements in tightly synchronized, multi-channel systems,” he adds. “Whether customers are measuring higher baud rates, higher-order QAM signals or multi-channel systems, these next-generation scopes will meet their needs.”

[www.keysight.com/en/pcx-x2015004/oscilloscopes](http://www.keysight.com/en/pcx-x2015004/oscilloscopes)

# IQE's Photonics sales growth of 28% outweighs further Wireless sales drop of 11%

## IP licensing revenue supplementing return to Wireless growth in 2016

For full-year 2015, epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has reported revenue of £114m, up 2% on 2014's £112m.

Growth was tempered by Wireless sales falling by a further 11%, from 2014's £89.1m to £79.5m. This reflects the slowdown in the smartphone market in second-half 2015, exacerbated by inventory adjustments through the supply chain.

However, further diversification of revenues was driven by significant growth in non-wireless sales, from 20% of total revenue in 2014 to about 30% in 2015.

In particular, Photonics sales rose strongly, by 28% from £12.5m to £16m, driven by increasing adoption for a wide range of applications including data centers, consumer applications, industrial processes, and fibre-to-the-premises (FTTx). Revenues in other markets were broadly flat year-on-year at £10.5m, including InfraRed revenue falling slightly from £9.3m to £8.9m, while CMOS++ revenue rose from £1.1m to £1.7m.

Overall segment revenue has fallen from £112m to £106m. However, this was supplemented by a new revenue stream comprising the first Licensing income of £8m (a combination of upfront and recurring income), earned from licenses to IQE's joint ventures (JVs).

"The group had another strong financial performance in 2015, with continued growth in revenues, profits and cash generation," says chief executive Dr Drew Nelson.

Adjusted gross margin remained stable at about 28%. Adjusted selling, general and administration expenses (SG&A) was cut from £13.9m to £13.5m, including the benefit of improved efficiencies.

While adjusted operating profit rose by 8% from £17.6m to £19m, earnings before interest, tax, depre-

ciation and amortisation (EBITDA) almost doubled from £16m to £29m. Adjusted diluted earnings per share (EPS) has risen from 2.42p to 2.6p.

Cash inflow from operations rose by 41% from £14.9m to £21m. "Our strong cash generation has enabled us to continue to invest in new technologies whilst de-leveraging our balance sheet," says Nelson.

Capital expenditure (CapEx) has been increased from £9.4m to £10m. Investment in new product development was maintained at about £5m, while investment in other intangibles was slightly lower at £1.2m (down from £1.3m). Investment in property, plant & equipment rose by £0.6m from £3.2m to £3.8m (which remains towards the low end of the normal expected maintenance CapEx).

"Our balance sheet leverage peaked in January 2013 at about £94m on the back of

acquisitions, but we have significantly reduced this to about £40m by the end of 2015 [down by 22% from £51.9m in 2014 to £40.3m in 2015, as gearing reduced from 30% to 22%]" says Nelson. This reflects that

**Diversification of revenues was driven by significant growth in non-wireless sales, to about 30% of total revenue**

**The outlook for wireless remains attractive, with recent gains in market share, contract wins, and new product qualifications for base-station applications. In the short term, IQE expects the Wireless materials market to grow at a rate of about 5%**

deferred consideration relating to previous acquisitions fell by £3.5m from £20.6m to £17.1m, and that net debt has been cut by 26% (£8.1m) from £31.3m to £23.2m.

Going forward, IQE expects further diversification of revenues, driven by a photonics market outlook and strong pipeline that supports continuing double-digit growth. In addition, upfront license income from JVs should be about £2m in Q1/2016.

IQE notes that it has a growing portfolio of epitaxial IP, including more than 100 patents and a rich pool of trade secrets for the design and manufacture of advanced semiconductors. In particular, direct engagement with multiple tier-1 OEMs reflects the increasing importance of epitaxial IP as a key enabling technology within electronic systems. Market dynamics also reflect the increasing focus on advanced semiconductor materials technologies (with a US-based competitor being acquired for 3.5x revenues).

Also during 2015, joint ventures were established in the UK and Singapore for the development and commercialization of advanced semiconductor technologies. The significance of the technology was also recognised by the UK government with a £50m commitment this January to fund a Compound Semiconductor Applications Catapult in Cardiff.

"Our focus on building a strong IP portfolio reflects our vision of global leadership across a range of markets as advanced semiconductor materials become an increasingly important enabler of a wide range of electronics applications," says Nelson. "This strategy underpins our strong financial performance."

IQE says that the outlook for wireless remains attractive, with recent gains in market share, contract

► wins, and new product qualifications for base-station applications. In the short term, IQE expects the Wireless materials market to grow at a rate of about 5%.

The firm sees continued progress in other markets. Activity in the power semiconductor market continues to intensify. IQE has secured a strong IP position with cREO (Rare Earth Oxide) technology (licenced exclusively from Translucent Inc). Qualifications with multiple end-users are underway, in addition to continued technology development, enabled by cREO and other in-house IP.

Advanced solar is making good

progress in space applications, mitigating slow progress in the terrestrial market (which has been hampered by macroeconomics). Overall, the outlook remains positive, says IQE. Product qualification is underway with a leading satellite manufacturer, paving the way for increasing production revenues in 2017 from this sector of the market.

IQE says that its InfraRed business maintains its market leadership position, announcing on 26 January a \$3.7m contract with a leading global substrate maker that underpins its strong outlook for 2016. IQEs expect the Infrared market to grow at a rate of 5–10% for the

near future.

"Moving forward, we envisage a return to growth in Wireless, accelerating growth in Photonics, increasing contributions from Power and Solar, and continuing leverage of our powerful IP position through licensing, new product development and introductions," says Nelson.

"We have had a good start to 2016, and are trading in line with our expectations," he notes. "The outlook remains positive, which underpins the board's confidence that we remain on track to achieve our expectations for the full year."

[www.iqep.com](http://www.iqep.com)

## IQE's Andrew Griffiths wins Young Engineer of the Year title

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK says that Andrew Griffiths, process engineer at IQE's Photonics business unit based in Cardiff, was named Young Engineer of the Year at the ESTnet Awards 2016 at a gala ceremony held on 2 March at the Wales Millennium Centre.

The independent judging panel awarded Griffiths the title for his achievements at IQE, where he tackled a number of key projects. He has played an active role and made significant contributions to a number of process improvement



**IQE's Andrew Griffiths, winner of the Young Engineer of the Year award (courtesy ESTnet).**

activities within IQE's photonics business unit that have helped fur-

ther advance the teams engineering and operational capabilities.

"This award is a well-deserved recognition of Andrew's hard work and commitment," says IQE's CEO Dr Drew Nelson. "Now in its fifth year, the ESTnet awards act to showcase excellence in the electronics, software and technologies sector in Wales," he adds. "The importance of attracting and retaining young talent into our industry cannot be overestimated and is essential to building a vibrant, high-tech economy."

<http://estnet-awards.co.uk>

## Solid State Lighting & Energy Electronics Center selects Nippon Sanso MOCVD reactor for UVC-LED development

Matheson Tri-Gas Inc of Basking Ridge, NJ, USA, together with its parent company Taiyo Nippon Sanso Corp (TNSC) of Tokyo, Japan, says that the Solid State Lighting & Energy Electronics Center (SSLEEC) at the University of California, Santa Barbara (UCSB) has installed an SR-4000HT-grade gallium nitride metal-organic chemical vapor deposition (MOCVD) reactor for its continued compound semiconductor device developmental work for deep-ultraviolet light-emitting

diodes (UVC-LEDs). SSLEEC is co-directed by Nobel Prize-winning professor Shuji Nakamura and professor Steven DenBaars.

It is said that the unique design of the SR-4000HT assists in growing high-aluminium-content devices at high growth rates, while operating at pressures higher than 40kPa and elevated temperatures.

"We have already obtained preliminary growth results which demonstrate the unrivaled performance of the SR-4000HT reactor," comments

Nakamura. "We look forward to using the MOCVD reactor from TNSC to grow the high-quality III-nitride-based materials and devices," he adds.

"We believe that the designed features of our reactor, which enable well controlled vapor phase reactions, will allow UCSB to enjoy a large process window to develop their devices," says TNSC's CSE Division Manager Koh Matsumoto.

<http://ssleec.ucsb.edu>

<http://www.mathesongas.com>

# Veeco's Q4/2015 hit by China MOCVD push-out, but full-year revenue still up 21%

## Annual growth in Advanced Packaging, MEMS & RF double the target

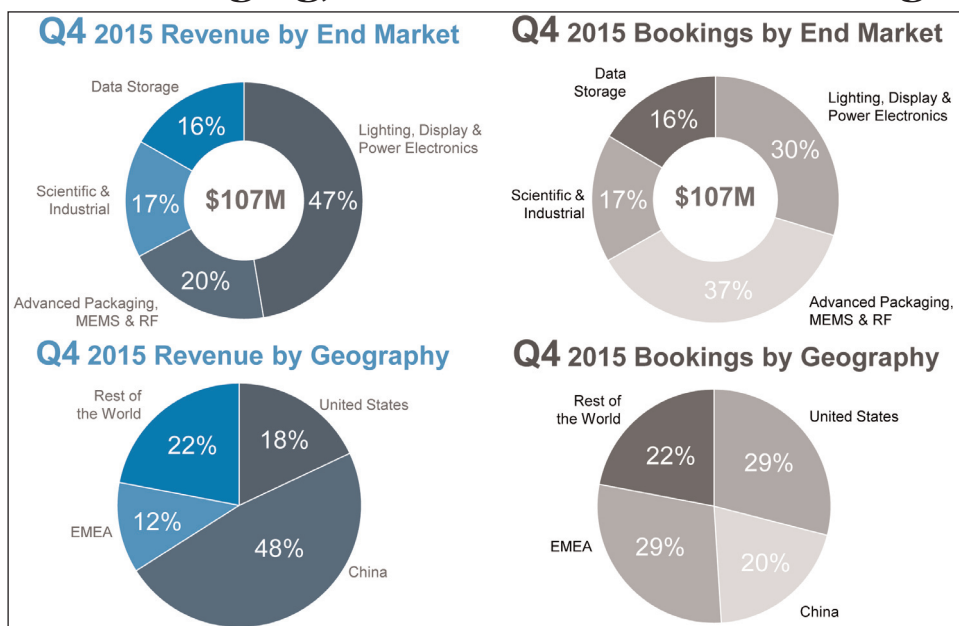
Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue for full-year 2015 of \$477m, up 21% on 2014's \$392.9m.

Fourth-quarter 2015 revenue was \$106.5m, down 6% on \$113.6m a year ago and 24.5% on \$141m last quarter. Veeco had warned in late October of an impact on Q4 of the push-out of a number of metal-organic chemical vapor deposition (MOCVD) systems into 2016 by a China-based LED maker (while this customer faced challenges in securing letters of credit). Nevertheless, Q4 revenue was still towards the upper end of the \$90-110m guidance range.

On a geographic basis, China comprised 48% of total revenue (falling back from 58% last quarter), the USA 18%, EMEA (Europe, the Middle East & Africa) 12%, and the rest of the world 22% (including growth from both Japan and Taiwan).

The Lighting, Display & Power Electronics segment — primarily MOCVD systems — contributed 47% of total revenue (falling from 67% last quarter) and included the remaining EPIK MOCVD system from the Sanan order announced in December 2014.

The Advanced Packaging, MEMS & RF segment contributed a record 20% of revenue (doubling from 10% last quarter), focused heavily on the RF device segment. For Precision Surface Processing (PSP) — formerly Solid State Equipment Holdings LLC (SSEC) of Horsham, PA, USA until its acquisition in Q4/2015 — full-year revenue growth was more than 20%, significantly exceeding the targeted 10%. "PSP has enabled us to significantly expand our footprint in the RF and MEMS markets and also gain entry into the high-growth Advanced Packaging space," says chairman & CEO John R. Peeler.



The Scientific & Industrial segment contributed 17% of revenue (up from 10%), driven by ion beam etch sales and the highest sales in more than three years for molecular beam epitaxy (MBE) systems (used to produce high-end gallium arsenide RF switches). The Data Storage segment rose slightly from 13% to 16% of revenue.

On a non-GAAP basis, gross margin was 36.8%, down from 38.5% a year ago and 39.1% last quarter, but higher than the expected 32-35% due to a slightly stronger product mix. Full-year gross margin rose from 36.3% in 2014 to 38% for 2015.

Operating expenses in Q4 were \$38m, roughly level with \$38.1m a year ago but up from \$36.4m last quarter and slightly above the expected \$35-37m due to variable compensation expense. Operating income was \$1.1m (down from \$18.6m last quarter). So, after depreciation of \$3.3m, adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) was \$4.4m, down from \$8.3m a year ago and \$21.8m last quarter. Full-year adjusted EBITDA was \$41.7m, up on 2014's \$2.6m.

Net income in Q4 was \$0.6m (\$0.01 per share), down on \$5.1m

(\$0.13 per share) a year ago and (\$0.33 per share) last quarter. However, full-year net income of \$22.1m (\$0.54 per share) compares with a loss of \$4.1m (\$0.10 per share) in 2014.

"We ended 2015 on a positive note, delivering solid Q4 revenue and adjusted EBITDA and exceeding the high end of our guidance range for gross margin," notes Peeler.

For full-year 2015, Veeco generated \$16m in cash from operations (the 12th consecutive year of positive operational cash flow). However, for Q4/2015 net cash used by operations was \$6m. Also in Q4, Veeco spent \$9.2m to repurchase common stock. Altogether, during the quarter, cash and short-term investments fell by \$18m from \$403m to \$385m.

Following the sharp dip to \$52m last quarter, order bookings more than doubled sequentially to \$107m in Q4.

Advanced Packaging, MEMS & RF orders rose from 27% of total orders last quarter to 37% in Q4 (mostly due to RF orders growing by over 300%, driven by incremental capacity investments for future smartphone demand). "A majority of the RF device manufacturers

► utilize our PSP tool for production, and we won business from a new customer this quarter, further strengthening our RF position,” says chief financial officer Sam Maheshwari. “We also saw significant momentum for PSP in advanced packaging. We received production orders from multiple customers including a leading Asian foundry and penetration into an Asian OSAT [outsourced semiconductor assembly & test provider],” he adds.

Scientific & Industrial fell from 27% of total orders last quarter to 17%. However, orders increased sequentially on a dollar basis and were divided evenly between MBE for advanced materials research and ion beam deposition tools for optical coating. Data Storage fell from 30% of total bookings last quarter to 16% in Q4.

Lighting, Display & Power Electronics rebounded from the sharp dip to 23% of total orders last quarter to 30% in Q4. “While this is a clear improvement over Q3, it still reflects

the weak LED industry environment and the oversupply condition,” says Maheshwari. “Sales for certain applications, such as automotive LEDs, have been less impacted by current market conditions,” he adds.

“The vast majority of our MOCVD orders were for US- and Europe-based customers, who have a more diversified product portfolio,” says Maheshwari. On a geographic basis, China comprised just 20% of total orders, the USA 29%, EMEA 29%, and the rest of the world 22%.

Order backlog at the end of Q4/2015 remained flat quarter-to-quarter at \$186m, down on \$287m a year ago.

“Entering 2016, we continue to face a weak macro-economic environment and challenging LED industry conditions. As a result, we expect investments for MOCVD equipment will remain soft through the first half of this year,” says Peeler. “During this time, we continue to strengthen our product portfolio and recently introduced the TurboDisc K475i MOCVD reactor

[for arsenic phosphide (As/P) red, orange, yellow (R/O/Y) LEDs] to complement our industry-leading EPIK 700 MOCVD product [for gallium nitride blue LEDs]. We remain focused on positioning the company for long-term growth,” he adds.

“Since our bookings in Q3 of 2015 were low, we see its impact in projected Q1 revenue,” says Maheshwari. For first-quarter 2016, Veeco expects revenue to drop sharply to \$70–80m. Nevertheless, gross margin should still rise to 37–39%. Operating expenses are guided to be \$38–40m. Veeco expects an adjusted EBITDA loss of \$9–5m and a net loss of \$14–10m (\$0.35–0.25 per share).

“We have been successful in our efforts to lower material cost for EPIK and stabilize pricing, which should support gross margin expansion going forward,” notes Maheshwari. “We believe our target of 40% is achievable at closer to \$100m in revenue levels,” he adds.

[www.veeco.com](http://www.veeco.com)

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# Aixtron's revenue grows 14% in Q4 as diversification outweighs LED-related China loss

## Positive EBITDA achieved in second-half 2015

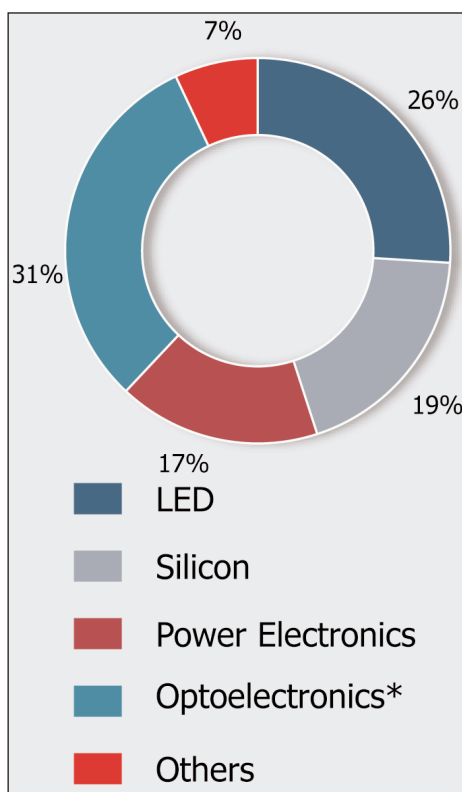
Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported full-year revenue for 2015 of €197.8m, up 2% on 2014's €193.8m.

Contrary to expectations, San'an Optoelectronics Co Ltd (China's largest LED maker) did not qualify Aixtron's new AIX R6 metal-organic chemical vapor deposition (MOCVD) system (contributing to Asian revenue falling from 83% of total revenue in 2014 to just 60% in 2015, while Europe rose from 13% to 18% and the Americas from just 4% to 22%). Full-year revenue was hence down about 16% on the original forecast (given in February) of €220–250m. But despite this, revenue was towards the upper end of the revised guidance of €190–200m given in late October. Most recently, fourth-quarter 2015 revenue was €62.5m, up 8% on Q4/2014's €58m and up 14% on Q3/2015's €54.6m.

"We were able to do this by compensating for lower revenues in the LED segment with significant growth in other technology areas," says president & CEO Martin Goetzeler. "This is a result of the progress we have made in implementing our diversification strategy," he adds.

As demand for high-performance and energy-efficient components for use in markets such as communications, data storage or electric mobility increases, demand is growing for semiconductors for optoelectronics and power electronics, says Aixtron. In contrast, the LED market remains challenging even though the global trend towards LED lighting continues, adds the firm. However, excess capacities and very intense competition between LED makers in Asia put a strain on the demand for MOCVD production systems.

The broader distribution of revenue by application reflects the greater diversification of the technology



**Full-year 2015 revenue by end-application (equipment only).**

and product portfolio: from 2014 (as a proportion of total revenue), while LEDs have fallen from 68% to 26%, in contrast optoelectronics (excluding LEDs) has risen from 9% to 31%, silicon-based microelectronics from 11% to 19%, power electronics from 7% to 17%, and other markets from 5% to 7%. "Aixtron has a promising technology and product portfolio which we are developing systematically," says Goetzeler. "Leaving aside LEDs, we were able to register the best year for optoelectronics (especially for applications such as laser, infrared LEDs and photovoltaics, as well as power electronics) in a long time by partially tripling our revenues," he adds. "Although we are in an early phase in the area of carbon nanotechnology, we achieved another improvement in revenues in 2015. Based on our technology for memory chips, we almost doubled our revenues in the silicon industry and we

have continued to drive forward our market positioning for the development of new logic applications."

Gross margin was 31% in Q4/2015, down slightly from 33% in Q3 but up from 18% a year ago. Full-year gross margin has risen from 20% in 2014 to 25% for 2015, driven by an improving product mix and favorable currency effects.

Operating expenses were €21.1m in Q4/2015, up from €16.3m in Q3 but cut from €30.5m a year ago. Reflecting the better cost control, full-year operating expenses have been cut from €98m in 2014 to €76.5m in 2015, remaining well below the targeted €80m. This is despite significant R&D investment of €55.4m (down from 2014's €66.7m) in system technologies such as organic light-emitting diodes (OLEDs) and III-V-on-silicon (TFOS).

Full-year EBITDA (earnings before interest, tax, depreciation and amortization) improved from –€41.3m for 2014 to –€16.4m for 2015. However, although down on +€13.9m a year ago, Q4/2015 EBITDA was +€1.3m (following +€4.1m in Q3/2015). Hence, with an overall positive EBITDA of +€5.4m, Aixtron met the expectations of EBITDA break-even in second-half 2015, reflecting the evolving product mix, the favorable currency performance, and increased in productivity. "Achieving positive EBITDA in the second half of 2015 as planned and without the revenue share from China confirms our cost discipline as well as the progress in the implementation of our diversification strategy," says Goetzeler.

However, free cash flow has deteriorated further, from +€5.9m a year ago and –€10m in Q3/2015 to –€35m in Q4. Full-year free cash flow has declined from –€47m in 2014 to –€57.3m for 2015. This was driven mainly by a partial repayment of advance payments from

► San'an for the originally ordered 50 AIX R6 systems. The remaining repayment was made in Q1/2016.

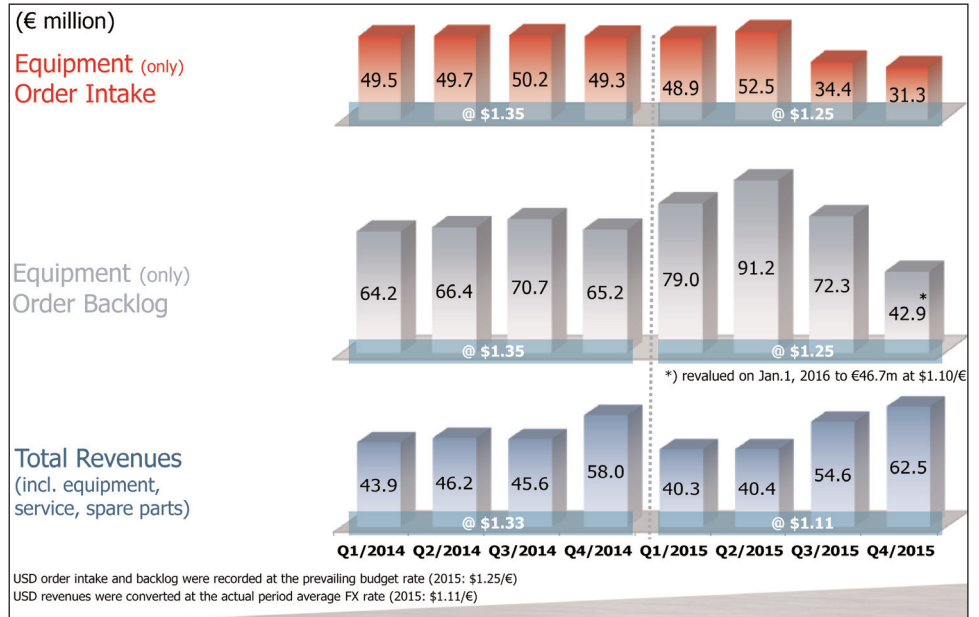
Capital expenditure in Q4/2015 was €2.9m (level with Q3), contributing to full-year CapEx of €13.3m in 2015 (roughly level with €13.4m in 2014).

During 2015, cash and cash equivalents has hence fallen by €58.7m from €268.1m at the end of 2014 to €209.4m at the end of 2015.

Full-year equipment order intake has fallen by 16% from €198.7m in 2014 to €167.1m in 2015 (including €31.3m in Q4, down 9% on €34.4m in Q3 and down 37% on €49.3m a year ago), due mainly to lower overall market demand especially for LED production systems

as well as the effect from the longer-than-expected qualification process of the AIX R6. Due to internal policies regarding the registration of system orders, the major order from San'an was not part of the equipment order backlog. Total equipment order backlog of €42.9m at the end of 2015 was 34% lower than the €65.2m at end-2014 and 38% lower than the January 2015 opening backlog of €69m, due to the high level of deliveries as scheduled at the end of 2015 in combination with low order intakes.

Aixtron says that, to speed up the firm's transformation, it is working continuously on efficiency and productivity improvements in the course of its internal Quality & Business Improvements (QuBI)



initiative. In addition, the company is continuing to proceed with the diversification of its technology and product portfolio. By expanding technologies solutions for power semiconductors, logic and memory, carbon nanostructures as well as targeted investments in OLED technologies, Aixtron aims to exploit new market opportunities. "With the installation of our Gen8 demonstration system and the acquisition of the encapsulation technology from PlasmaSi [of Fremont, CA, USA, which provides low-temperature silicon nitride plasma-enhanced chemical vapor deposition (PECVD) systems for the encapsulation of organic thin-films], we see ourselves in a good position for the current year," notes Goetzeler.

Based on Aixtron's current order situation, Aixtron expects revenue of €170–200m for full-year 2016, with significantly stronger revenue generation in second-half 2016 compared to first-half 2016. Currency-adjusted order intake is expected to be level with 2015.

Depending on completion of qualification processes and market entry efforts as well as the achievement of revenues at the high end of the revenue guidance range, Aixtron expects another improvement in results in 2016. EBITDA, EBIT, net result and free cash flow are expected to improve slightly on 2015 but to remain negative for full-year 2016. Positive EBITDA is expected for full-year 2017.

[www.aixtron.com](http://www.aixtron.com)

## Epistar finalizes qualification of Aixtron's AIX R6 MOCVD system

The world's largest LED epiwafer and chip maker Epistar Corp of Hsinchu Science-based Industrial Park, Taiwan has achieved all milestones in the internal qualification process of Aixtron AIX R6 beta-type MOCVD production system.

Aixtron says that, in the course of the qualification process, the AIX R6 confirmed its value proposition in terms of throughput maximization, intrinsic yield and uniformity. Designed in particular for LED mass production, the AIX R6 also

demonstrated its cost advantages through precursor efficiency and continuous run production operation, the firm adds.

"We have been satisfied with the performance of Aixtron's Showerhead tool during the internal test phase, especially with its improved uniformity which is the basis for high-quality LED products," says Epistar's president Dr M. J. Jou. "We are looking forward to benefit from the system's low cost of ownership in the future," he adds.

"The AIX R6 is a state-of-the-art LED manufacturing system that recognizes the needs of the LED industry, especially with regard to output, efficiency and costs," says Aixtron's executive VP & chief operating officer Dr Bernd Schulte. "Based on our long-standing and trustful business relationship with Epistar, we are looking forward to the further cooperation with one of the leading and most innovative players in the global LED market."

[www.epistar.com.tw](http://www.epistar.com.tw)

## Aixtron ships AIX G5+ C MOCVD system to Exagan for production ramp of GaN-on-Si power-switching devices

### Aixtron and Exagan partner to accelerate GaN-on-Si power HEMT manufacturing on 200mm silicon

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has shipped an AIX G5+ C metal-organic chemical vapor deposition (MOCVD) system to start-up company Exagan.

Based in Grenoble, France (with a branch office in Toulouse), Exagan was spun off in 2014 from Soitec and micro- and nanotechnology research center CEA-Leti (with financial support from each), and licenses materials and technology from both organizations. Exagan aims to accelerate the power-electronics industry's transition from silicon-based technology to smaller and more efficient electrical converters based on GaN-on-silicon technology. Its GaN power switches are designed for full compatibility with standard 200mm-wafer silicon foundries to deliver high-performance, high-reliability products through a robust supply chain.

Exagan will use the system to begin volume production of GaN-on-Si materials for power-switching devices.

The AIX G5+ C Planetary Reactor epitaxy production platform comes in a 5x200mm configuration with

single-wafer rotation and is equipped with full cassette-to-cassette wafer loading as well as Aixtron's in-situ reactor cleaning feature for high-volume manufacturing.

Exagan, in collaboration with its R&D partner CEA-Leti, selected the AIX G5+ C system after evaluating its effectiveness in achieving tight uniformity control and high throughput using Exagan's proprietary G-Stack process technology, which is used in creating a unique stack of GaN-based materials that enables the fabrication of the firm's G-FET high-power, high-efficiency transistors. Along with Soitec's industrial facility and expertise and CEA-Leti's 200mm equipment and characterization tools, Aixtron's equipment adds to Exagan's supply chain as it ramps up its material production facility in Grenoble.

Installation is a major step in Exagan's and CEA-Leti's strategic partnership to accelerate Exagan's GaN-on-Si integration roadmap. The partnership is supported by the 'G-drive+' R&D project, which is funded by Bpifrance via the French government 'Investissements d'Avenir'

('Invest for the Future') program.

"Aixtron and our parent company CEA-Leti have enjoyed a long and successful R&D relationship developing GaN-on-Si technology," notes Exagan's chief operating officer & co-founder Fabrice Letertre. "Now, Exagan is partnering with Aixtron to deliver on our industrial roadmap by using epi to reach our cost milestones. By implementing an efficient GaN-on-Si manufacturing process on 200mm silicon substrates, we are aligning GaN technology with silicon manufacturing standards. This makes our G-FET products the most cost-efficient wide-bandgap solution for the solar, IT electronics, connectivity and automotive markets," he reckons.

"Our AIX G5+ C is the only system to date offering full automation of GaN-on-Si MOCVD processes, as commonly encountered in the silicon industry," says Dr Frank Wischmeyer, Aixtron's VP Power Electronics. "The system achieves the highest on-wafer layer uniformity in a batch multi-wafer configuration for maximum throughput and yield."

[www.exagan.com](http://www.exagan.com)

## LG Innotek using AIX G5 WW system to develop SiC epiwafers

Aixtron SE of Herzogenrath, near Aachen, Germany says that Seoul-based LG Innotek (a subsidiary of South Korean electronics company LG Group) has selected an AIX G5 WW (Warm-Wall) reactor for the development of silicon carbide (SiC) epitaxial wafers aimed mainly at power devices for automotive and renewable energy applications. Configured for 8x6" substrates, the system was delivered in fourth-quarter 2015.

The AIX G5 WW vapor phase epitaxy (VPE) system is based on Aixtron's production-proven plane-

tary reactor platform, giving the largest batch capacity and highest throughput in the industry, it is reckoned. The equipment design aims to minimize production costs while maintaining production quality.

"We see rising demand for SiC-based systems from major automotive manufacturers," says LG Innotek vice president Dr Minseok Kang, the leader of Korea's WPM (World Premier Material) national project for SiC materials development (led by LG Innotek). "Based on our long-term experience with Aixtron epitaxy systems, we believe

that Aixtron's G5 WW tool offers unique advantages such as high throughput and yield on 6" wafers. Furthermore, we can pre-qualify SiC epitaxial wafer samples using Aixtron's SiC application lab and we appreciate the outstanding, dedicated SiC customer support package," he comments.

"We will provide full support to LG Innotek for the quick installation and SiC process qualification of the system," notes Dr Frank Wischmeyer, vice president Power Electronics at Aixtron.

[www.lginnotek.com](http://www.lginnotek.com)



# Plessey expands GaN-on-Si LED production capacity with Aixtron AIX G5+ C cluster

Aixtron SE of Herzogenrath, near Aachen, Germany says that UK-based Plessey Semiconductors Ltd has ordered an AIX G5+ C cluster system (for delivery in third-quarter 2016) to expand its production capacity for gallium nitride LEDs manufactured on silicon wafers (GaN-on-Si).

The AIX G5+ C cluster for Plessey consists of two multi-wafer AIX G5+ reactors, supplemented by Aixtron's next-generation cassette-to-cassette wafer handler for large-scale, fully automated epitaxy production. Plessey purchased the Aixtron planetary system mainly to expand its 150mm GaN-on-Si wafer production but it is also working towards 200mm production qualification mid-term, as Aixtron's G5+ system enables the processing

**AIX G5+C MOCVD cluster with cassette-to-cassette wafer handler**



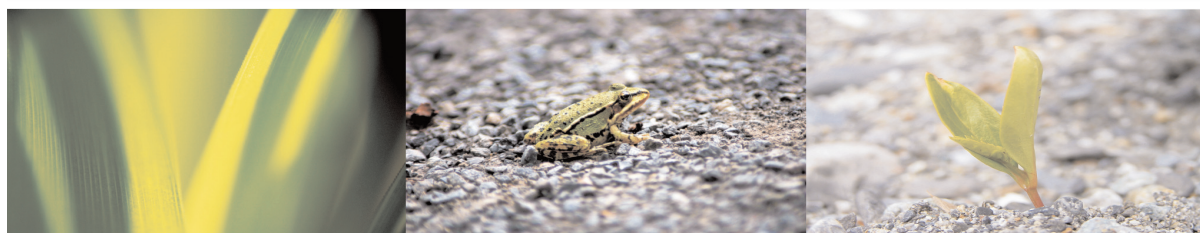
of eight 150mm wafers or five 200mm wafers at the same time.

"We are now moving from proof of capability for our GaN-on-Si LED products into a capacity expansion phase," says Plessey's operations director Mike Snaith. "In the meantime, we have built significant demand for a range of our LED products. We have decided to purchase Aixtron's latest planetary

system, as the AIX G5+ C combines outstanding on-wafer uniformity and run-to-run performance at lowest cost of ownership — aspects that are crucial for efficient high-volume GaN-on-Si production," he adds.

"We have a longstanding and trustful relationship with Plessey," comments Dr Frank Schulte, vice president Aixtron Europe. "Our AIX G5+ C planetary system resolves the common challenges of high-yield, high-quality and high-throughput production of GaN-based materials on large-area silicon wafers through its fully automated cassette-to-cassette loader and a thermally activated gas etch of the MOCVD chamber," he adds.

[www.plesseysemiconductors.com/led-plessey-semiconductors.php](http://www.plesseysemiconductors.com/led-plessey-semiconductors.php)  
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# LayTec details accurate wafer temperature measurement during GaN-on-Si MOCVD for power electronics

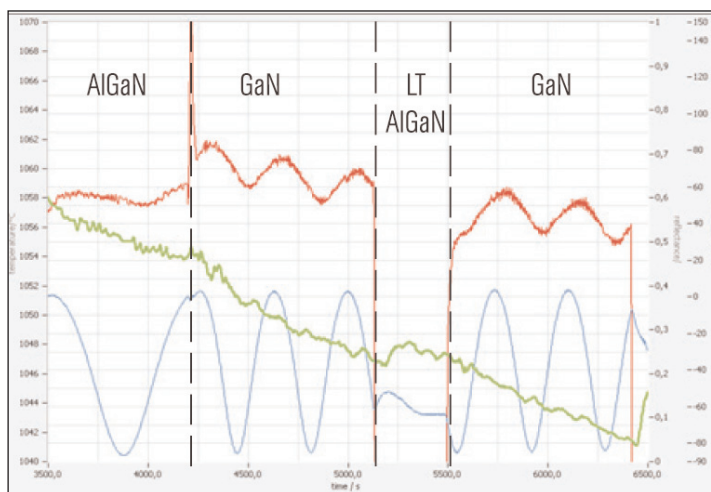
## UV rather than IR pyrometry screens out complex buffer layer structure

Temperature measurement during metal-organic chemical vapor deposition (MOCVD) growth of GaN-on-silicon (GaN/Si) devices is challenging, notes in-situ metrology system maker LayTec AG of Berlin, Germany. Theoretically, conventional infrared (IR) pyrometry should be sufficient because the silicon substrate is IR absorbing in the full range of relevant growth temperatures. However, one artifact makes feedback control difficult and prohibits precise statistical process control in industrial applications.

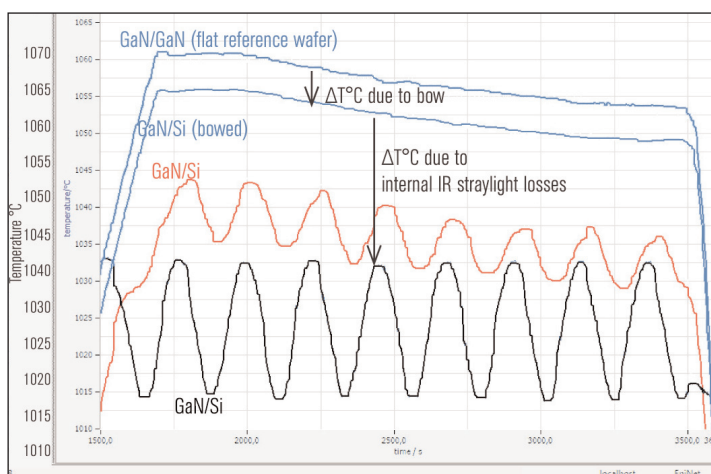
Figure 1 shows this phenomenon: when GaN is grown, the temperature signal (red) starts oscillating by  $\pm 2\text{K}$ .

Together with partners at Otto-von-Guericke University of Magdeburg (professor Armin Dadgar and his team) and FBH (Ferdinand-Braun-Institut, Leibniz-Institut für Hochfrequenztechnik) of Berlin, Germany (Dr Frank Brunner), LayTec searched for a solution and found out that, no matter how perfect the IR pyrometer is, these oscillations are inevitable. They are caused by a complex interaction between two effects: on the one hand the IR-transparent GaN/AlGaN strain-engineering layers together with the defect-reducing buffer structure, and on the other hand the thermal IR radiation out of the silicon wafer that passes through the grown structure. LayTec's solution was to use a pyrometry wavelength range in which the complex buffer layer structure Si/AlGaN/GaN/LT-AlGaN/GaN is not 'visible' for the pyrometer.

Using LayTec's ultraviolet (UV) pyrometer Pyro 400 (developed some years ago for GaN-on-sapphire growth in the LED industry), the results are shown in Figure 2. The same wafer as in Figure 1 was transferred to a reactor at FBH equipped with two in-situ tools: the Pyro 400 for UV pyrometry and the EpiCurve TT for IR pyrometry



**Fig. 1: GaN/Si template run for creating a compressively pre-strained buffer (as can be seen in the curvature data): red - temperature; green - curvature; blue - reflectance (950nm). Data courtesy of Otto-von-Guericke University.**



**Fig. 2: Overgrowth of template of Figure 1 with GaN in a planetary G3 reactor: the blue - UV pyrometry, red - IR pyrometry, black - reflectance (950nm) temperature of the GaN buffer measured by Pyro 400 (lower blue curve) is completely free of Fabry-Perot oscillations. The IR temperature (red) again shows oscillations but (even more essential) it is also downshifted by  $-15\text{K}$  from the true temperature of its GaN surface. Data courtesy: FBH.**

(950nm emissivity corrected), reflectance and wafer bow measurements. The UV pyrometer (Figure 2 — blue) gives a very stable wafer temperature signal without oscillations during GaN growth. Measurements on a reference GaN/GaN wafer in the same run (not shown here) verified that both the IR pyrometer and the Pyro 400

are well calibrated and give exactly the same temperature on an ideally flat and smooth GaN/GaN wafer. Figure 2 shows UV pyrometry measurements clearly indicating that the true GaN surface temperature of the GaN/Si template wafer is  $\sim 5\text{K}$  lower than that of the basically flat GaN/GaN wafer due to the  $\sim 100\text{km}^{-1}$  convex bow of the silicon template measured by EpiCurve TT.

Further, it became clear that the remaining oscillations in the IR pyrometry signal (red) are not the most important artifact. Due to interactions of the thermal IR radiation with the internal structure of the GaN/Si buffer, there is an extra downshift in this temperature signal by as much as about  $15\text{K}$ .

This effect is attributed to the fact that the thermal IR radiation coming out of the silicon suffers intensity losses while passing the highly defective region at the Si/GaN interface. These internal stray light losses depend on the Fabry-Perot resonance within the total GaN thickness and, therefore, also contribute to the IR temperature oscillations.

[www.laytec.de/power-rf-electronics](http://www.laytec.de/power-rf-electronics)

## SPTS named Company of the Year at ESTnet Awards

SPTS Technologies Ltd of Newport, Wales, UK (an Orbotech company that manufactures etch, PVD and CVD wafer processing solutions for the MEMS, advanced packaging, LED, high-speed RF on GaAs, and power management device markets) has been named Company of the Year at the 4th Annual ESTnet Awards, presented on 2 March at the Wales Millennium Centre in Cardiff. Also, Corey Lewis, now customer support engineer at SPTS, was awarded Apprentice of the Year in recognition of the extraordinary achievements in his work studies and job role at SPTS.

The ESTnet Awards celebrate excellence in the electronics, software and technologies sector in Wales by recognizing the outstand-

ing achievements of individuals and companies that make up the Welsh technology community. Supporting young talent and the future of engineering, SPTS also sponsored the Young Engineer of the Year Award.

"We have had very rapid growth in the company and been able to expand market share and improve footprint in all of our served markets," said Kevin Crofton, president of SPTS Technologies and corporate VP at Orbotech. "We hired 20 new employees in the course of the past year at our headquarters in Newport, and we have been very active in growing our apprenticeship program," he added. "This is a huge recognition for our workforce and the important role that SPTS plays in the Welsh economy."

ESTnet is a network of technology enterprises created to form strong business relationships, exchange knowledge and share ideas. Associated members include supply chains and the professional services that support them. Affiliate members provide the industry with professional services. Academic members provide the industry with graduates and opportunities to collaborate on research and innovation.

The network provides a collaborative environment in which people and organizations working with these enabling technologies can create strong business relationships, exchange knowledge and share ideas.

[www.spts.com](http://www.spts.com)

## Tiger Optics launches analyser for detection of moisture in ammonia down to 2ppb

At the Pittcon conference in Atlanta (6–10 March), laser-based trace gas analyzer manufacturer Tiger Optics LLC of Warrington, PA, USA exhibited the new ALOHA+ H<sub>2</sub>O analyzer, which refines the detection of moisture in ammonia to levels down to 2 parts-per-billion (ppb), achieving five times the sensitivity of incumbent technology, it is reckoned. Also at Pittcon, senior scientist Dr Florian Adler presented the paper 'Cavity Ring-Down Spectroscopy Analyzer for Trace Moisture Detection in Ultra-Pure Ammonia' in the Specialty Gas Analysis session.

Five years ago, Tiger introduced its original ALOHA H<sub>2</sub>O analyzer for the high-brightness light-emitting diode (HB LED) market, meeting the need to detect moisture in ammonia at levels to 10ppb, as higher concentrations impair the electroluminescent intensity of HB LEDs and diminish process yields. This directly affects profit margins, as brightness determines whether an LED finds use in a flat-screen TV



**Tiger Optics's new ALOHA+ H<sub>2</sub>O analyzer.**

or is relegated to use in lower-value consumer products.

"When we entered the moisture in ammonia analysis market back in 2004, we did so with an analyzer that had the lowest detection limit available," says founder & chief executive Lisa Bergson. "We've developed close relationships with the leading gas manufacturers, purifier makers and end-users of

ammonia," she adds. "When they told us that they needed an analyzer that had limits lower than even our best analyzer, we developed the ALOHA+ H<sub>2</sub>O analyzer and reduced the LDL [lowest detection limit] to an astonishingly low level of 2ppb."

With the new ALOHA+ H<sub>2</sub>O analyzer, Tiger Optics is addressing the evermore exacting needs of HB LED makers, tool manufacturers, purifier makers and the gas companies that supply ammonia, the preferred source of nitrogen for the production of gallium nitride (GaN)-based HB LEDs.

The compact analyzer fits two to a 19" rack and features the firm's proven cavity ring-down spectroscopy (CRDS) laser-based technology. Often used in remote locations (where skilled technicians and support services are not available) and offering a combination of sensitivity and robustness, the analyzers require little maintenance and are easy to install and to operate, says Tiger.

[www.tigeroptics.com](http://www.tigeroptics.com)

## ClassOne's Plating-Plus capability adds processing chambers to Solstice plating tool

ClassOne Technology of Kalispell, MT, USA, which manufactures wet-chemical processing equipment (especially for emerging markets and other cost-conscious users of  $\leq 200\text{mm}$  substrates), has announced its new Plating-Plus capability, which allows additional processes to be integrated into a single plating tool. The firm says that this can optimize utilization of the  $\leq 200\text{mm}$  Solstice electroplating equipment and give substantial net cost savings as well as process enhancements.

"A lot of our customers, especially those with low to moderate production levels, are seeing significant benefits in incorporating additional processes into our Solstice plating tool," says Win Carpenter, VP of international sales. "With Plating-Plus, many users can eliminate the need to purchase additional downstream equipment — and that eliminates the costs of adding floor space, operators, training, spare parts, etc. Our customers can maximize the use of a single Solstice and streamline their process flow. They can gain the benefits of single-wafer processing with reduced queue times and less excess capacity. The result is a more efficient solution with better capacity matching and lower overall costs."

"Plating-Plus is made possible because of the unique flexibility we designed into our Solstice plating tools right from the start," notes president Kevin Witt. "The Solstice S8 provides eight modular chamber positions that can be used for different processes — all within one standard, highly reliable platform," he adds. "Users can get the special functionality they want simply by ordering their new Solstice with a specific configuration of chambers."

Three new chambers  
To date, ClassOne has introduced three new modular Plating-Plus processing chambers that can be installed on Solstice plating tools. These are high-performance, high-efficiency chambers that enable high-pressure metal lift-off, resist strip, and UBM (under-bump metallization) etch. The new high-pressure metal lift-off chamber is designed for high-efficiency metal removal without re-deposition. The resist strip chamber is an advanced spray module that handles solvents safely and can run a single stripping process across a range of different resists. The UBM etch chamber incorporates an intelligent optical end-point detection technology that controls etching precisely and consistently to avoid undercut.

ClassOne says the new Plating-Plus capabilities make Solstice a highly productive tool for applications including advanced packaging, MEMS, LEDs and optoelectronics. The multi-processing system is suited to a range of needs, from patterned plating to redistribution layers (RDL), from flip-chip/bump/wafer-level packaging to applications that require through-resist plating, resist removal and etching of seed layers.

In future, ClassOne plans to add more new Plating-Plus chambers to cover additional processes. Pricing for each of these chambers is designed to be significantly less than the costs of adding a new stand-alone tool.

The Solstice electroplating line serves many cost-sensitive emerging markets such as MEMS, sensors, LEDs, RF and others that use 200mm and smaller wafers. Solstice tools are available in three different models for production and development and can electroplate many different metals and alloys, either on transparent or opaque substrates. ClassOne claims that the systems are priced at less than half of what similarly configured plating systems from larger manufacturers would cost.

[www.classone.com/products](http://www.classone.com/products)

## Plasma Etch announces robust sales of low-cost commercial-grade plasma cleaning system

Plasma Etch Inc of Carson City, NV, USA has announced robust sales for 2015 on its entry-level plasma cleaner for small research facilities and universities. The firm says that increasing interest in plasma processing has driven a strong increase in sales of its signature PE-25 plasma cleaning system.

The PE-25 low-cost plasma cleaner is an entry-level option for plasma treatment. The firm describes it as a robust machine

that is suitable for small production facilities, research labs and universities. The \$5900 machine was designed for plasma cleaning and surface modification.

"The PE-25 is very popular with the research community, as well as universities, due to its low cost and easy to use interface," says president Greg DeLarge. "Many of our PE-25 customers come back to purchase larger machines after they get their process nailed down and

decide exactly what they need for production runs."

This opening price-point system also includes features such as automatic plasma control and a built-in control panel with a plasma timer. Plasma Etch says that the PE-25 is easily upgradable to be controlled by any PC or laptop and can include a light tower for easy-to-read indication of the steps in the plasma processing sequence.

[www.plasmaetch](http://www.plasmaetch)

## University of Bath installs Eulitha's Phable lithography system to develop nano-engineered semiconductor manufacturing techniques

Eulitha AG of Würenlingen, Switzerland (a spin-off of the Paul Scherrer Institute in Villigen that offers nano-lithographic equipment and services for photonics and optoelectronic applications) says that one of its PhableR 100 photolithography systems has been installed at the UK's University of Bath.

The PhableR 100 exposure tool incorporates Eulitha's proprietary Displacement Talbot Lithography technology, which enables robust printing of very high-resolution periodic patterns at low cost. The system was purchased by the university as part of a comprehensive research program designed to develop manufacturing techniques for nano-engineered semiconductors, particularly gallium nitride (GaN).

The system's purchase was made possible following the award of a 5-year, £2.7m grant from the UK Engineering & Physical Sciences Research Council (EPSRC) as part of the council's Manufacturing of Advanced Functional Materials funding program.

The university has been active in GaN research since 1999 and has a reputation for combining nanofabrication techniques with semiconductor growth in order to improve the

performance of optoelectronic devices such as light-emitting diodes.

Specifically, creating three-dimensional structures at the nanoscale provides a route to improving the quality of these materials and in turn the performance of devices. This should ultimately increase the energy efficiency in these and other emerging applications, such as water purification, where ultra-violet LEDs are used to prevent viruses reproducing.

As a result of the EPSRC investment, researchers in the Department of Electronic & Electrical Engineering now have access to a new nanolithography suite within the David Buller Nanofabrication Cleanroom, of which the PhableR system forms part, alongside the existing access to crystal growth reactors and more conventional fabrication facilities.

The PhableR 100 system was chosen as it offers what is claimed to be the unique capability to pattern large areas up to 100mm in diameter with high fidelity in a very simple way. Its capability will be compared with another low-cost patterning technique, nanoimprint lithography, as part of the research.

"Initial results from the tool have

matched and even exceeded our expectations," comments lead researcher Dr Philip Shields (lecturer in the Department of Electronic and Electrical Engineering). "There has been a lot of interest from other researchers to use the tool, and we look forward to developing new research collaborations as a consequence," he adds.

"Their research program focuses on manufacturing technologies for nano-engineered semiconductors which is an area where our innovative technologies have the potential to make a significant impact," says Eulitha's CEO Dr Harun Solak about the University of Bath.

The PhableR 100 system is capable of exposing periodic patterns down to feature sizes below 150nm, which rivals more expensive high-end i-line steppers. The patented focus-free imaging technology enables uniform printing on non-flat samples often found in photonic and optoelectronic sectors. Eulitha had recently announced the delivery of further lithography systems to Twente University in The Netherlands and to CIOMP Institute in China.

[www.eulitha.com](http://www.eulitha.com)

[www.ManuGaN.org](http://www.ManuGaN.org)

[www.bath.ac.uk/research](http://www.bath.ac.uk/research)

## Riber wins order for fully automated research MBE system from University of Chicago

Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, says that on 17 February it received an order from the University of Chicago for a fully automated new-generation Compact 21 research MBE system (with enhanced cell and equipment capabilities, including electron-gun), for delivery by the end of 2016.

The system will be placed at the Argonne Research Laboratories in Lemont, IL, as part of a joint research project on new oxides and oxychalcogenide materials deposition between Argonne and the University of Chicago.

Argonne is a National Laboratory funded by the US Department of Energy's (DoE) Office of Science, whose main fields of research are in photovoltaics and energy storage

applications. The focus of the group concerns new energy-conversion and power-efficient energy technologies.

The Compact 21 Cluster is claimed to be one of the best-performing thin-film deposition research systems on the market. Riber says that it was chosen for its high level of flexibility, its reliability, and its ability to be run remotely (enabling it to be shared with research groups worldwide).

[www.riber.com](http://www.riber.com)

# Rubicon's revenue halves in Q4 due to weak demand and delayed ramp-up at PSS wafer customer

## Excess inventory suppresses pricing but other markets to drive recovery

For fourth-quarter 2015, Rubicon Technology Inc of Bensenville, IL, USA (which makes monocrystalline sapphire substrates and products for the LED, semiconductor and optical industries) has reported revenue of \$2.45m, more than halving from \$5.35m last quarter and down on \$8.9m a year ago, as the sapphire market in general remained weak. Full-year revenue has almost halved, from \$45.7m in 2014 to \$23.8m in 2015.

Optical and R&D revenue (mainly optical) was \$1.1m, down from \$1.4m last quarter and half the \$2m a year ago.

Wafer revenue fell to \$0.9m, down from \$2.1m last quarter and \$2m a year ago. However, this was due mainly to a key customer for 6-inch patterned sapphire substrate (PSS) wafers delaying the start of its volume purchase order by a quarter, from 1 October to 1 January (based on revised end-customer demand). PSS wafers hence contributed just \$0.4m (roughly level with \$0.5m a year ago but down from \$1.4m last quarter). Polished wafers contributed \$0.46m (down from \$0.76m last quarter and \$1.47m a year ago).

Also, excess sapphire capacity and fluctuations in inventory levels in the supply chains of the two major existing markets (LEDs and mobile devices) have reduced demand, creating additional downward pressure on pricing. Rubicon hence limited its sales of 2- and 4-inch cores, for which revenue totaled just \$0.5m, down from \$1.8m last quarter and \$4.8m a year ago. Specifically, revenue for 4-inch cores has fallen from \$1.6m a year ago and \$1.2m last quarter to \$0.47m, while revenue for 2-inch cores (used predominantly for the mobile device market) was just \$10,000, down from \$0.55m last quarter and as much as \$3.2m a year ago.

Given the lower demand for 2- and 4-inch cores, Rubicon has scaled back crystal growth production further, from 40% to 30% of capacity (to reduce core and boule inventory). Idle plant cost hence rose from \$1.8m last quarter to \$2.3m. The further weakening of sapphire pricing required Rubicon to evaluate the carrying value of its raw material, leading to a \$2.3m non-cash charge to adjust the raw material inventory to its estimated replacement value.

Operating expenses were \$3.3m, up from \$3m last quarter due to higher legal and professional fees.

On a non-GAAP basis (excluding non-cash charges), net loss was \$9.9m (\$0.38 per share), up from \$7.7m (\$0.29 per share) last quarter and \$9.4m (\$0.36 per share) a year ago.

Building consignment inventory of 6-inch PSS wafers for the key customer (in preparation for volumes ramping in the first quarter) and limiting the sales of cores increased the net cash used in operating activities from \$1.9m last quarter to \$5.5m (above Q3's level of \$5.1m). During the quarter, cash and short-term investments fell further, from \$34.1m to \$30m.

Total capital expenditure for full-year 2015 was kept under \$1m,

**Continued decline of 4" wafer prices has delayed the migration to 6". However, 4" wafer pricing is now at or below cash cost and not likely to get much lower. We believe that more LED chip makers will adopt the 6" platform and that 6" PSS should become the fastest-growing sub-segment of the LED substrate market**

investing only in tools to reduce wafer polishing cost. "Improving cash flow remains a top priority," says chief financial officer Mardel Graffy. "We are implementing changes that we expect to reduce wafer costs over the next several months and expect cash flow from operations to improve," he adds.

"Our key 6-inch customer began drawing on consignment inventory in January," notes CEO Bill Weissman. Rubicon hence expects wafer revenue to rebound in first-quarter 2016 to at least Q3/2015's level of about \$2m (driven by growth in 6-inch PSS wafer sales), while 4-inch core sales should also increase. Rubicon believes that 2-inch core inventory levels have come down, but there continues to be excess inventory in the supply chain. "We have begun seeing some more interest in 4-inch core for the LED market but pricing remains very weak," notes Weissman. Overall revenue should hence rebound slightly to \$4-5m. The firm expects some reduction in cash used in operating activities. Additional growth in the wafer business is expected in second-quarter 2016.

"Continued decline of 4-inch wafer prices has delayed the migration to 6-inch. However, we believe 4-inch wafer pricing is now at or below cash cost and not likely to get much lower," comments Weissman. "Therefore, we expect to see chip manufacturers put a greater focus on 6-inch migration going forward. We believe that more LED chip manufacturers will adopt the 6-inch platform and that 6-inch PSS should become the fastest-growing sub-segment of the LED substrate market," he adds.

"While PSS pricing is impacted by the macro of sapphire pricing environment, it tends to be less volatile. We believe we have a competitive advantage in being able to produce

PSS wafers in a vertically integrated process starting from powder aluminum oxide, particularly in larger diameters — few competitors have that capability,” Weissman continues. “For customers that are very sensitive to potential disruptions in their supply chain and consistency of quality, that vertical integration is very important. This was a significant factor in our qualification at an important 6-inch PSS customer and we believe it will become increasingly important to other LED chip manufacturers over time,” he adds.

“The customer qualification process for these wafers can be quite lengthy, which can lead to greater customer loyalty and intimacy. However, despite the limited number of capable competitors for 6-inch PSS wafers, current pricing is also weak because the demand for the 6-inch wafers today is fairly limited,” Weissman says. “Therefore it is essential that we continue to expedite cost reductions in our polishing operation so that we can optimize the potential of our vertical integration model, particularly as it relates to our PSS opportunity,” he adds.

“We also recently terminated the resource-sharing agreement we entered into with another polisher last year. Given the current market conditions, the other party is no longer in need of extra capacity,” says Graffy. “That agreement was aimed at gaining some additional insight into low-cost polishing of smaller diameters while potentially reducing some of our idle plant

costs in the near-term,” he adds. “While the other party did not complete all of their obligations, we benefited from the arrangement from their polishing insight and we are now back to our full capacity for when it is needed.” Rubicon is on track to reducing costs for 6-inch polishing operations over the next several months.

“Our efforts to reduce wafer costs are well underway and we are expecting to see progress in the first quarter as we introduce new consumables and refine processes [followed by a more substantial reduction in the second quarter],” Weissman says. “Paramount among our objectives this year is the drive to reduce the use of cash and become cash-flow-positive as soon as possible... We will continue to tightly manage CapEx. ”

“The overall weak sapphire pricing environment is primarily the result of excess capacity which has been driven by the prospect of sapphire cover glass in mobile devices,” notes Weissman. “While the prospects for that application coming to market remains uncertain, there are several new applications in various stages of development that have the potential to become large consumers of sapphire and help to reduce the current market imbalance and supply and demand,” he adds. “During this difficult time, we are focused on building value to developing new and more differentiated products, while aggressively working on cost reductions. In addition to pursuing our PSS poten-

tial, we are targeting high-margin optical applications and developing new products,” he adds. “We are working with developers of some very interesting potential new applications for sapphire [primarily in the consumer electronics and medical device markets] which fit particularly well with Rubicon’s unique set of sapphire knowledge and capabilities.”

Having begun supplying samples to these optical business opportunities, Rubicon expects to move two new technologies into production later this year: its LANCE technology (which produces large rectangular windows for defense and commercial applications) and its SapphirEX coating technology. “We are on track to complete our LANCE crystal growth deliverables this year, producing windows as large as 36” x 18” x 2”, which are unprecedented in the market,” notes Weissman. “We also expect to move SapphirEX into production later this year and we are pleased with the initial interest in that product,” he adds.

“Our goal is to drive growth that is more balanced between large-diameter PSS, optical products, bulk crystal like cores and rectangular blocks and new products,” explains Weissman. “Pricing remains depressed, particularly for bulk crystal, but that could change quickly as the cover glass application or the other new applications currently in development are adopted.”

[www.rubicon-es2.com](http://www.rubicon-es2.com)

## Monocrystal showcases first 300kg KY sapphire crystal at SEMICON China

At the SEMICON China 2016 event in Shanghai (15–17 March), Monocrystal Inc of Stavropol, Russia (which makes large-diameter sapphire substrates and cores for LED, optical product and RFIC applications) exhibited the first 300kg KY (Kyropoulos) sapphire crystal, together with its traditional

products for LED, consumer electronics and optics.

Monocrystal says that last July it became the first company to grow a 300kg sapphire crystal using the Kyropoulos method. “We welcome our existing and potential customers to our booth to discuss the prospects of large-size sapphire

applications, which can be enabled by our extra-large crystals,” says CEO Oleg Kachalov.

As well as showcasing the 300kg crystal, Monocrystal also gave a presentation on 16 March at the LED China Conference 2016 in the Kerry Hotel Pudong, Shanghai.

[www.monocrystal.com](http://www.monocrystal.com)

## Soraa supports TM-30 as better color test than CRI

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, has declared its support for advances in color science and the new TM-30 method released by the Illuminating Engineering Society (IES). TM-30 uses an optimized calculation method to preclude the errors found in the existing color-rendering index (CRI) standard.

"IES' TM-30 method offers significant progress over the CRI," says chief scientist Aurelien David (who served as a lead technical contributor for the new TM-30 method). "For customers, TM-30 will provide better insight into how the colors of

a light source compare to colors under natural light. And for manufacturers, the information found under TM-30 — combined with other aspects of color science — will be key for developing better products and optimizing the trade-off between color rendition and other criteria of light quality," he adds.

The TM-30 test was developed to provide a more accurate indication of the color rendition of an object by comparing its color under a test source (e.g. an LED lamp) to those under a reference illuminant (a standard emitter such as idealized sunlight or filament bulb, depending on the correlated color temperature). By doing so, the test will

indicate if the colors under the test source are different from natural colors — providing a more precise indication of color fidelity.

TM-30 distinguishes itself from the CRI test in two significant areas. First, it uses state-of-the-art color science to test a light source's color rendition of more color samples, which will preclude the inaccurate predictions of rendering seen with the CRI — in particular for narrow-band sources. Second, it provides users with more information: the color fidelity index R<sub>f</sub> is now complemented by a color gamut index R<sub>g</sub> and by a color vector graphic, which further characterize the appearance of colors.

## Soraa expands GU10 LED lamp range to 5W and 9W versions

Soraa has added both lower- and higher-wattage 120V MR16 GU10 LED lamps to its product portfolio.

The 5W lamps are replacements for 35W-equivalent halogen lamps, and the 9W lamps replace 65–75W halogens. The two new lines join the firm's existing line of 7.5W lamps (50W halogen equivalent).

"Like all of our lamps, they feature Soraa's signature elements of light quality — Point Source Optics and Violet-Emission 3-Phosphor technology," says George Stringer, senior VP of global sales & marketing.

Point Source Optics technology features full-visible-spectrum GaN-on-GaN LED with a unique folded optic with precision-cut prismatic lenses, resulting in crisp, high-intensity and uniform beams.

Violet-Emission 3-Phosphor (VP<sub>3</sub>) LED technology enables rendering of colors and whiteness. Utilizing all colors of the rainbow, especially deep red emission, VP<sub>3</sub> Vivid Color renders warm tones accurately and achieves a CRI of 95 and deep red (R<sub>9</sub>) rendering of 95. Also, unlike blue-based white LEDs without any

violet emission, the VP<sub>3</sub> Natural White is achieved by engineering the violet to properly excite fluorescing brightening agents including natural objects like human eyes and teeth, as well as manufactured white materials such as clothing, paper and cosmetics.

The new 5W and 9W GU10 lamps are compatible with a wide variety of dimmers and are available in three different beam angles as well as 2700K and 3000K color temperatures.

[www.soraa.com](http://www.soraa.com)

## Crystal IS boosts DUV LED output for instrumentation

Crystal IS Inc of Green Island, NY, USA, an Asahi Kasei company that makes proprietary UVC ultraviolet LEDs, has augmented its Optan SMD (surface-mount device) product line for instrumentation with the addition of higher light output and wavelength-specific bins (SKUs). The newest offering is the result of increased demand for UVC LEDs in fluorescence spectroscopy, imaging and biofouling control.

Like other Optan products, the UVC LED uses lattice-matched native aluminium nitride (AlN) substrates,

which are proven to overcome limitations of other UVC LEDs for instrumentation, the firm claims.

With high output at wavelengths from 250–280nm, new or improved example applications include:

- fluorescence spectroscopy (label-free spectroscopy is important in biological cell imaging, tissue diagnostics and proteomics);
- flow cytometry (routinely used in bio-analytics and medical diagnosis, cell counting, cell sorting and bio-marker detection);
- biofouling control (UVC LEDs can

now be used for protecting larger sensors and those operating in environments that experience significant biofouling); and

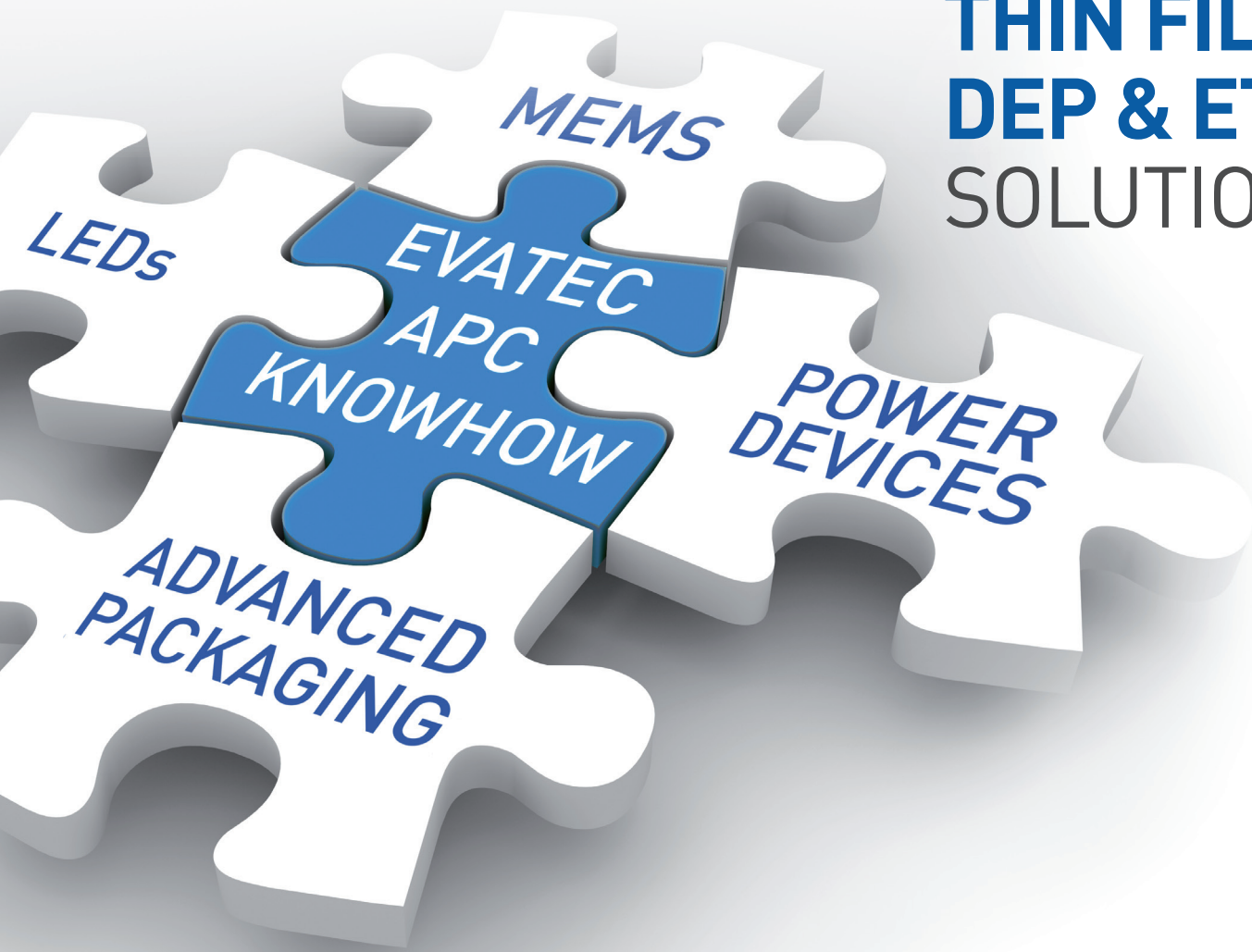
- light source for catalyzing persulfate oxidation in TOC (total organic carbon) measurement (high levels of TOC can degrade water purification systems used in semiconductor and pharmaceutical manufacturing).

"Our newest Optan SMD bin has a higher light output and longer lifetime than any LEDs commercially available now," claims CEO Larry Felton.

[www.cisuv.com](http://www.cisuv.com)



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## Samsung boosts color quality in small-LES CoB LEDs for premium commercial LED lighting

Samsung Electronics Co Ltd of Seoul, South Korea has introduced new color quality improvements for its small-LES (light-emitting surface) chip-on-board (COB) package LC series: the LC010, LC020 and LC040. The improvements are based on 'Vivid' color technology that has been optimized for high-color-quality LED lighting, especially for use in premium commercial lighting applications.

"With Samsung's new small-LES COB packages, LED luminaire manufacturers can enjoy exceptionally high color quality and design flexibility," says Jaewook Kwon, vice president of Samsung Electronics' LED Strategic Marketing Team.

Available in correlated color temperatures (CCTs) of 2700K, 3000K, 3500K, 4000K, 5000K and 5700K, the small-LES LC series offers three alternatives: the LC010C with an operating wattage of 10W and an LES diameter of 6mm; the LC020C with 20W and an 8mm LES diam-



**Samsung's small-LES COB LEDs.**

eter; and the LC040C with 40W and an 11mm LES diameter.

The small-LES LC series reduces the space required for the LES by 50%, while doubling the center-beam candle power (CBCP) over that of existing standard COB LED packages.

Improved quality of light in the small-LES LC series is enabled by Samsung's Vivid color feature, which provides special color spectrums optimized for retail markets such as grocery and premium commercial stores. The Vivid color spectrums add more brilliance to displays of fresh meat and fruits, for example.

The small-LES line-up also features high CRI (color rendering index) — over 80, 90 and 95, respectively. These improvements will help to satisfy requirements for premium commercial lighting applications, says the firm, where color quality is a critical factor in lighting performance.

In addition, Samsung's flip-chip and phosphor dispensing technologies have been adopted to reduce the size of the LES throughout the LC series, in compliance with Zhaga Book 12. The small-LES LC series can increase cost effectiveness by significantly reducing the size of key elements within a luminaire such as its optics, heat-sink and holders. Also, they can be adapted to be used in spotlights (even those with a narrow beam angle of 15–25°).

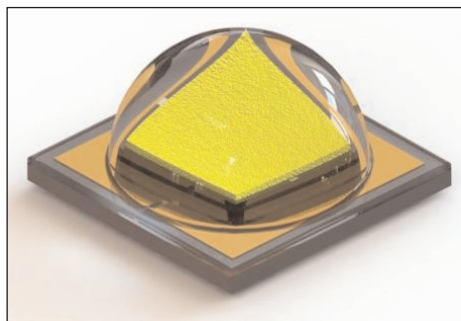
Samsung showcased its small-LES LC series along with other LED component solutions at the Light + Building trade fair in Frankfurt, Germany (13–18 March).

[www.samsung.com](http://www.samsung.com)

## Plessey launches LED beam control modules for medium- and high-power lighting

At the Light + Building 2016 trade fair in Frankfurt, Germany (13–18 March), UK-based Plessey Semiconductors Ltd released its new LED beam control module. Stellar is its latest GaN-on-silicon LED solution and showcases the combination of the firm's MaGIC low-cost, high-efficiency, surface-emitting LEDs with modular optics.

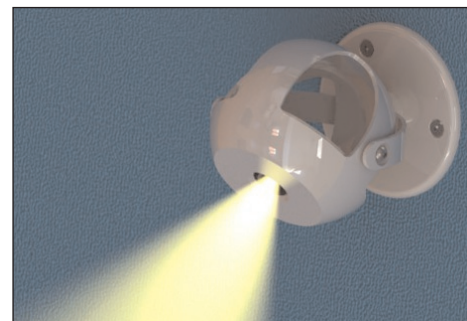
"As part of our chip-scale optics development we have developed a variety of solutions for beam control off the LED chip," says chief technology officer Dr Keith Strickland. "Getting light to where you need it is critical in industrial, retail, hospitality and outdoor lighting. Stellar provides lighting designers with the design freedom needed for light-weight, low-profile, less bulky



**Plessey's high-power integrated LED.**

designs," he adds.

"With the release of Stellar, we have demonstrated that we have the technology and supply chain to provide mass customization of lighting solutions for manufacturers in all segments of the lighting market," says LED sales director Giu-



**Plessey's new Stellar beam-forming integrated retail lights.**

liano Cassataro. "Stellar will permit lighting designers to improve the reliability and quality of light using our state-of-the-art LED light engine for most applications," he adds.

[www.plesseysemiconductors.com/led-plessey-semiconductors.php](http://www.plesseysemiconductors.com/led-plessey-semiconductors.php)

# Samsung launches full line-up of LED components based on chip-scale packaging technology

Samsung Electronics Co Ltd of Seoul, South Korea has introduced a full line-up of chip-scale LED packages (CSP), including 0.6W- and 3W-class packages, CSP arrays and PoW (Phosphor on Wafer) packages.

Samsung says its CSP technology reduces the size of a conventional LED package by combining flip-chip technology with phosphor coating technology, eliminating any need for metal wires and plastic molds. This shift enables more flexible and compact designs when manufacturing LED lighting modules or fixtures, and lowers the production and operational costs of LED lighting systems. The firm adds that its CSP products also allow flexibility in adjusting the size of the light-emitting surface and its associated luminance level, to meet the diverse requirements of a wide variety of lighting applications including bulbs, spot lighting, down-lighting and street lighting.

"Our new CSP products overcome what had been significant performance limitations of conventional LED packages," says Jacob Tarn, executive VP, LED Business Team, Samsung Electronics. "By expanding our CSP line-up, we expect to provide greater value to the LED lighting market, enabling new possibilities in LED lighting and giving our customers greater design flexibility," he adds. "We are aggressively innovating through the introduction of well-differentiated LED components, while further strengthening our presence in the LED marketplace in terms of technology and cost."

The new CSP line-up has been strengthened with a wide range of operating current options from 0.6W to 3W and even 10W LED packages. The new packages complete Samsung's CSP technology roadmap (announced at the LIGHTFAIR International 2015 event when the firm's CSP technology commercialization plan was unveiled).

## Mid-power, 0.6W-class CSP LED packages

Based on advanced flip-chip technology, the 149lm/W LM101A and 135lm/W LM102A (Samsung's new mid-power CSP packages for LED lighting) feature ultra-slim form factors and simple package structures aimed to enhance their cost competitiveness. Each offers two voltage options (3V and 6V), making the packages applicable to many applications including bulb, high-bay lighting, down-lighting and spot lighting. The mid-power CSP LED packages also provide wide beam angles, giving greater design flexibility. The LM101A and LM102A packages are available in full-color temperatures with three color rendering index (CRI) options from 70 to 80 and 90.

## High-power, 3W-class CSP LED package

The LH181A is a high-power CSP package with about 12% higher luminous flux at a maximum current of 1.5A, compared to Samsung's 3W-class ceramic-based high-power LED package. Luminous flux is typically about 162lm/W (at a drive current of 350mA, Ra70 and 5000K). Each LH181A measures 1.91mm x 1.91mm (about 30% smaller than Samsung's ceramic-based LED). The package's ultra-small size enables much smaller lighting designs and better lumens-per-dollar value (especially useful in outdoor and spot lighting applications). A wide beam angle of 140° makes it also applicable to street lighting by adding a lens as a secondary optic solution.

## CSP arrays

The LH204A and LH309A CSP arrays (for mass production in second-quarter 2016) are high-power LED solutions with an operating wattage range from 5W to 10W. The 124lm/W LH204A is a 2x2 array of CSP LED chips that delivers 12V at a 5W-class operating wattage. The 127lm/W LH309A is a 3x3 chip array

offering 26V at a 10W-class operating wattage. Samsung says that the CSP arrays provide high light quality by adhering a single phosphor to the FX (flexible) circuit board on which CSP LED chips with low thermal resistance are arranged. The use of a thin flexible-film FX circuit board accentuates the thin design of the arranged CSP LED chips. The CSP arrays are suitable for spotlighting applications where high light quality is required from a single light source.

## Phosphor-on-Wafer LED package

Samsung says that its Phosphor-on-Wafer (PoW) LED package technology embraces the advantages of CSP LED packaging while overcoming limitations of cost reduction by upgrading the chip manufacturing process through the use of 8-inch GaN-on-Si wafers instead of 4-inch sapphire wafers. The firm says that this transition will enable a higher-quality CSP LED package by eliminating the chip rearrangement process, because the phosphors can be coated directly on the surface of the GaN-on-Si wafers before being diced whereas sapphire wafers have to be cut into chips first and then rearranged to be coated with phosphor. By simplifying the LED component manufacturing process and improving LED package quality, the PoW LED package technology is expected to contribute significantly to the growth of the LED lighting industry. Samsung has already (several years ago) applied its PoW technology to 4-inch wafers in flash LED packages for mobile devices. The firm also plans to utilize the PoW technology for its new CSP product line-up for lighting applications by the end of 2016.

Samsung showcased the new CSP products at the Light + Building 2016 trade fair (under the theme 'Lighting & Beyond') in Frankfurt, Germany (13-18 March).

[www.samsung.com](http://www.samsung.com)

## Seoul Semiconductor claims record efficiency of 210lm/W for Acrich MJT 5630 LED package 220lm/W targeted within a year, reaching DoE's goal for 2020

South Korean LED manufacturer Seoul Semiconductor Co Ltd says that its Acrich MJT 5630D package has achieved record luminous efficiency of 210lm/W for a single LED package, and the package's mass production has begun.

Seoul Semiconductor has provided 5360 LED packages (5.6mm wide x 3.0mm long) for application to the lighting and IT fields. The new MJT 5630D+ LED package's most distinctive characteristic is the upgrade of its luminous efficiency to 210lm/W by using LED chips that incorporate Seoul Semiconductor's multi-junction technology (MJT).

According to the Solid-State Lighting R&D Plan released in May 2015 by the US Department of Energy (DoE), the LED is likely to comprise 40% of the US lighting market (which includes fluorescent lamps and halogen lamps) by 2020. In addition, it is forecasted that by 2030, more than 88% of lighting equipment will be replaced by LEDs.



**LED that achieved record luminous efficiency of 210lm/W.**

The plan projects that, to reach its goals, the luminous efficiency of the lighting appliance needs to achieve at least 200lm/W

**The LED is likely to comprise 40% of the US lighting market by 2020. It is forecasted that by 2030, more than 88% of lighting equipment will be replaced by LEDs**

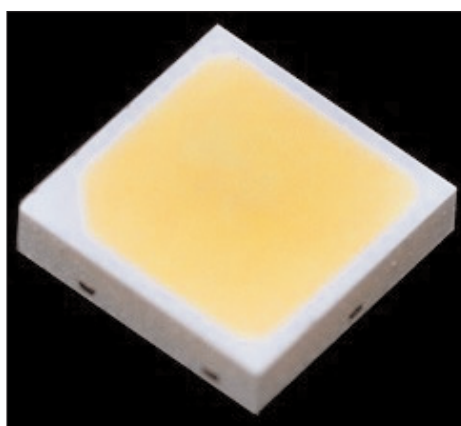
and the luminous efficiency of LED packages needs to be at least 220lm/W. In addition, it suggested a strategy for improving the performance of converters that has lowered the efficiency and life of existing LED lamps and a strategy for extending AC LEDs and high-voltage LEDs as a way to improve the efficiency of LED lighting applications. Seoul Semiconductor says that its Acrich driving technology and Acrich MJT technology are in compliance with the AC and high-voltage technologies described in the report released by the US DOE and are also recognized as the best solution for correcting the current problems of high defect rate and short life of converters. The firm plans to expand Acrich MJT supply.

Seoul Semiconductor's chief technology officer Ki-bum Nam says that the firm aims to further prove its technology by achieving LED package efficiency of 220lm/W (the DOE's target by 2020) within a year. [www.SeoulSemicon.com](http://www.SeoulSemicon.com)

## Toyoda Gosei develops 200lm/W surface-mount 3030-type white LED package for general lighting

Toyoda Gosei Co Ltd of Kiyosu, Aichi Prefecture, Japan has developed a new surface-mount 3030-type white LED package (measuring 3.0mm x 3.0mm x 0.65mm) for general lighting applications (such as bulbs, tubes, downlights and ceiling lights) that produces up to 200 lumens per watt (lm/W), while maintaining color fidelity. The firm says that the new package (combining two blue LED dies with phosphors) offers a cost-effective alternative to fluorescent and lower-CRI (color rendering index) LED products and can help to reduce overall energy consumption.

Toyoda Gosei says that the increase in efficiency (compared



**Toyoda Gosei's new surface-mount 3030-type white LED package.**

with its prior LED package) has been achieved through improvements to both die and package

materials. The package combines high efficiency and low thermal resistance to enhance the performance of the LED, and uses thermo-setting plastics to provide high reliability while maintaining a superior gas barrier, says the company.

Samples of the 200lm/W package (TG White 30 H) will start shipping available in March. Additionally, Toyoda Gosei will launch a 185lm/W package (TG White 30 E, containing one die) that is cost competitive. Mass production will start in April. Further development of an even higher-efficiency package is planned for fall 2016.

[www.toyoda-gosei.com](http://www.toyoda-gosei.com)

## Everlight boosts 5630 high-efficiency LED series to 210–220 lumens per Watt

Taiwan's Everlight Electronics Co Ltd has launched a version of its low-mid-power 5630 package series that attains what is claimed to be record luminous efficiency of 210–220lm/W (at a color temperature of 5000K), as well as a tight 3SDCM ellipse binning for maximum color consistency, suitable for a broad range of professional, commercial and industrial lighting applications. Samples of the 5630 HE KK7D-ELB (0.2W) are available now (for mass production in second-quarter 2016). The existing versions — the 5630 HE KK5D (195lm/W at 5000K) and the 5630 HE KK6D (205lm/W at 5000K) — are already in mass production.

Using thermal plastic materials with high reflection, high lifetime and improved optical structures, the 5630 HE KK7D-ELB LED series



**Everlight's 5630 HE KK7D-ELB series (0.2W) LED, which achieves 210–220lm/W, for professional, commercial and industrial lighting applications.**

has been optimized to obtain high optical efficiency without modifying the circuit and PCB layout compared to previous versions, says Everlight. The number of LEDs

needed (or the power used) can hence be greatly reduced to save energy for the whole application. For example, a 2000lm linear fixture designed using the 210–220 lm/W 5630 HE KK7D-ELB requires

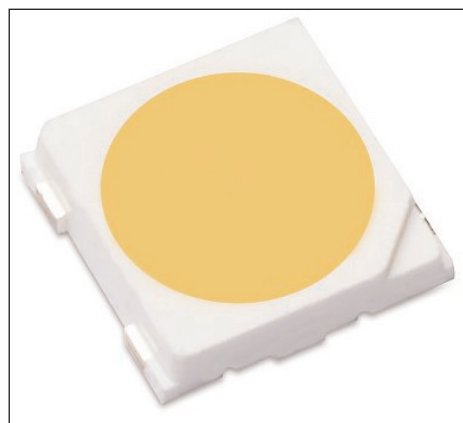
less than 12W of power consumption from the LEDs (a 30–40% energy saving compared with comparable existing LED designs). [www.everlight.com](http://www.everlight.com)

## Lumileds launches 3535 form-factor high-efficiency mid-power LED approaching 200lm/W

Lumileds of San Jose, CA, USA has launched LUXEON 3535L HE Plus in the familiar 3535 form factor, enabling upgrade to a mid-power LED satisfying the need for luminous efficacy approaching 200lm/W at the LED level and 160lm/W or greater at the luminaire level.

"In one of the industry's most popular formats, customers are requiring the highest efficiency with all of the fantastic features delivered by our LUXEON 3535L Line," says Matthew Everett, senior director of LUXEON Mid Power Products.

Lumileds claims that only it has proven reliability for its mid-power LEDs that rivals that of high-power products. For example, LM-80 data for the LUXEON 3535L at a temperature of 85°C and a drive current of 200mA after 10,000 hours indicates that the LEDs will maintain



**Lumileds' LUXEON 3535L HE Plus LED.**

90% of lumen output after seven years of continuous operation (projection using TM-21). Everett also claims a better color over angle with the LUXEON 3535L emitter versus its competitors, enabling better color consistency over the LED's useful life.

Typical performance of the LUXEON 3535L HE Plus at a color temperature of 4000K and color rendering index (CRI) of 80 is 52 lumens at 100mA drive current and 186lm/W luminous efficacy, or 34 lumens at 65mA drive current and 194lm/W. The 3V parts are initially available in color temperatures of 2700K, 4000K and 6500K and 80 CRI. They are tested at 100mA and are 1/7th ANSI color binned.

For maximum design flexibility, the LUXEON 3535L line is offered at four performance levels: entry-level (3535LS), standard (3535L) and high-efficiency (3535L HE, HE Plus). The LUXEON 3535L HE Plus is one of the breakthroughs introduced during Lumileds' Mid Power March series of product launches.

[www.lumileds.com/LUXEON3535L](http://www.lumileds.com/LUXEON3535L)

## Lumileds & BluGlass to co-develop RPCVD-enhanced LEDs

### Continued collaboration to last 6–12 months initially

BluGlass Ltd of Silverwater, Australia has entered into an exclusive collaboration agreement with Lumileds of San Jose, CA, USA (which manufactures and distributes LEDs and automotive lighting products). The two firms will work together to explore potential use of low-temperature remote-plasma chemical vapor deposition (RPCVD) for specific LED applications defined by the agreement (which follows an initial collaboration between the two firms announced last November).

Spun off from the III-nitride department of Macquarie University of Sydney, Australia in 2005, BluGlass developed a low-temperature process using RPCVD to grow materials including gallium nitride (GaN) and indium gallium nitride (InGaN) on glass substrates,

potentially offering cost, throughput and efficiency advantages for the production of LEDs. Based on its RPCVD technology, BluGlass has hence developed patented hardware and processes targeting the production of more efficient semiconductor devices (both LEDs and power electronics) at lower cost.

**Collaboration will not prevent BluGlass from entering into any other agreements concerning RPCVD equipment development, manufacturing or sale and will not restrict the use of RPCVD outside the specific field of use in LEDs**

The initial terms of the collaboration are envisioned to continue for 6–12 months. BluGlass will provide exclusivity of the RPCVD technology (for the specific field of use as stipulated in the agreement) to Lumileds for the period of the collaboration.

The collaboration will not prevent BluGlass from entering into any other agreements concerning RPCVD equipment development, manufacturing or sale and will not restrict the use of RPCVD outside the specific field of use in LEDs. BluGlass is continuing its industry evaluation agreements in other fields of use, including green LEDs, power electronics and RPCVD equipment development.

[www.bluglass.com.au](http://www.bluglass.com.au)  
[www.lumileds.com](http://www.lumileds.com)

## Lumileds launches LUXEON 2835 line of LEDs for cost-effective retrofit lamps, downlights and troffers

LED maker Lumileds of San Jose, CA, USA has introduced the LUXEON 2835 line as an upgrade for an industry-standard LED package.

LUXEON 2835 LEDs is available in five configurations of light output and string voltage and ESD protection for a variety of illumination applications including retrofit lamps, downlights and troffers.

"The LED retrofit bulb and other application segments are taking off right now. We decided to optimize for each application requirement via different offerings within the LUXEON 2835 Line," says Matthew Everett, senior director of Mid Power Products.

To cater to the market, the LUXEON 2835 is offered in two light output ranges: 2835C for higher efficacy and what is claimed to be an industry-leading 240mA maximum drive current with 3V and 6V options; and 2835E for the most cost-effective retrofit lamp designs with 6V and 9V options.



**Lumileds' new LUXEON 2835 LED.**

Lumileds says that manufacturers of low-cost retrofit bulbs targeting soft white (2700K, 80 CRI) can benefit from the 2835E 9V, which produces 72lm at 134lm/W when driven at 60mA. For entry-level bulbs, a lighting manufacturer might choose the 2835E 6V, which produces 49lm with the same luminous efficacy. Dimmable bulbs, LED candles and downlight manufacturers might choose the 2835C 6V, which produces 103lm at 138lm/W in 2700K and 80 CRI

when driven at 120mA. Lumileds says that a key advantage of all LUXEON 2835 LEDs is their ability to be driven at double these reference drive currents to achieve even higher flux and use fewer LEDs per bulb.

For designers of mid-range troffers, linear fixtures and downlights, the 2835C 3V is available in two versions, one with a TVS (Zener) and one without. The 2835C 3V LED without TVS produces 58lm at 156lm/W in 4000K and 80 CRI when driven at 120mA.

The LUXEON 2835 Line is offered across a correlated color temperature (CCT) range of 2700–6500K at 70 and 80 CRI. All LUXEON 2835 6V and 9V LEDs are hot-color targeted to ensure that the color remains within ANSI bin specifications at typical application conditions. Micro color binning allows users to easily create 3-, 4- or 5-step MacAdam Ellipse kits.

[www.lumileds.com/LUXEON2835](http://www.lumileds.com/LUXEON2835)

## Lumileds launches LUXEON XR-3020 ultra-slim module to speed indoor area lighting design

LED maker Lumileds of San Jose, CA, USA has launched the LUXEON XR-3020, an ultra-slim module that serves as a building block for TLEDs or thin office and industrial fixtures.

As the latest addition to the Matrix Platform family of infinitely configurable LED boards, linear flex strips and modules, the slim (20mm) products are available with 24 LEDs on a 280mm thermally conductive board (~1ft) or 48 LEDs on a 560mm board (~2ft). The modules provide 1100lm or 2200lm, respectively, at 160lm/W luminous efficacy and 100mA drive current per LED, with a board temperature of 45°C.

"Common indoor area lighting applications such as troffers or TLEDs benefit from drop-in solutions that enable rapid luminaire assembly," says Lumileds Matrix Platform product manager Andrew Cohen.

**Lumileds' LUXEON XR-3020 1ft (24-LED) and 2ft. (48-LED) modules**



The turnkey nature of LUXEON XR-3020 minimizes time to market and simplifies the supply chain by reducing optical and mechanical design efforts, says the firm. The LUXEON 3020 LEDs used on the modules can be driven at a maximum drive current of 240mA (the highest in the industry for mid-power LEDs, it is claimed) and have passed 50,000 hours of LM-80 testing. The modules also have a five-year warranty.

The XR-3020 is available in color temperatures of 3000–5000K at a color rendering index (CRI) of 80

and at 4000K at 90 CRI.

Up to 10 of the 280mm modules can be connected in series or 16 modules connected in parallel, utilizing the four poke-in connectors per board (driven at 200mA). For the 560mm modules, up to 10 modules can be connected in series or 8 modules connected in parallel (driven at 400mA). Each board is also capable of high-current operation (480mA and 960mA, respectively). The XR-3020 module uses a Super CEM3 PCB (composite epoxy material), enabling superior mechanical robustness and maximum heat dissipation.

Lumileds' Matrix Platform includes off-the-shelf and built-to-spec options, enabling a virtually limitless range of solutions for any lighting application, says the firm.

[www.lumileds.com/XR3020](http://www.lumileds.com/XR3020)

## Luminus launches third-generation chip-on-board LEDs with up to 170lm/W efficacy

Luminus Inc of Sunnyvale, CA, USA, which makes LEDs and solid-state light sources, has launched a third-generation family of chip-on-board (COB) LED arrays with what is claimed to be record luminous efficacy and quality of light. The new product family has typical performance of 150 lumens per Watt efficacy at a correlated color temperature (CCT) of 3000K, color rendering index (CRI) of 80+ and junction temperature  $T_j$  of 85°C for use in indoor applications and 170 lumens per Watt at 6500K, 70CRI, 85°C for outdoor applications.

Luminus claims that, with this third-generation launch, it has eclipsed its major competitors who have recently announced their own new generations of COBs with lower performance. The new COBs deliver up to 20% higher efficacy than previous second-generation products by leveraging the firm's



**Luminus' third-generation of chip-on-board LED.**

latest high-performance packaging technology and premium chips made by Luminus' parent company San'an. With volume production starting in May, Luminus will offer its full range of CCT and CRI combinations, including the 95+ CRI Accuwhite and Sensus below-black-body products.

"We have accelerated our COB performance roadmaps to deliver industry-leading efficacy, which enables customers to build new luminaires and retrofit bulbs with higher CRI, more flux, and lower thermal loads," says senior product marketing director David Davito.

The third-generation COB family is available in a wide range of CCT and CRI combinations, and light-emitting surface diameters including 9mm, 11mm, 14mm, 18mm, 22mm and 27mm. As with all Luminus COB products, the third-generation family is 100% specified and tested at 85°C to guarantee hot performance in both indoor and outdoor applications.

Luminus exhibited its third-generation COBs and other new illumination light sources at the Light+Building 2016 trade fair in Frankfurt, Germany (13–18 March).

[www.luminus.com](http://www.luminus.com)

## XLamp CXA2 high-density LEDs double lumen output

Cree Inc of Durham, NC, USA has launched the XLamp CXB1310 and CXB1520 high-density LED arrays. Incorporating elements of the firm's SC5 Technology Platform, the new LEDs deliver the highest lumen density at 6mm and 9mm — which is claimed to be the most lumens in the industry for their LES [light-emitting surface] sizes. The advance enables new LED lighting form factors for applications such as track lights, lamps and down-lights, says the firm. For example, the CXB1520 LED packs the lumen output of seven 60W-replacement lamps into an area much smaller than a dime, allowing lighting manufacturers to put more light where it is intended at a lower system cost.

The high performance of the CXA2 high-density LED arrays allow lighting manufacturers to reduce thermal, mechanical and optical costs at the system level. For example, when combined with a 74mm-diameter optic, the 3000K, 80CRI CXB1520 high-density LED array delivers over 50,000 candela in a 10° beam while drawing only



**Cree's CXA2 high-density LED array.**

40W. This high lumen density allows lighting manufacturers to deliver the performance of a 70W ceramic metal halide (CMH) PAR38 lamp through a much smaller PAR20-size optic using 43% less power. The CXB1310 high-density

**CXA2 high-density LED arrays are available in the same form factor as the CXA LED arrays**

LED array delivers up to 3200 lumens in a 6mm LES, allowing similar reductions in size and power from traditional light sources.

Offering what is claimed to be the industry's best color consistency for designs that use only one LED, XLamp CXA2 high-density LED arrays are characterized and binned at 85°C, available in 2-, 3- and 5-step EasyWhite color temperatures (2700–6500K) and correlated color temperature (CRI) options of 70, 80 and 90. The CXB1310 and CXB1520 LEDs have LM-80 long-term test data available immediately, delivering reported L90 lifetime projections of at least 36,300 hours at 85°C and 105°C.

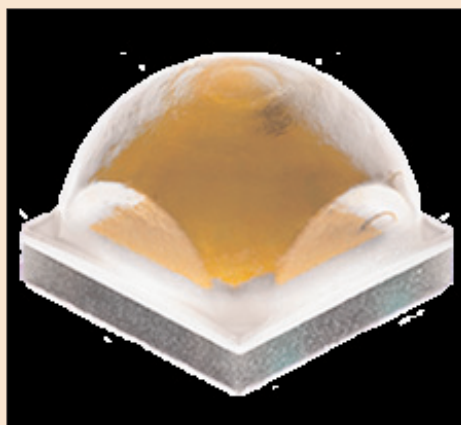
The CXA2 high-density LED arrays are available in the same form factor as the CXA LED arrays, allowing the use of existing optics, holders and drivers. The CXA2 high-density LED arrays are also UL-recognized and feature a level 4 rating. Product samples are available now, and production quantities are available with standard lead times.

[www.cree.com/cxa2](http://www.cree.com/cxa2)

## Cree boosts output of XLamp XP LEDs by 9%

LED chip, lamp and lighting maker Cree Inc of Durham, NC, USA says that, by leveraging key elements of its SC5 Technology Platform, its high-power XLamp XP-L and XP-G2 LEDs now provide up to 9% more lumens and lumens-per-watt (LPW) than previously available. The firm says that the enhancements allow lighting manufacturers to quickly increase performance for existing designs without any additional investment or re-qualification.

"We originally selected the XP-G2 LED for our street-lighting products because of its high performance and proven reliability," comments Dante Cariboni, CEO of Italy-based firm Fivep SpA (Cariboni Group). "The brighter and more efficient XP-G2 LED announced today will



**Cree's XLamp XP-L LED.**

allow us to improve the performance of our products without changing the design," he adds.

"The higher-performing XPL and XPG2 LEDs are examples of how Cree delivers innovation that our customers can use immediately to

improve existing designs," says Dave Emerson, VP & general manager for Cree LEDs.

Sharing the same 3.45mm x 3.45mm footprint as the industry-standard XP platform, the XP-L LED delivers up to 1150 lumens, while the XP-G2 LED delivers up to 586 lumens, both at 85°C. Reflecting the long-term reliability of the XLamp XP platform, both the XP-L and XP-G2 LEDs have 10,000 hours of LM-80 data available at 105°C, delivering reported L90 lifetimes of greater than 36,000 hrs (less than 10% light loss after four years).

Product samples are available now and production quantities are available with standard lead times.

[www.cree.com/SC5](http://www.cree.com/SC5)

[www.cree.com/xlamp](http://www.cree.com/xlamp)





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# Osram introduces first 10° binning for white LEDs

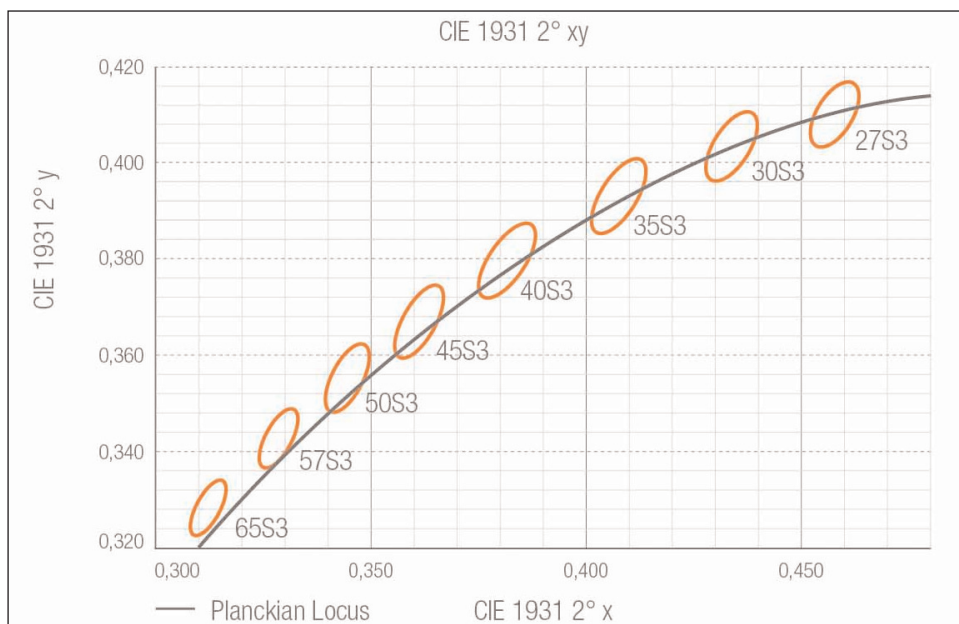
Osram Opto Semiconductors GmbH of Regensburg, Germany says that its new TEN° binning provides the basis for what is claimed to be unprecedented color consistency for white LEDs, used for example as single-LED light sources in spotlights and downlights. To achieve this, the existing standard CIE 1931 2° xy color space has been supplemented with CIE 2015 10° u'v', recently developed by the International Commission on Illumination and implemented by Osram Opto as 10° binning. TEN° is available on the market in the firm's third generation of Soleriq S 13 LEDs as an additional feature from March.

Osram says that its new TEN° binning is differentiated from the established CIE 1931 2° color space in that it corresponds much better to the physiological perception of color, hence 10° binning. This is of interest for achieving uniform illumination from spotlights and downlights in which individual white chip-on-board (CoB) LEDs are primarily used. TEN° will first be used in the new generation of the Soleriq S 13 and will provide optimum color consistency in applications.

"Soleriq LEDs comply with current industry standards and remain completely compatible with existing white groupings," notes Alexander Wilm, key expert for General Lighting at Osram Opto. "TEN° binning is simply an additional property — and an extremely useful one," he adds.

When Soleriq LEDs that have been binned on the basis of these latest findings are installed in spotlights for example, it will be much easier to avoid differences in light colors compared with products grouped according to the old CIE 1931 2° standard, says Osram Opto. This results in fewer process stages for luminaire manufacturers which would otherwise be necessary due to different white color impressions in the ultimate application.

Osram noticed that two LEDs with the same color coordinates in the CIE 1931 2° color space could still

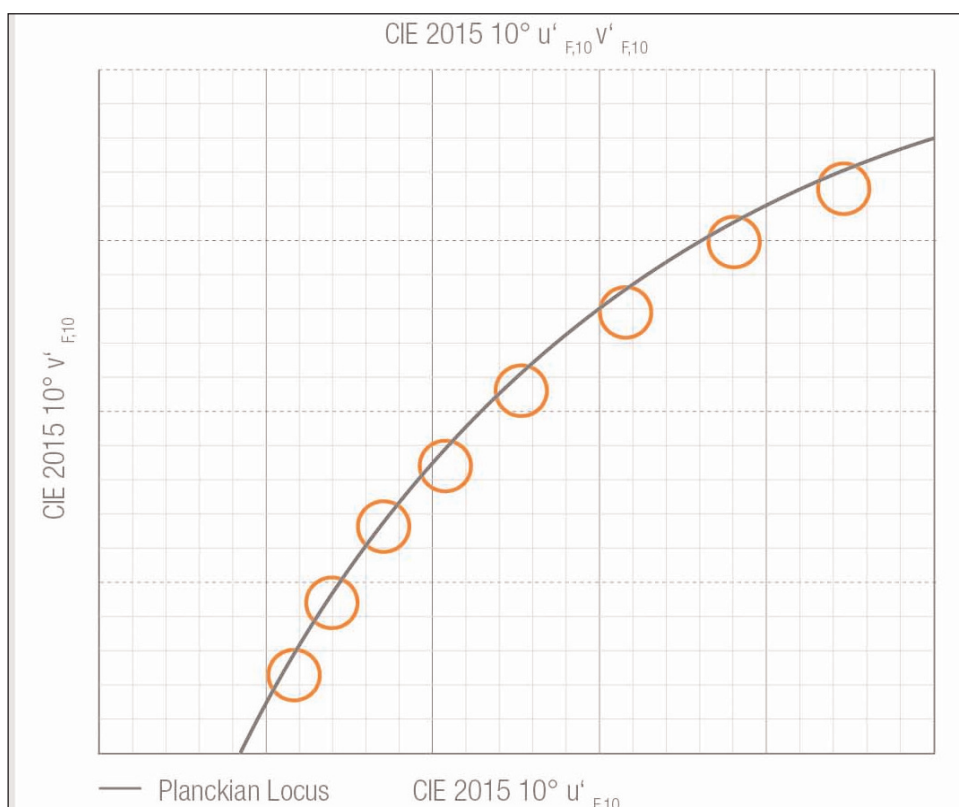


Standard three SDCM binning in the CIE 1931 2° xy color space.

exhibit noticeably different white tones, which resulted in the starting point for development activities to overcome this issue. One reason is for the difference is that the small rods responsible for color perception in the human eye are not evenly distributed, leading to different color perceptions even

with LEDs in one SDCM binning with conventional metrics. This problem has been known and researched by scientists for many decades, but the results of their research have never been applied to general lighting. Osram says it has now changed that.

[www.osram-os.com/tenbinning](http://www.osram-os.com/tenbinning)



TEN° binning in the 2015 10° u'v' color space.

# Osram's new Duris P 10 LED provides 1100lm and thermal benefits, cutting system cost by up to 50%

At the Light + Building 2016 trade fair in Frankfurt, Germany (13–18 March), Osram Opto Semiconductors GmbH of Regensburg, Germany is unveiling its Duris P 10 LED, suitable for use in professional outdoor lighting systems. Offering typical luminous flux of 1100 lumen (at a color temperature of 5000K) from a robust, lead-frame-based, high-performance package, the Duris P 10 can enable up to 50% lower system costs, it is reckoned, while also delivering second board reliability, ensuring long-term operation even in fluctuating ambient temperatures.

The Duris P 10 contains four 2mm<sup>2</sup> UX:3 chips, which are also used in the Oslon family of LEDs. Compared with similarly sized ceramic packages, the lead-frame technology combines improved thermal properties with what is claimed to be excellent second board reliability. Whereas fluctuations in temperature may cause mechanical stress at the solder connections, lead-frame packages can be optimized in terms of their thermal behavior and their second board reliability.



Osram Opto's new Duris P 10 LED.

Measuring a compact 7mm x 7mm, the Duris P 10 package simplifies luminaire design and reduces the space needed for the printed-circuit board and luminaire housing, requiring less material overall. The high lumen value reduces the number of secondary optics needed. By streamlining the handling of the luminaire in production, system costs can be reduced by as much as 50%, it is claimed. With Duris P 10, users benefit from optimized heat removal through the lead frame compared with similarly sized LEDs with ceramic packages. The copper core of the lead frame ensures optimal heat removal and more efficient operation of the luminaire in the chosen application if the

same cooling system is used, or savings in the cooling system for the same luminaire efficiency.

"We are able to deliver these product benefits thanks to our automotive expertise," says system expert Dr Ralph Bertram. "In developing different LEDs for headlights, we gained extensive experience in package technology and high-current chips. With our experience in LED mass production, we developed the new Duris P 10, an extremely powerful and cost-effective product for general lighting."

All of the materials used in the new LED are extremely robust, says Osram Opto, and are suitable for outdoor applications or use in corrosive atmospheres. The main applications are street lighting, tunnel lighting and high-bay and low-bay LED lighting systems in industrial buildings.

The Duris P 10 is available now along with its new sister LED, the Duris P 8, which has smaller package dimensions and a luminous flux of 290lm. Within a year, the Duris P 9 (with a luminous flux of 450lm) will also be launched.

[www.osram-os.com/duris](http://www.osram-os.com/duris)

## Nanoceramics for high-power packaged LEDs

At the Strategies in Light show in Santa Clara, CA, USA (1–3 March), Dr Giles Humpston, applications engineer at Cambridge Nanotherm Ltd of Haverhill, Suffolk UK, outlined how thermal management technology can help LED designers square the circle of performance-to-price in his presentation 'Using Nanoceramic to enhance the performance of LED subsystems at reduced cost'.

As LEDs continue to transition into the general lighting market, high-power packaged LEDs are becoming ubiquitous. High-power LEDs are typically >1W in a small (10mm<sup>2</sup>) footprint, notes the firm. At best, only 45% of the electrons put into

the device will be converted into visible photons — the other 55% will be converted into heat. This is the problem: How to get the heat out of the packaged LED as quickly, and cost effectively, as possible?

Until now electronics-grade ceramics, in particular cost-effective alumina (Al<sub>2</sub>O<sub>3</sub>), have been used as a substrate in high-power LEDs. Where Al<sub>2</sub>O<sub>3</sub> falls down is in its thermal performance — at about 20W/mK it's a poor performer, says the firm. For the more exotic aluminium nitride (AlN) this is 160–200W/mK; good thermal performance but costly. What is needed is a solution that offers good enough thermal per-

formance with a price tag that is more palatable than AlN.

Humpston demonstrated how a patented process to convert the surface of standard aluminium into an ultra-thin layer of nanoceramic, finished with a fully inorganic sputtered copper wiring trace, is a suitable material for the high-power packaged LED industry.

Falling right in the thermal sweet-spot of 152W/mK with a price tag sitting between Al<sub>2</sub>O<sub>3</sub> and AlN, nanoceramics open up a new class of material, says the firm, aided by ease of manufacture, filled copper vias and economies of scale.

[www.camnano.com](http://www.camnano.com)

## VerLASE extends patent portfolio in 2D semiconductor materials for light sources

VerLASE Technologies LLC of Bridgewater, NJ, USA (a spin-off from technology development firm Versatilis LLC of Shelburne, VT, USA) says that the US Patent Office has issued US Patent No. 9,269,854, a fundamental patent covering the use of two-dimensional (2D) semiconductor materials as the active, light-emitting layer in LEDs, laser diodes and other optoelectronic devices.

The technology enables low-cost, novel electroluminescent devices, which can be tailored to directly emit in any color in the visible, or in a mixed combination for white light at a desired color temperature, without phosphors or other color-converting media. Such devices can be made entirely of inorganic materials using existing, often depreciated silicon foundries, or even made using liquid chemistry with well accepted, scalable techniques.

VerLASE says that the technology, which can also be hybridized with some organic layers, challenges organic light-emitting diodes (OLEDs) in applications requiring smaller pixel sizes, such as micro-displays for augmented and virtual reality applications, where OLEDs have had extreme difficulty in achieving small pixels with sufficient brightness. Other applications include smaller displays of all kinds, ranging from wearables to smartphone and tablet screens, offering a practical

way around some of the technical and cost hurdles pacing broader adoption of OLEDs.

Semiconducting 2D materials like graphene have captured a much attention for their potential use in multiple applications. Such materials can be grown in crystalline layers that are weakly bound to each other (like sheets in a ream of paper) and can be readily cleaved or exfoliated into extremely thin layers. The firm has been investigating using photoluminescent quantum wells (QWs) made from nano-platelets (NPLs) of 2D materials (such as gallium selenide, gallium sulphide and tungsten disulphide) as highly efficient down-converting phosphors that can also be free of cadmium or other heavy metals.

VerLASE had previously secured a broad patent (US 9,035,344) covering the use of such 2D semiconductor materials as phosphors, analogous to quantum dots (QDs) but in a 'flat' or 2D aspect. The new patent extends this work to cover use of such 2D materials as electroluminescent layers in active devices, solidifying the firm's IP portfolio in 2D materials.

QDs were originally envisioned as being disruptive in a similar way for electroluminescent devices, but have so far been used successfully mainly as remote phosphors in LCD displays for modifying backlighting color. They face numerous challenges in

expanding their applications range, particularly to active layers, and the best QD materials to date typically contain cadmium.

At the same time, an emerging body of research around the world points to the inherent advantages of 2D semiconductor materials for a wide range of applications. They offer similar optical advantages as QDs with narrow spectral characteristics, better colors and color saturation, but with better efficiency and much better thermal characteristics for superior stability in many lighting, projector and display applications, says VerLASE.

It can also be easier to work with 2D semiconductor materials in depositing the other layers needed to make active devices, the firm adds. VerLASE is in the process of showing simple, working prototypes of such electroluminescent devices, thinning down the active 2D layer to demonstrate direct red, green and blue emission.

"The unique attributes of 2D QWs can enable the original QD vision of inorganic electroluminescent devices," believes chief technical officer Ajay Jain (inventor of the technology), adding that the same basic 2D semiconductor materials can also be used as gain media for lasers and other high-value electro-optical devices.

[www.verlase.com](http://www.verlase.com)  
[www.versatilis.com](http://www.versatilis.com)

## Cree complements lighting product portfolio with new commercial brand Essentia by Cree

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has announced 'Essentia by Cree' as a new brand of commercial lighting products offering a 90+ LPW (lumens per Watt) and correlated color temperatures (CCTs) between 2700K and 5000K. The new brand complements Cree-branded lighting products.

The Essentia by Cree lighting portfolio is engineered to provide outstanding performance for new construction and renovation applications and comes with a five-year limited warranty. Available from March, the new product categories in the portfolio are targeted to include track lighting, downlights, exit and emergency lighting,

flat-panel troffers, and outdoor flood and area lighting.

"Powered by Cree LEDs, this new product portfolio ensures that our customers have a complete line of products available from Cree with superior value and ROI," says Norbert Hiller, executive VP of lighting at Cree.

[www.cree.com](http://www.cree.com)

## SoraaLaser presents visible laser light source technology for specialty lighting

At the Strategies in Light conference in Santa Clara, CA, USA (1-3 March), SoraaLaser of Goleta, CA, USA (which is commercializing visible laser light sources for display, automotive and specialty applications) presented its light source technology, featuring what are claimed to be unique performance properties such as collimated output and waveguide delivery and providing advantages over LED, OLED and legacy sources in specialty lighting.

SoraaLaser is an independent spin-off from Soraa Inc of Fremont, CA, USA — which develops solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates — and was co-founded by the 2014 Nobel Laureate in Physics professor Shuji Nakamura and professor Steve Denbaars. "Laser diodes are droop-free, and can be combined with phosphors to safely produce highly directional output with superior delivered lumens per watt compared to other light sources," says Nakamura.

SoraaLaser's visible laser light sources are based on its proprietary and patented semi-polar GaN laser diodes, combined with phosphor technology. The laser light sources provide novel properties compared with other light sources by combining the benefits of solid-state illumination (such as minimal power consumption and long lifetime) with the highly directional output that has been possible only with legacy technology.

Because the laser light is focused to a small spot on the phosphor and converted to white light, SoraaLaser says that its light sources enable safe, highly collimated white light output, superior optical control with miniature optics and reflectors, along with high-efficiency fiber-optic transport and glare-free waveguide delivery. These features are suitable for specialty lighting applications

including architectural, hospitality, retail, security, entertainment, and automotive, says the firm.

At Strategies in Light, SoraaLaser presented during the 'Quality of Light' Workshop as well as a Seminar on laser-phosphor sources.

Also at Strategies in Light, the firm exhibited its laser light sources, including fiber-optic and direct-emitting white and blue laser modules.

[www.soraalaser.com](http://www.soraalaser.com)  
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# IRT Nanoelec project integrates III-V laser directly on silicon with Mach–Zehnder modulator

## 25Gbps transmission achieved over 10km single-mode fiber

Nanoelec Research Technological Institute (IRT) in Grenoble, France — an R&D consortium headed by CEA-Leti focused on information & communication technologies (ICT) using micro- and nanoelectronics — has announced the first co-integration of a III-V/silicon laser and silicon Mach–Zehnder modulator demonstrating 25Gbps transmission on a single channel. This transmission rate usually is achieved using an external source, over a 10km single-mode fiber (SMF).

Existing interconnect technologies, which use micro-optics integration to assemble a discrete laser and a silicon photonic circuit, will soon reach their limits and new solutions must be found to handle increasing traffic.

Integrating photonics capabilities on silicon chips is replacing currently established technologies,

vastly increasing bandwidth, density and reliability, while dramatically reducing energy consumption. In the age of photonics-on-silicon, data transmission will be measured in terabits per second.

“Jointly obtained by STMicroelectronics and Leti in the frame of the IRT Nanoelec cooperation, these results — especially fabricating the laser directly on silicon — demonstrate IRT Nanoelec’s world-wide leadership in III/V-on-silicon integration to achieve high-data-rate fiber-optic modules,” says the project manager Stéphane Bernabé. “IRT Nanoelec and its partners on this project — Leti, STMicroelectronics, Samtec and Mentor Graphics — are paving the way to integrating this technology in next-generation transceivers for optical data links,” Bernabé continues.

To achieve the recent results, silicon photonics circuits integrating the modulator were processed first on a 200mm silicon-on-insulator (SOI) wafer, although 300mm wafers also could be used in the near future. Then, a 2-inch wafer of III-V material was directly bonded on the wafer. In the third step, the hybrid wafer was processed using conventional semiconductor and/or MEMS process steps to produce an integrated modulator-and-laser transmitter.

IRT Nanoelec launched its silicon photonics program in 2012, with core members Mentor Graphics, STMicroelectronics and CNRS. The program brings together, under one roof, the expertise and equipment needed to address the entire photonics-on-silicon value chain.

[www.irtnanoelec.fr/photronics-on-silicon](http://www.irtnanoelec.fr/photronics-on-silicon)

# POET and A\*STAR’s IMRE to jointly develop smart pixels for augmented reality applications

## New 18-month project to enhance POET’s GaAs process and develop GaN epi growth for integrated optoelectronic light engines

POET Technologies Inc of San Jose, CA, USA — which 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 announced a research and development initiative for future generations of smart pixels and other applications in association with the Institute of Materials Research and Engineering (IMRE), a part of the Singapore-based Agency for Science, Technology and Research (A\*STAR).

Jointly funded by POET and IMRE, the 18-month project is designed in part to adapt the POET platform to

potential applications in smart pixel technology for the burgeoning augmented reality market.

Additional aspects of the new initiative include enhancing POET’s gallium arsenide (GaAs) process technology platform, as well as R&D on novel gallium nitride (GaN) epitaxial growth technologies to potentially support integrated optoelectronic light engines for the smart lighting market.

With this initiative, POET expects to expand its intellectual property (IP) portfolio and roadmap, and to enrich its III-V applications suite. The firm will have joint ownership of any developed IP with IMRE, with a right of first refusal related to

exclusive rights to any IP that is developed.

“We are gratified to be partnering with an esteemed global leader like IMRE in advancing our disruptive and enabling process technology,” says POET’s CEO Dr Suresh Venkatesan. “The unique aspect of the POET process platform is its versatility in supporting multiple applications,” he adds. “This joint initiative is also significant as a great stride toward developing alternate applications and developing the POET roadmap beyond the inaugural addressable market of data communications.”

[www.imre.a-star.edu.sg](http://www.imre.a-star.edu.sg)  
[www.poet-technologies.com](http://www.poet-technologies.com)

# WIN Semiconductors launching foundry services for optical device manufacturing

**New 2–4” InP epi growth, device processing and test services due for full release by Q4/2016 to support high-data-rate applications**

WIN Semiconductors Corp of Tao Yuan City, Taiwan — the largest pure-play provider of compound semiconductor wafer foundry services — has announced its entry into the high-data-rate optical device market by adding optical device production capabilities to its broad gallium arsenide (GaAs) and gallium nitride (GaN) technology portfolio.

The new foundry services provide flexible, large-scale manufacturing of a variety of complex laser and photodiode designs for 2.5G, 10G and 25G data rates. This vertical production capability provides customizable manufacturing services

including epitaxial growth/re-growth, material and device characterization as well as full device fabrication and testing. **Flexible epi growth and optical device manufacturing will accommodate InP substrates from 2-inch to 4-inch diameter**

WIN's flexible epitaxial growth and optical device manufacturing will accommodate indium phosphide (InP) substrates from 2-inch to 4-inch diameter.

Epitaxial growth/characterization services for lasers and photodiodes are now in place, and installation/

development of a complete optical device fabrication line is underway and scheduled for full release by fourth-quarter 2016. WIN says that the vertically integrated device capability will provide the optical market with access to its manufacturing scale, production efficiency and technology expertise.

WIN attended the Optical Fiber Communications Conference (OFC 2016) in Anaheim, CA, USA (20–25 March), where its technologists and sales representatives provided full details of the firm's new optical device wafer foundry services.

[www.winfoundry.com](http://www.winfoundry.com)

## GigOptix announces \$5m investment from Shanghai Pudong Science and Technology Investment Proceeds to fund additional strategic growth opportunities

Shanghai Pudong Science and Technology Investment Co Ltd (PDSTI) and its affiliate are to invest about \$5m in GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks).

PDSTI will purchase 1,754,385 unregistered shares of common

stock at a price of \$2.85 per share (a premium of about 17% to GigOptix's average trading price over the prior 30 days). Immediately following the closing of the investment, PDSTI will hold about 3.77% of GigOptix's issued and outstanding common stock.

Proceeds from the investment will go towards providing financial flexi-

bility and pursuing additional strategic growth opportunities.

"We welcome PDSTI as a new investor to GigOptix, as we continue to grow our core high-speed enterprise communications and cloud connectivity business," says GigOptix's founder, chairman & CEO Dr Avi Katz.

[www.gigoptix.com](http://www.gigoptix.com)

## GigOptix signs Avnet as distributor for China

GigOptix has signed global technology distributor Avnet Inc as distributor for all its product lines sales in China.

GigOptix says that establishing the partnership with Avnet enhances its already solid business in the Chinese Enterprise and Cloud connectivity markets, and supports the anticipated rapid growth in business over the next few years.

"Adding GigOptix to our line-card

will enable us to offer better and cost-effective customer-focused solutions to reach a larger customer base in China," says Frederick Fu, regional president, Avnet Electronics Marketing China. "Avnet's comprehensive portfolio of products and breadth of capabilities combined with GigOptix's expertise, in particular on applications in Enterprise and Cloud connectivity, will allow us to capitalize on the

growth opportunities in the China market," he adds.

"Their strong presence will enable us to expand our current market reach and will provide the breadth of expertise that enables us to address new market segments," says Dr Raluca Dinu, GigOptix's executive VP global customer operations, about Avnet.

[www.avnet.com](http://www.avnet.com)  
[www.gigoptix.com](http://www.gigoptix.com)

## II-VI Inc completes acquisition of Anadigics

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has completed its acquisition of broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA for about \$78.2m (\$0.85 per share in cash). The purchase price was funded primarily from the firm's existing capacity under its credit facility.

As a result of the merger, Anadigics has become a subsidiary of II-VI, with its common stock being delisted and ceasing trading on Nasdaq.

Also, II-VI's outlook for fiscal third-quarter 2016 (issued on 26 January) has now been raised, from revenue of \$185–195m to \$190–198m. Adjusted earnings per share (EPS) is expected to be \$0.26–0.29 (inside the original guidance range of \$0.25–0.29).

The results exclude one-time items, but do include the results of operations for two months of EpiWorks Inc of Champaign-Urbana, IL, USA (which manufactures epitaxial wafers for optical components, wireless devices and high-speed

communication applications) — acquired on 1 February — and the results of Anadigics for 15–31 March. One-time items are expected to be \$0.05–0.06 per share and include investment banking and legal fees and one-time expense for fair value inventory adjustments. EPS on a reported basis is now expected to be \$0.21–0.23.

II-VI has begun its evaluation of assets and integration with the leadership teams of EpiWorks and Anadigics. This work is expected to give rise to additional one-time costs.

### II-VI Inc ramps volume production of low-noise optical amplifiers with integrated tunable filters for 400Gb/s DWDM transponders

II-VI Inc is ramping up shipments of low-noise optical amplifiers with integrated tunable filters for 400Gb/s DWDM transponders.

High-bit-rate DWDM transponders enable interconnectivity among geographically dispersed data-centers. II-VI's low-noise optical amplifiers improve the reach of 400Gb/s DWDM transponders by boosting the optical power of the transmitted signal with high fidelity due to an integrated wavelength-tunable optical noise filter.

"Our optical amplifier technology platform with integrated tunable

filter (announced in early 2015) generated strong market demand," says Dr Sanjai Parthasarathi, VP product marketing & strategy, Optical Communications Group. "We are now ramping up production of our low-noise optical amplifier module designed for 400Gb/s DWDM transponder line-cards."

Higher transmission rates increase the difficulty of distinguishing optical signal from noise at the receiver. Tunable optical filters improve 400Gb/s transmission by filtering out amplified spontaneous emission (ASE), which is the

most significant contributor of optical noise.

II-VI designs and manufactures in-house a complete portfolio of miniature hybrid micro-optics, tunable optical components and 980nm pump lasers to achieve vertically integrated optical amplifier solutions. Low-noise optical amplifiers are Telcordia qualified at the individual component level and as a module. They are commercially available as a full assembly or in various sub-assembly configurations.

[www.ii-vi-photonics.com](http://www.ii-vi-photonics.com)

## II-VI Inc presents new laser modules at Photonics West

At SPIE Photonics West 2016 in San Francisco (16–18 February), engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA presented a broad portfolio of products from several of its business divisions, showcasing new products and services.

In particular, the subsidiary II-VI Laser Enterprise GmbH of Zurich, Switzerland showcased a higher-power 1060nm single-mode laser diode seed module and a new line of high-power multi-bar stack laser diode modules. The new 1060nm laser diode seed module delivers

kink-free powers of up to 1.5W in nanosecond pulse operation enabling fiber-laser systems with highly efficient pulse amplification and improved frequency conversions. The expanded portfolio of high-power multi-bar stack laser diode modules includes a new series of tap-water-cooled stacks for medical, pumping and defense applications.

In addition, subsidiary II-VI Suwtech of Shanghai, China highlighted its new 808nm fiber-coupled diode laser module, which offers output powers from 15W up to 30W. The module is a single-

emitter cascaded generic design that allows higher output powers with increased wall-plug efficiency and simplified thermal management.

Finally, II-VI Photop of Fuzhou, China showcased a new 5kW laser combiner and new acousto-optic modulators. The laser combiner is available in configurations ranging from 3x1 to 31x1 and is capable of handling pump laser powers of up to 300W to achieve power levels exceeding 5kW. The acousto-optic modulators are designed for pulsed fiber lasers operating at 1µm wavelength.

<http://spie.org/photonics-west.xml>





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## US curbs exports to China's ZTE for violating Iran controls US adds ZTE to list of companies acting contrary to national security or foreign policy interests

The US Department of Commerce has added China's Zhongxing Telecommunications Equipment Corp (ZTE), its affiliates ZTE Kangxun Telecommunications Ltd and Beijing 8-Star, and Iranian firm ZTE Parsian to a list of entities "acting contrary to the national security or foreign policy interests of the United States" under Export Administration Regulations, with immediate effect [[www.federalregister.gov/articles/2016/03/08/2016-05104/additions-to-the-entity-list](http://www.federalregister.gov/articles/2016/03/08/2016-05104/additions-to-the-entity-list)].

"Specifically, the ZTE Corporation document 'Report Regarding Comprehensive Reorganization and Standardization of the Company Export Control Related Matters' (available at [www.bis.doc.gov](http://www.bis.doc.gov)) indicates that ZTE Corporation has re-exported controlled items to sanctioned countries contrary to United States law," reports Kevin J. Wolf, Assistant Secretary for Export Administration, in the Federal Register 'Daily Journal of the United States Government'. "The ZTE Corporation document 'Proposal for Import and Export Control Risk Avoidance' (available at [www.bis.doc.gov](http://www.bis.doc.gov)) describes how ZTE Corporation also planned and organized a scheme to establish, control, and use a series of 'detached' (i.e. shell) companies to illicitly

re-export controlled items to Iran in violation of US export control laws," he adds.

ZTE replied to the ruling: "ZTE is fully committed to compliance with the laws and regulations in the jurisdictions in which it operates. ZTE has been cooperating, will continue to cooperate and communicate with all US agencies as required. The company is working expeditiously towards resolution of this issue."

"China is opposed to the US citing domestic laws to place sanctions on Chinese enterprises," comments China's Foreign Ministry spokesperson Hong Lei. "We hope the US stops this erroneous action and avoids damaging Sino-US trade cooperation and bilateral relations [[www.fmprc.gov.cn/mfa\\_eng/xwfw\\_665399/s2510\\_665401/t1345751.shtml](http://www.fmprc.gov.cn/mfa_eng/xwfw_665399/s2510_665401/t1345751.shtml)]."

One company affected by the ruling is Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications), as seen in falls in stock prices. The firm has supplied multi-

ple products to ZTE. Oclaro is currently reviewing the impact of the Department of Commerce action on its ability to continue to ship products to ZTE, adding that it "intends to fully comply with the Department's final rule".

To date, ZTE is projected to comprise more than 10% of Oclaro's revenue in fiscal third-quarter 2016. Oclaro now expects its results to be at the low end of the guidance ranges it provided on 2 February.

Other ZTE suppliers include Intel, Qualcomm, and Texas Instruments. It is thought that the ZTE announcement also affected the stock positions of Lumentum, NeoPhotonics, Fabrinet, Finisar, and telecom analog/mixed-signal chip-maker Inphi.

The ruling will also affect companies that include a significant proportion of US-made components in their products. Export licenses will be needed for US firms to supply ZTE, which in general are expected to be denied. ZTE will continue to be able to sell smartphone handsets in the USA.

ZTE has annual sales of more than \$15bn and has a 7% share in the US smartphone market.

[www.zte.com.cn](http://www.zte.com.cn)

[www.oclaro.com](http://www.oclaro.com)

Author: Mike Cooke

**China is opposed to the US citing domestic laws to place sanctions on Chinese enterprises**

## NeoPhotonics' revenue guidance unaffected by US Department of Commerce ruling on ZTE

NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated optoelectronic modules and subsystems for high-speed communications networks) has issued a statement regarding the US Department of Commerce's publication in the Federal Register of a 'final rule' amending the Export Administration Regulations

that added four entities to the 'Entity List' maintained by the Department of Commerce for actions contrary to the national security and foreign policy interests of the USA. The additions included the following two customers of NeoPhotonics: China's Zhongxing Telecommunications Equipment Corp (ZTE) and its subsidiary ZTE Kangxun Telecommunications Ltd.

NeoPhotonics says that its revenue from ZTE during full-year 2015 was about 1% of its total revenue, and that it does not anticipate materially different revenue from ZTE for first-quarter 2016 or full-year 2016. The firm says that this event has therefore caused no change to the outlook for first-quarter 2016 that it provided on 1 March.

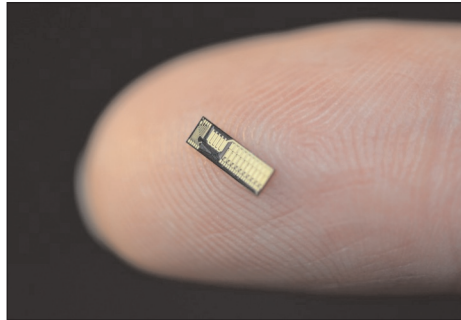
[www.neophotonics.com](http://www.neophotonics.com)

# EFFECT Photonics samples its first optical system-on-chip product family

## Eindhoven spin-off's InP-based photonic integrated circuits target low-cost 100Gbps DWDM over 80km

EFFECT Photonics b.v. — a spin off from the Technical University of Eindhoven (TU/e) in The Netherlands that develops optical components using indium phosphide (InP)-based multi-channel photonic integrated circuits (PICs) for mobile networks and data-centers — is launching its first product family based on its optical system-on-chip (SoC) technology platform (which integrates all the active and passive components of a DWDM system within a single chip, without traditional gold box packaging). The launch is the culmination of 5 years work to bring the technology to market-readiness.

EFFECT Photonics is aiming to address soaring demand for affordable bandwidth between data-centers and back from mobile cell towers by bringing dense wavelength division multiplexing technology to the edges of the network. By using high-integration system-on-chip technology, port density



**EFFECT Photonics' optical SoC.**

can be increased by over six times and operational expenses reduced by 40% compared with existing approaches, the firm reckons.

The product family includes transceivers for the transmission of 100Gbps over 80km targeting the lowest cost and power, together with high-density solutions containing many wavelengths for emerging WDM access markets in front-haul, back-haul and NG-PON2. Industry-standard sockets are supported including CFP and CFP2, so the products can be used

in existing and future systems.

"We could see a bandwidth crunch coming at the edges of the network and knew that DWDM could be the answer, but it had to be done differently, so we developed a holistic solution from the ground up," says CEO James Regan. "We have completely re-thought how to tackle the issues of cost, power and density," he adds. "As well as integrating many optical functions into a single chip, we have reduced the cost and complexity of our packaging, resulting in a commercially viable solution. We are now at the sampling stage," Regan continues.

"100Gbps over 40-80km is a significant market opportunity that has no cost-effective solution today," comments Andrew Schmitt, founder & principal partner at market analyst firm Signal AI. "This is the next battleground for 100G solutions."

[www.ofcconference.org](http://www.ofcconference.org)  
[www.effectphotonics.nl](http://www.effectphotonics.nl)

## MACOM ships PMD chip-set for 100G SR-4 QSFP modules

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) has begun volume shipments of its physical media device (PMD) chip-set for 100Gbps short-reach SR-4 applications. The chip-set includes the MALD-37045, a four-channel 25.78G/28.05G VCSEL driver, and the MATA-37044, a transimpedance amplifier (TIA)/limiting amplifier, both with integrated clock & data recovery (CDR) functionality. The devices offer ultra-low power consumption, making them suitable for small-form-factor applications, says MACOM.

The integrated CDR functionality provides improved jitter performance and lower power compared with discrete chip-sets. Targeted for QSFP module applications, the devices feature direct, DC-coupled wire-bonding to vertical-cavity surface-emitting lasers (VCSELs) and photodetectors. Together, the devices offer a complete one-stop solution for 100Gbps QSFP optical modules, active optical cables (AOCs) and on-board optical engines for Ethernet and InfiniBand applications.

"The MALD-37045 and MATA-37044 extend MACOM's leading portfolio of CDRs, laser drivers and TIAs to support short-reach applications," says Marek Tlalka, direct of product marketing, High-Performance Analog.

"The industry-leading high integration, small chip-size and low power of MACOM's VCSEL driver chipset make it an ideal solution for 100Gbps connectivity in high-volume data-center and high-performance computing applications," comments Infinity Huang, head of R&D at China-based Hisense Broadband Multimedia Technologies Co Ltd, which is one of the first companies to ship volume quantities of 100G optical QSFP connectivity products based on MACOM's new chip-set.

The MALD-37045 and MATA-37044 were on display at the Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22-24 March).

[www.macom.com](http://www.macom.com)

# NeoPhotonics reports record revenue of \$89.1m for Q4, driven by 100G sales in China

## Firm adding capacity at chip, component and module levels

For fourth-quarter 2015, NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated opto-electronic modules and subsystems for high-speed communications networks) has reported record revenue of \$89.1m, up 6.7% on \$83.6m last quarter and up 12.8% on \$79m a year ago (and above the \$82–86m guidance range). Full-year revenue has risen by 10.9% from \$306.2m in 2014 to a record \$339.4m in 2015, despite headwinds from product-pruning activities during first-half 2015.

The two 10%-or-greater customers comprised 69% of total revenue collectively: US-based Ciena (14% of total revenue, down from 26% last quarter) and China's Huawei Technologies (55% of total revenue, up from 41%, reflecting the strength of 100G deployments in China). Of total revenue, China hence rose from 49% to 67% (reflecting the burgeoning demand) as the Americas fell back from 30% to 17% (reflecting quarterly skewing — NeoPhotonics sees no meaningful change over the longer term). Japan fell from 4% to 3%, while the rest of the world fell from 17% to 13%.

Driven by China, sales of High Speed Products (for 100G-and-beyond) hence rose 10% sequentially to \$51.7m (58% of total revenue, up from 56% last quarter, and the highest 100G percentage in the industry it is claimed).

Revenue for Network Products and Solutions (lower-speed transceivers, <100Gb/s) was up 2% sequentially to \$37.4m. "We view these products as mature and therefore may decline over the medium term," notes chief financial officer Ray Wallin. "This decline is anticipated to have an uplift effect on gross margins."

"For the quarter, we reported record revenue, non-GAAP gross profit and

net income," says CEO Tim Jenks. "And for the year we reported both record revenue and record non-GAAP earnings, making it the best year in the company's history."

On a non-GAAP basis, gross margin was 32.4%, up from 30.3% a year ago and 29.8% last quarter, driven by the greater mix of higher-margin High Speed Products as well as manufacturing cost reductions. Full-year gross margin rose from 25% in 2014 to 31.5% in 2015, driven by the 100G product growth.

Operating expenses (OpEx) were \$22.6m (25.4% of revenue), up on \$20.7m (24.8% of revenue) last quarter and \$19.2m (24.3% of revenue) a year ago. Full-year operating expenses were \$84.7m (24.9% of revenue), roughly level with \$84.6m (27.6% of revenue) in 2014 despite acquiring Emcore's tunable laser product line at the beginning of 2015.

Non-GAAP results exclude \$2.8m of end-of-life inventory write-down charges related to the firm's drive to optimize the tunable laser product line in alignment with its 100G-and-beyond product strategy. NeoPhotonics is terminating support of certain versions of tunable lasers that are not aligned with this strategy.

Net income was \$6.9m (\$0.16 per diluted share), up on \$4.6m (\$0.11 per diluted share) last quarter and \$6.3m (\$0.19 per diluted share) a year ago (the firm's sixth consecutive non-GAAP profitable quarter). Full-year net income was a record \$21.1m (\$0.53 per diluted share) in 2015, a strong improvement on the net loss of \$9.2m (\$0.29 per diluted share) in 2014.

**The market for 100G-and-beyond optical networks [for both telecom and data-center applications] is growing very robustly**

Likewise, adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) was \$11.8m (13% of revenue, close to the target model of 15%), up on \$10.2m last quarter and \$11.6m a year ago. Full-year adjusted EBITDA was a record \$43.2m (13% of revenue) in 2015, up from \$12m in 2014.

Cash flow generated from operations was \$5m in Q4 (contributing to \$26m in full-year 2015). Capital expenditure was \$5.8m (up from \$5.4m last quarter), taking full-year CapEx to \$16.8m.

During Q4, cash and cash equivalents, short-term investments and restricted cash and investments fell from \$103.6m to \$102m.

Despite the first quarter historically being seasonally low (due to completing annual price negotiations and due to the timing of Chinese New Year and lower Access shipments in the winter), for Q1/2016 NeoPhotonics expects revenue to rise by 3–10% to \$92–98m due to strong momentum from 100G demand (in Q4/2015, NeoPhotonics acquired the precision optical power monitor business of EigenLight Corp, but this will contribute only about 1% of revenue). Gross margin should be 30–33%, and diluted earnings per share \$0.10–0.18.

NeoPhotonics' target model remains the same in 2016: 35% gross margin, OpEx of 25% of revenue, 10% operating margin, and 15% EBITDA margin.

"The market for 100G-and-beyond optical networks [for both telecom and data-center applications] is growing very robustly and NeoPhotonics' leading product positions, coupled with our new product introductions for coherent transport and data-center applications, places us in an advantageous position for the coming year," reckons Jenks. "We are currently expecting full-

► year revenue growth for 2016 to be in the range of 15% overall. To support this growth, we are adding capacity at chip, component and module levels, expanding assembly & test capacities, and we are working with our supply-chain partners on their expansion plans," he adds.

"We believe NeoPhotonics has the highest share of micro tunable lasers and integrated coherent receivers for the expanding range of coherent transmission applications, from 100G to 400G data rates," says Jenks. "This market will drive continuing growth in revenue," he believes. "To support our accelerating demand conditions across each of our high-speed products, we are increasing our capital expenditures for the coming full year to a range of 7–9% of revenue," adds Wallin.

"Our client-side business is seeing strong sequential growth as well," says Jenks. "Extending this product range, our new 100G QSFP28 modules are expected to ramp to volume shipments over the following two quarters for high-density, telecom-client and data-center applications. Further, we are devel-

oping 400G client-side modules in CFP8 configurations that will be based on our leading 28Gbaud lasers at 50Gbps using a PAM4 architecture. Taking this development one step further, we are also introducing an ultra-high-speed 56Gbaud EML laser and driver IC set which enables single-wavelength PAM4 100G applications as well as eventually four-wavelength 400G intra-datacenter transmission," he adds. "Also, for mega-datacenter applications we have introduced a series of new high-power laser diode array products designed to power short-reach silicon photonics-based 100G intra-datacenter interconnections which use parallel single-mode architectures (PSM4)."

NeoPhotonics also announced that it will be entering the coherent module market. The first product is a new CFP2-ACO module, to be sold initially in a Class 3 configuration (shipping in 2016), and exhibited to lead customers at the Optical Fiber Communications conference in Anaheim, CA, USA (22–24 March). "Our coherent module products will feature NeoPhotonics high-

performance components inside, enabling these modules to meet the highest specifications in the industry," says Jenks.

In addition, NeoPhotonics is supplying multiple other CFP2-ACO module manufacturers with its high-performance components. "We are very well positioned to benefit as a leader in both pluggable modules and components as coherent applications grow," believes Jenks.

Also at OFC, NeoPhotonics featured a new 43Gbaud integrated coherent receiver (ICR), which will extend the reach of 200G coherent transmission to more than 1000km and is suitable for use either in pluggable modules or on high-density line-cards.

"These introductions represent a significant increase in product breadth and capability for NeoPhotonics as we move into this heightened demand cycle," notes Jenks. "As a result, we believe we are well positioned for the expansion in 100G-and-beyond networks," he adds.

[www.neophotonics.com](http://www.neophotonics.com)

## NeoPhotonics sampling 100G Class 3 coherent pluggable CFP2-ACO

NeoPhotonics has announced initial sample availability for the ClearLight CFP2-ACO (analog coherent optics) Class 3 coherent pluggable module (the firm's first CFP-2 ACO module in a Class 3 configuration).

Building on NeoPhotonics' strength in components for coherent transport systems, the new product is the first in a series of high-performance pluggable modules and represents an expansion to the firm's coherent product suite to meet growing demand for high-density coherent solutions for both telecom and data-center networks.

The ClearLight CFP2-ACO combines all of the optical functions necessary for a coherent transport in a standard-form-factor compact pluggable module and is

designed to fully support the Optical Internetworking Forum (OIF) 'Implementation Agreement for CFP2-Analog Coherent Optics Module' (OIF-CFP2-ACO-01.0, 22 January) for Class 3. The module incorporates NeoPhotonics' ultra-narrow-linewidth external-cavity tunable laser and high-responsivity integrated coherent receiver (ICR), exhibits low electrical power consumption, and is suitable for 100G DP-QPSK and 200G 16QAM operation. The ClearLight Class 3 CFP2-ACO is compatible with digital signal processor (DSP) solutions from multiple vendors, and places the control of the optics outside the module with the DSP.

"We are building upon our core strength in advanced hybrid photonic integrated circuits [PICs] to combine multiple different func-

tions in a compact module utilizing the right material technology for each element," says chairman & CEO Tim Jenks. "This will allow us to follow this first product with a series of modules to meet the ever increasing performance demands of future networks."

In addition to demonstrating the new CFP2-ACO, at the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March) NeoPhotonics exhibited its suite of standard and small-form-factor PIC-based components for 100G coherent line-side applications, along with its 100G client-side CFP2 and QSFP28 transceivers and its next-generation multi-cast switch for contentionless networks.

[www.ofcconference.org](http://www.ofcconference.org)

# Oclaro qualifies and begins production of 2km and 10km 100Gb/s QSFP28 client-side transceivers

## Transceivers meet CWDM4 MSA/CLR4 alliance and IEEE 100GBASE-LR4 optical interface specs, and IEEE 802.3bm CAUI-4 electrical interface specs

Oclaro has now qualified and released to production both its 2km CWDM4 QSFP28 and 10km LR4 QSFP28 client-side transceivers designed for 100Gb/s inter-connections between switches within data centers in addition to conventional router and transport 100Gb/s client-side interfaces in core networks.

By delivering low power consumption and high transmission performance quality through Oclaro's internal 1310nm 28Gb/s laser diode and lens-integrated receiver technologies, the CWDM4 and LR4 QSFP28 transceivers will enable data centers to transition to longer-reach single-mode fiber (SMF) interconnections needed to support growing bandwidth demands.

"Oclaro has a proven track record of delivering leading-edge 100Gb/s client transceivers to customers transitioning to higher-speed networks," says Yves LeMaitre, president, Optical Connectivity Business at Oclaro. "With our unique and proprietary 28Gb/s laser diode and lens-integrated receiver technologies, we can now offer two flavors of single-mode QSFP28 optimized for data-center topology and reach. Our goal is to provide data-center operators with a reliable supply of 100Gb/s transceiver solutions that support multiple standards while also

ensuring low power consumption and high transmission quality in a cost-effective small form factor," he adds.

"The availability of QSFP28 optics will be instrumental in spurring major growth for 100GbE in the data-center market," comments Vladimir Kozlov, founder & CEO of LightCounting Market Research. "Our current forecast shows this market to be approximately \$500m by the 2018 timeframe and Oclaro is well positioned as a trusted supplier ready to meet this growing demand."

The CWDM4/CLR4 QSFP28 transceiver is designed to address the requirements of cloud data-center operators that need to move to SMF at 100Gb/s because mesh interconnection between Leaf and Spine switches require connectivity of up to 2km over duplex single-mode fiber. To facilitate that transition, the CWDM4/CLR4 QSFP28 provides a low-cost solution that features maximum 3.5W power consumption and high transmission quality through Oclaro's uncooled 1310nm 28Gb/s laser diode technology. Additional features of the CWDM4/CLR4 QSFP28 include:

- utilizing cost-effective integrated transmitter and receiver designs leveraging Oclaro's manufacturing experience gained as a supplier of

single-mode 100Gbit/s client-side transceivers;

- leveraging Oclaro's experience in 25Gb/s electrical signal design for PCB, gold box, and flex circuits; and
- supporting both the CWDM4 MSA and CLR4 alliance specifications to offer flexible solutions.

Oclaro says that the LR4 QSFP28 transceiver delivers high performance, ensures interoperability with existing CFP/CFP2 and CFP4 products, and supports OTU4 specifications by using in-house 28G laser diode technologies. Due to its narrower width and lower power consumption, the LR4 QSFP28 can support up to 18 100Gb/s ports (36 ports with dual stack implementation) while also providing superior optical performance and transmission quality. Additional features of the LR4 QSFP 28 include:

- taking advantage of Oclaro's cooled 1310nm 28Gb/s laser diode and lens-integrated receiver technologies covering both IEEE LR4 and ITU-T OTU4 specifications ('dual rate' performance);
- leveraging Oclaro's proven track record in delivering volume 100Gbit/s LR4 transceivers; and
- ensuring interoperability with the existing installed base of CFP/CFP2/CFP4 LR4 products.

[www.oclaro.com](http://www.oclaro.com)

## Infinera appoints former Altera president & CEO to board

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 appointed John P. Daane to its board of directors.

Infinera says that Daane has deep understanding of high-performance

programmable networking components and the networking ecosystems, especially regarding data-center and cloud architectures.

Daane was president, CEO & board member of programmable network chip firm Altera Corp from late 2000 to its acquisition (by Intel) last December (and chairman from 2003).

Prior to that, in 15 years at LSI

Logic, he went from engineering intern to executive VP of the Communications Products Divisions including the Networking, Wireless, Telecom, Computer and Consumer Divisions, and central engineering. He was also a board member of the Semiconductor Industry Association from 2003 to last December.

[www.infinera.com](http://www.infinera.com)

# Finisar's wavelength-selective switch Telecom sales growth offsets tail-off in 40G transceiver Datacom sales

For its fiscal third-quarter 2016 (to end-January), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA has reported revenue of \$309.2m, down 3.7% on \$321.1m last quarter but up slightly on \$306.8m a year ago.

There were two 10%-or-greater customers. The top 10 customers represented 58.4% of total revenue.

Telecom product sales rose by \$2.6m (2.9%) from \$87.4m last quarter to \$89.9m, driven by 25% growth in wavelength-selective switches (WSS) to nearly 30% of telecom revenue.

Datacom product sales fell by \$14.5m (6.2%) from \$233.8m last quarter to \$219.3m, driven by a decline in 40G transceivers, primarily due to reduced levels of capital spending by Web 2.0 and hyperscale data-center customers in anticipation of the roll-out of next-generation 100G QSFP28 transceivers.

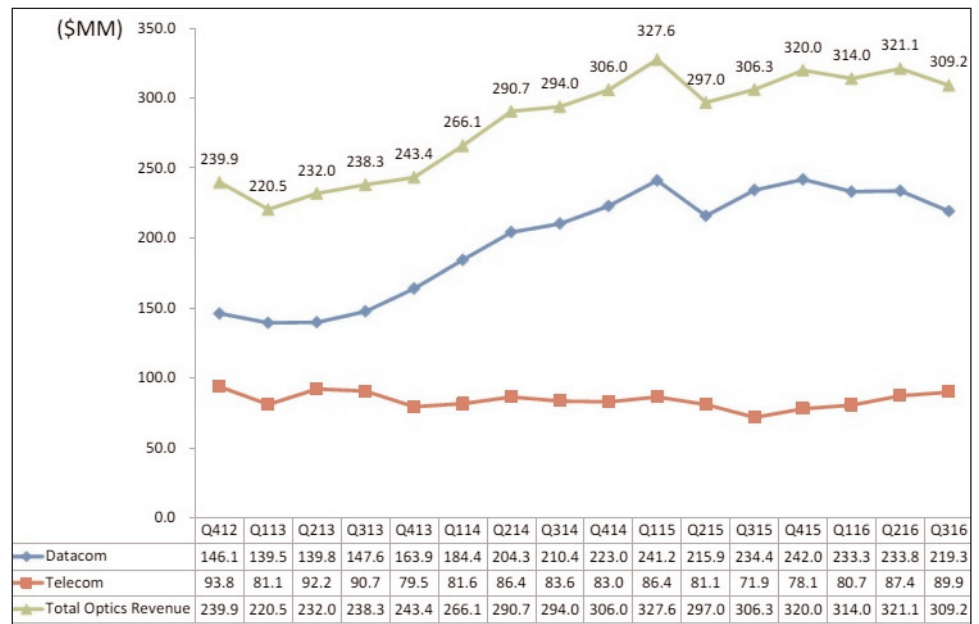
On a non-GAAP basis, gross margin rose from 30% last quarter to a better-than-expected 30.3%, as favorable product mix offset the impact of one month of annual telecom price negotiations (which typically take effect on 1 January).

Although up from \$65.3m a year ago, operating expenses have been cut from \$68m last quarter to a \$67.3m (21.8% of revenue), less than the expected \$67.5–68m.

Operating income was \$26.3m (operating margin of 8.5% of revenue), down from \$28.3m last quarter but on a par with \$26.9m a year ago, and at the top end of the expected range of 7.5–8.5% margin.

Net income was \$26.6m (\$0.25 per fully diluted share), roughly level with \$26.9m (\$0.25 per fully diluted share) last quarter and \$26.7m (\$0.25 per fully diluted share), and at the upper end of the \$0.19–0.25 guidance range.

Capital expenditure (CapEx) was \$26.8m, below the expected \$35m as some final expenditures associated with the fit out of the second



building in Wuxi, China rolled into fiscal Q4/2016 (when CapEx should rise to \$33m, then fall back to \$30m per quarter in fiscal 2017).

During the quarter, cash, cash equivalents and short-term investments rose from \$520.8m to \$531.1m.

For fiscal Q4/2016, Finisar expects revenue of \$307–327m (including growth in Datacoms and Telecoms). Gross margin should fall back to 30% (as the positive impact of favorable product mix is offset by the impact of three months of the annual telecom price reductions). Operating expenses are expected to be relatively flat at about \$67.5m. Operating margin will be 8.2–9.2%. Earnings per fully diluted share should be \$0.22–0.28.

"We are seeing strong growth from China, due to the continued long-haul and wireless build-outs at China Telecom, China Unicom and China Mobile, as well as strength in North America from the expansion of next-generation metro networks," says CEO & executive chairman Jerry S. Rawls. Finisar also expects telecom revenue growth from Europe and the Middle East.

Datacom revenue growth will be due to increased sales of 100 Gigabit Ethernet transceivers and CFP, CFP2, CFP4 and QSFP28 form factors.

Telecom revenue growth is expected to be due mainly to continued strong demand for wavelength-selective switches and ROADM line-cards. Growth is also expected from 100G and 200G line-side products such as CFP2-ACO.

"Given the strong demand for our 100G client-side modules as well as our wavelength-selective switches, WSS-based line-cards and our CFP2-ACO products, we are capacity constrained on all of these products, and we are actively adding capacity to meet customer demand," says Rawls.

"In fiscal 2017, we expect to benefit from the increased sales of many new products driven by both data-center construction and upgrades and increased deployment of ROADMs and the 100–200G coherent transceivers in telecom long-haul and metro," says Rawls. "Finisar's revenue is primarily driven by growth in the global demand for bandwidth from the increasing distribution and use of video, images and digital information. In addition, Finisar continues to benefit from the growth in cloud services, which drives networking hardware upgrades of existing data centers and the construction of new hyperscale data centers," he adds.

[www.finisar.com](http://www.finisar.com)

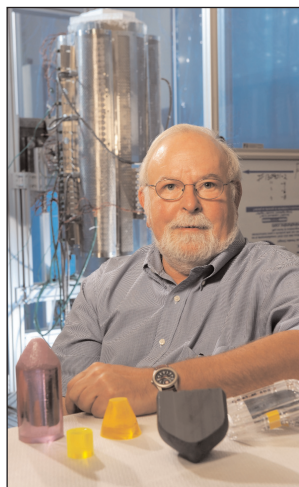
# NREL collaboration boosts maximum potential for CdTe solar cells to above 1V

## Purity control of phosphorus doping yields record open-circuit voltage

The US Department of Energy's National Renewable Energy Laboratory (NREL), in collaboration with Washington State University (WSU) and the University of Tennessee, has improved the maximum voltage available from a cadmium telluride (CdTe) solar cell (a key factor in improving energy conversion efficiency (James Burst et al, 'CdTe solar cells with open-circuit voltage breaking the 1V barrier', Nature Energy 16015 (2016); DOI: 10.1038/nenergy.2016.15). The research was funded by the DoE's SunShot Initiative, which aims to make solar cost-competitive with traditional energy sources. It was also supported in part by Oak Ridge National Laboratory's Center for Nanophase Materials Sciences.

Silicon currently represents 90% of the solar cell market, but it is difficult to significantly reduce their manufacturing costs. Offering a low-cost alternative, CdTe solar cells also have the lowest carbon footprint and adapt better than silicon in real-world conditions (including hot, humid weather and low light), says NREL. However, CdTe solar cells have not been as efficient as silicon-based cells until recently.

A key area where CdTe has underperformed is in the maximum voltage available from the solar cell (the open-circuit voltage). For decades, the quality of CdTe materials has prevented anyone



**WSU's Kelvin Lynn with crystals made in his lab. (Photo by WSU Photo Services.)**

from obtaining an open-circuit voltage of more than

900mV despite billions of CdTe solar cells having been produced; the vast majority have been limited to 750–850mV.

The research team improved cell voltage by shifting away from a standard processing step using cadmium chloride. Instead, they placed a small number of phosphorus atoms on tellurium lattice sites and then carefully formed ideal interfaces between materials with different atomic spacing to complete the solar cell. This approach improved the CdTe conductivity and carrier lifetime each by orders of magnitude, enabling the fabrication of CdTe solar cells with an open-circuit voltage breaking the 1V barrier for the first time.

The NREL researchers treated the crystals and built and characterized the solar cells. WSU researchers (including Santosh Swain and

Tursun Ablekim) developed the crystal material used in the cells.

The WSU researchers grow their crystals using melt growth, which allows precise control over purity and composition. Purity is critical to the process, so the researchers mix, prepare and vacuum-seal the materials in an industry-standard cleanroom. They then synthesize the crystal in a furnace above 1100°C and cool it from the bottom up at a rate of about 1mm per hour. The crystal is cut into polished wafers to make the solar cells.

"Others have tried dopants, but they didn't have the control and purity that we have. And the purity matters," says Kelvin Lynn, Regents professor in WSU's School of Mechanical and Materials Engineering and Department of Physics, who led WSU's effort. "WSU is known for growing really high-quality and purity crystals," he adds "You have to control every step."

While researchers have improved silicon-based cells almost to their theoretical limit, there is significant room for efficiency improvements for CdTe, which could be bettered by an additional 30%, reckons Lynn.

[www.nature.com/articles/nenergy201615](http://www.nature.com/articles/nenergy201615)

<http://energy.gov/eere/sunshot/sunshot-initiative>

[www.nrel.gov](http://www.nrel.gov)

## First Solar signs MoU to provide PV modules to utility-scale project development in Vietnam

First Solar Inc has signed a memorandum of understanding (MoU) to provide thin-film photovoltaic (PV) modules to power solar projects across several provinces in Vietnam that are being developed by owner Thien Tan Group. Construction on initial projects will start by end-2016.

"Cadmium telluride modules offer significant efficiency and reliability advantages over typical crystalline silicon modules, particularly in a hot and humid climate like Vietnam," notes Rob Bartrop, First Solar's business development director for South-East Asia.

Founded in 2004, Thien Tan Group specializes in funding and building hydropower generation, residential and industrial developments, real estate and solar energy generation. The MoU marks the first time that it has partnered with First Solar.

[www.firstsolar.com](http://www.firstsolar.com)



## First Solar EPC surpasses 6GW of installed PV capacity

Cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA says that in early February it surpassed 6GW<sub>DC</sub> of capacity installed by its Engineering, Procurement and Construction (EPC) group. The firm is currently installing 30–40MW<sub>DC</sub> per week on 2GW<sub>DC</sub> of active projects around the world.

Partnerships with strategic customers have enabled First Solar to continually lower the cost of utility-scale solar generation, says Alan Stringer, VP of global project management & construction serv-

ices, who adds that First Solar is setting the pace in driving down the cost of balance of systems (BoS). For example, First Solar's application of 1500V inverters is rapidly becoming an industry standard, notes Stringer. Also, the firm's manufacturing heritage, combined with the scale of installing 6GW, has enabled First Solar to develop a 'manufacturing in the field' concept that helps to drive down BoS cost. "Power plant owners benefit from both the lower cost of utility-scale projects built by First Solar and the proven track record of innovation

we bring to every project," says Stringer.

First Solar's inaugural EPC job was 2008's 10MW<sub>AC</sub> El Dorado Solar Project in Nevada, consisting of 220,000 modules, and taking nearly two years from ground-breaking to commissioning. In early 2015, First Solar completed construction of the 550MW<sub>AC</sub> Desert Sunlight Solar Project and the 550MW<sub>AC</sub> Topaz Solar Farms, each utilizing more than 8 million modules and built in about the same amount of time it took to construct El Dorado.

## First Solar surpasses 1GW of PV capacity shipped to India

First Solar has surpassed 1GW<sub>DC</sub> of photovoltaic (PV) solar capacity shipped to India, making it the first thin-film PV module manufacturer to achieve this milestone in the country.

"We thank our customers and stakeholders in India for placing their trust in First Solar. They are benefitting from differentiated technology that has proven its superior energy yield by delivering 5–9% more energy, compared to

polysilicon based modules in India for its customers over the past four years," says Sujoy Ghosh, First Solar's country head for India.

"Thin-film modules today have higher conversion efficiency and require less land per megawatt compared to poly silicon-based modules," Ghosh adds. "Our technology roadmap has us on a path to even greater conversion efficiencies, which will enable solar plants to be even more competi-

tive against conventional energy sources."

First Solar has been present in India since 2011, and provides its CdTe thin-film modules to solar developers. The firm also self-develops utility-scale solar PV projects and, through its Indian subsidiary, has 200MW<sub>AC</sub> of projects with contracted long-term power purchase agreements (PPAs) under development and operation in India.

## First Solar reaches 5GW of O&M assets

The Operations & Maintenance group of First Solar now has 5GW of assets in its portfolio of solar power plants, establishing it as the world's largest solar O&M provider, it is reckoned.

First Solar Energy Services, which has held the top position on GTM Research's 'Global O&M and Asset Management' report for the past two years, surpasses the next nearest O&M provider by about 1.8GW.

"Our customers have entrusted us to make sure they get the most out of their investments," says First Solar Energy Services' vice president Troy Lauterbach. "We help them minimize risk and maximize the value of their renewable energy assets."



**First Solar's NERC-registered Tempe-based US Operations Center.**

First Solar Energy Services has grown alongside the solar industry over the past half-decade. In 2009, the fledgling O&M group commenced operation of the 21MW Blythe Solar Project in California, which was then

the world's largest PV plant. The group now operates and maintains solar power plants for owners in 10 countries, including some of the largest PV power plants in the world.

First Solar Operations Centers (FSOC) are located in Tempe, AZ, USA, Sydney, Australia, and Berlin, Germany. The firm says that its flagship Tempe FSOC is frequently

visited by grid operators, regulators and energy industry experts from around the world seeking demonstrations of its operations technology and capabilities.

[www.firstsolar.com](http://www.firstsolar.com)

## Solar Frontier to supply 150MW of PV modules to Cypress Creek Renewables

Tokyo-based Solar Frontier — the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — has entered into a 150MW module supply agreement with Cypress Creek Renewables (CCR), which specializes in locally based development strategies and ownership of solar projects (with over 2.6GW of solar farms deployed or in development).

Solar Frontier will supply modules to a portfolio of Cypress Creek Renewables' projects in various

states including Indiana, South & North Carolina, Montana and Texas. The solar energy projects primarily range in size from 2–10MW and will be installed throughout 2016.

"Cypress Creek Renewables, a company recognized for its commitment to sustainable practices in local solar development, has become a bellwether relationship for Solar Frontier," says Charles Pimentel, chief operating officer of US subsidiary Solar Frontier Americas. "Our relationship matured as a result of the strength of our tech-

nology and its ability to deliver superior internal rate of return (IRR) on Cypress Creek Renewables' projects," he adds.

"Solar Frontier is a reliable partner in helping us achieve our goal of making solar energy an affordable local energy choice for the communities we serve," comments Cypress Creek Renewables' CEO Matthew McGovern. "The size of our commitment reflects our confidence in Solar Frontier and its product."

[www.ccrenew.com](http://www.ccrenew.com)

## Solar Frontier Americas sells 20MW solar power project to Southern Power/Turner Renewable Energy

Solar Frontier Americas — which is the US subsidiary of Tokyo-based Solar Frontier, the world's largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — has sold the 20MW Calipatria solar power generation plant to Southern Power and Turner Renewable Energy (representing Solar Frontier's second solar project sale to Southern Power).

Southern Power is a subsidiary of Southern Company (one of the largest utilities in the USA, with a renewable energy portfolio of over 1800MW of capacity ownership). Turner Renewable Energy (owned by Ted Turner) teamed with Southern Company through a subsidiary in 2010 to form a strategic alliance to pursue the development of renewable energy projects in the USA. The partnership has focused primarily on developing and investing in large-scale PV projects in the southwest USA. Solar Frontier America's Calipatria project is Southern Power's ninth solar acquisition with Turner Renewable Energy, and brings the partnership's overall solar capacity to more than 340MW operating or under development.



**The Calipatria Solar Project.**

Calipatria Solar Project is constructed with about 130,000 CIS modules mounted on single-axis trackers and has a 20-year power purchase agreement (PPA) with San Diego Gas & Electric Company. Located in Imperial County, California, the project is part of Solar Frontier America's 280MW US project pipeline. The firm currently has a series of projects in various stages of development in California.

The Calipatria solar power generation plant was developed by Solar Frontier Americas Development LLC, a division of Solar Frontier Americas with offices in San Francisco, CA,

and Reno, NV. Construction on the project started in August 2015 and is expected to be completed in first-

quarter 2016. The plant should be capable of generating enough solar energy to meet the electricity needs of about 5000 homes in the USA annually.

"This transaction is another demonstration of the strength and acceptance of our product in the US market," says Solar Frontier Americas' chief operating officer Charles Pimentel.

"Southern Power is building one of the most reliable and robust wholesale renewable energy generation portfolios in the US," says Southern Power's president & CEO Oscar C. Harper.

[www.solar-frontier.com](http://www.solar-frontier.com)

# MiaSolé signs multiple sales representatives worldwide

Copper indium gallium diselenide (CIGS) thin-film photovoltaic solar cell and panel maker MiaSolé of Santa Clara, CA, USA (which was founded in 2004 and acquired by Beijing-based renewable energy firm Hanergy in December 2012) has signed sales representative agreements with multiple companies for various regions.

In the USA, MiaSolé has agreed for solar power and energy solution provider SolEnergy LLC to represent it in Louisiana, Maryland, and North Virginia.

MiaSolé has also entered into a representative agreement for GTech Global to sell MiaSolé FLEX modules in Northern California.

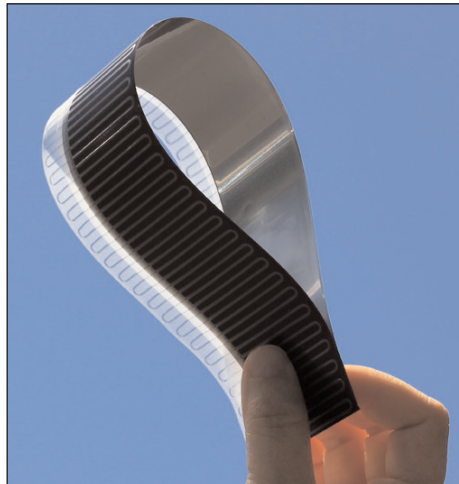
GTech Global (GTG) and its associates have more than 35 years of business experience in developing and implementing energy-efficient building solutions, focusing on energy management and conservation. GTG specializes in integrated solar and roofing solutions for industrial, commercial, and agricultural customers.

Outside mainland USA, MiaSolé has entered into a representative agreement for Advanced Roofing Technology Inc (which was founded in 1991 and specializes in roofing and construction) to sell its FLEX modules in Hawaii and the Pacific Islands.

MiaSolé has also agreed for Uber Énergies of Montreal, Quebec to represent it in the Canadian market, as well as certain special channels into which Uber Energies has distinct relationships and access.

Outside North America, MiaSolé has agreed for Australia-based Benmax Group (which specializes in the design, construction, commissioning, maintenance and service of heating, ventilating, air-conditioning and refrigeration systems) to represent it in the Australian, New Zealand and Singapore markets.

Benmax Environmental (a new division of Benmax Group) provides environmental advisory and



**MiaSolé's flexible solar cell.**

consulting services to help organizations throughout Australia and New Zealand rise to the challenge of changing environmental codes and standards. On the basis that sustainable building requires close cooperation of the entire project team (designers, architects, engineers and client) at all project stages, Benmax Group has a track record of working cooperatively with clients.

SolEnergy, GTech Global, Advanced Roofing Technology, Uber Énergies and Benmax will sell MiaSolé's FLEX modules, which are claimed to be the most efficient thin-film lightweight flexible modules on the market (with an energy efficiency rating of +16%).

The FLEX modules bond directly to a roof surface with a simple peel-and-stick adhesive. This eliminates the need for racking and reduces labor and logistics costs, providing a 20% lower BoS (balance-of-system)



**MiaSolé's FLEX module**

cost than traditional glass solar systems, it is claimed.

The low profile of the FLEX module also provides what is claimed to be superior wind resistance and a seismic advantage over traditional rack-and-panel systems (where their higher profile increases the likelihood of damage in a hurricane or earthquake), making FLEX modules suitable for seismically active areas such as Northern California and the Hawaiian and Island markets.

In addition, FLEX modules use by-pass diode technology that enables better shade performance.

"The ability to benefit from thin-film solar module characteristics in our northern climates or for certain off-grid applications is one of the key reasons why we chose to partner with MiaSolé," comments Uber Énergies' president Sass M. Peress.

The FLEX-02 Series module in particular (which is IEC 61646 & IEC 61730 and UL 1703 certified) is available in two formats. The FLEX-02W module is 39.3" x 102.3" and is rated at 360W, designed for low-slope commercial single-ply roof systems. The FLEX-02N module is 14.6" x 102.3" and is rated at 120W, designed specifically for standing-seam metal roofs.

The low weight of the FLEX-02 module (<0.7lb/ft<sup>2</sup>) allows installation on roofs that cannot support the weight of traditional glass solar panels. Because the panels adhere directly to the roof surface, there are no penetrations, eliminating the worry of leakage and damage to valuable contents within a building. The FLEX-02 also blends into both metal and TPO roofs, preserving the original look of the roof.

[www.solenergyonline.com](http://www.solenergyonline.com)  
[www.gtechglobal.net](http://www.gtechglobal.net)  
[www.advanced-roofing.com](http://www.advanced-roofing.com)  
[www.uberenergies.com](http://www.uberenergies.com)  
[www.benmax.com.au](http://www.benmax.com.au)  
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# Vertical epitaxial heterostructure GaAs optical transducers

Researchers claim highest reported optical-to-electric power conversion of more than 65%.

Researchers in Canada claim the highest reported optical-to-electric power conversion of more than 65% (Figure 1) for a  $150\text{W}/\text{cm}^2$  ( $\sim 1500$  suns) tuned narrow spectrum input from high-powered laser diodes [S. Fafard et al, Appl. Phys. Lett., vol108, p071101, 2016]. Multi-junction concentrated photovoltaic cells have achieved 46% conversion from the broad solar spectrum.

The optical transducers were based on a vertical epitaxial heterostructure architecture (VEHSA) design of a number of monolithically integrated thin n-p

gallium arsenide (GaAs) junctions. The team — consisting of researchers from Université de Sherbrooke, Azastra Opto Inc, and University of Ottawa — sees potential for microelectronic hybrid components and biomedical applications. Such uses could benefit from output voltages in the 5–12V range, enabled by employing stacks of junctions.

The researchers comment: “These features are sought after in order to enable more compact, electrically isolated, or long-lasting power sources. Such isolated power supplies are beneficial for regulating more

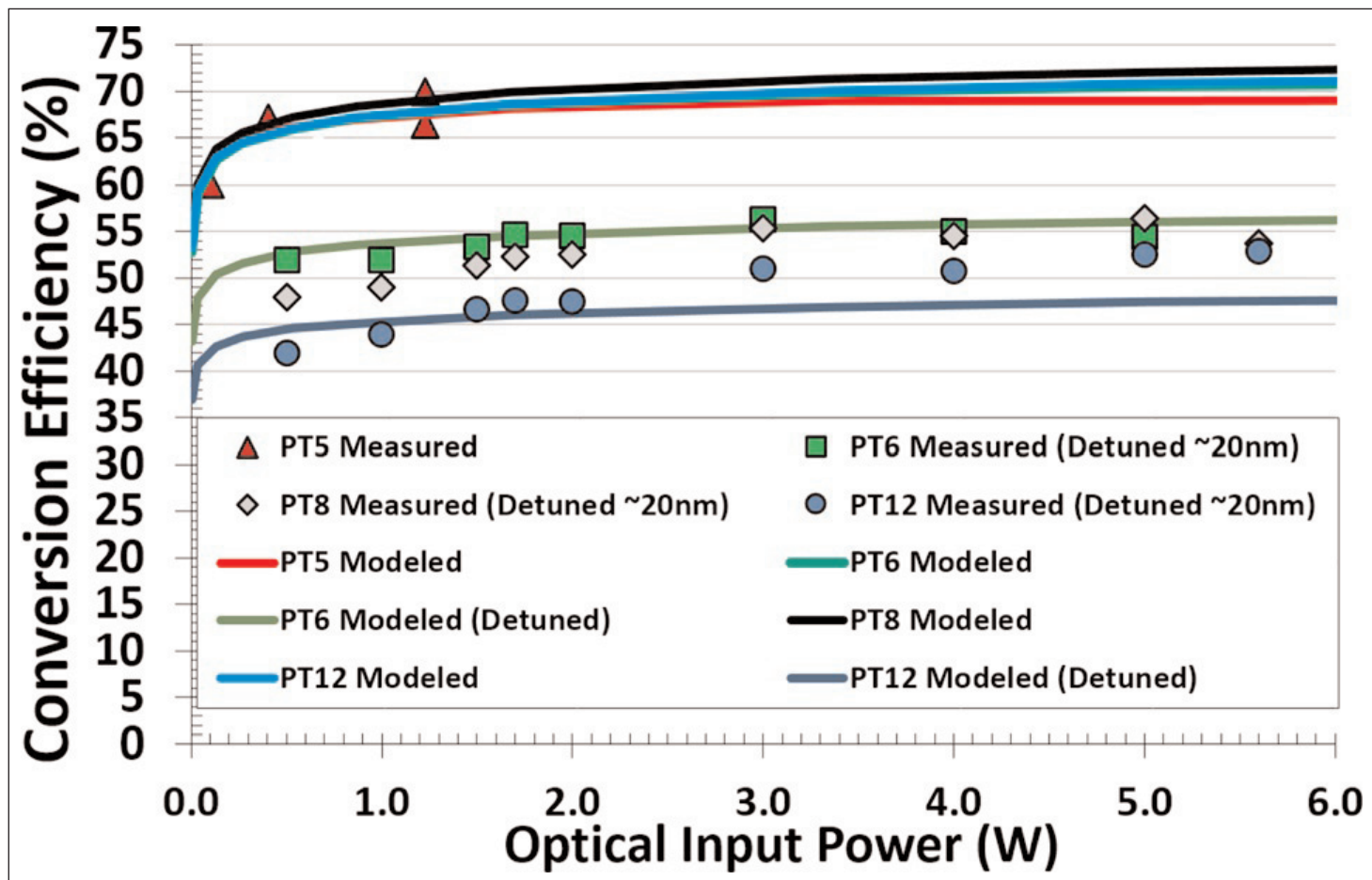


Figure 1. Power dependence of measured and modeled optical-to-electrical conversion efficiency for GaAs phototransducer heterostructures engineered with the VEHSA design. When input wavelength is tuned to peak response, the efficiency approaches 70%.

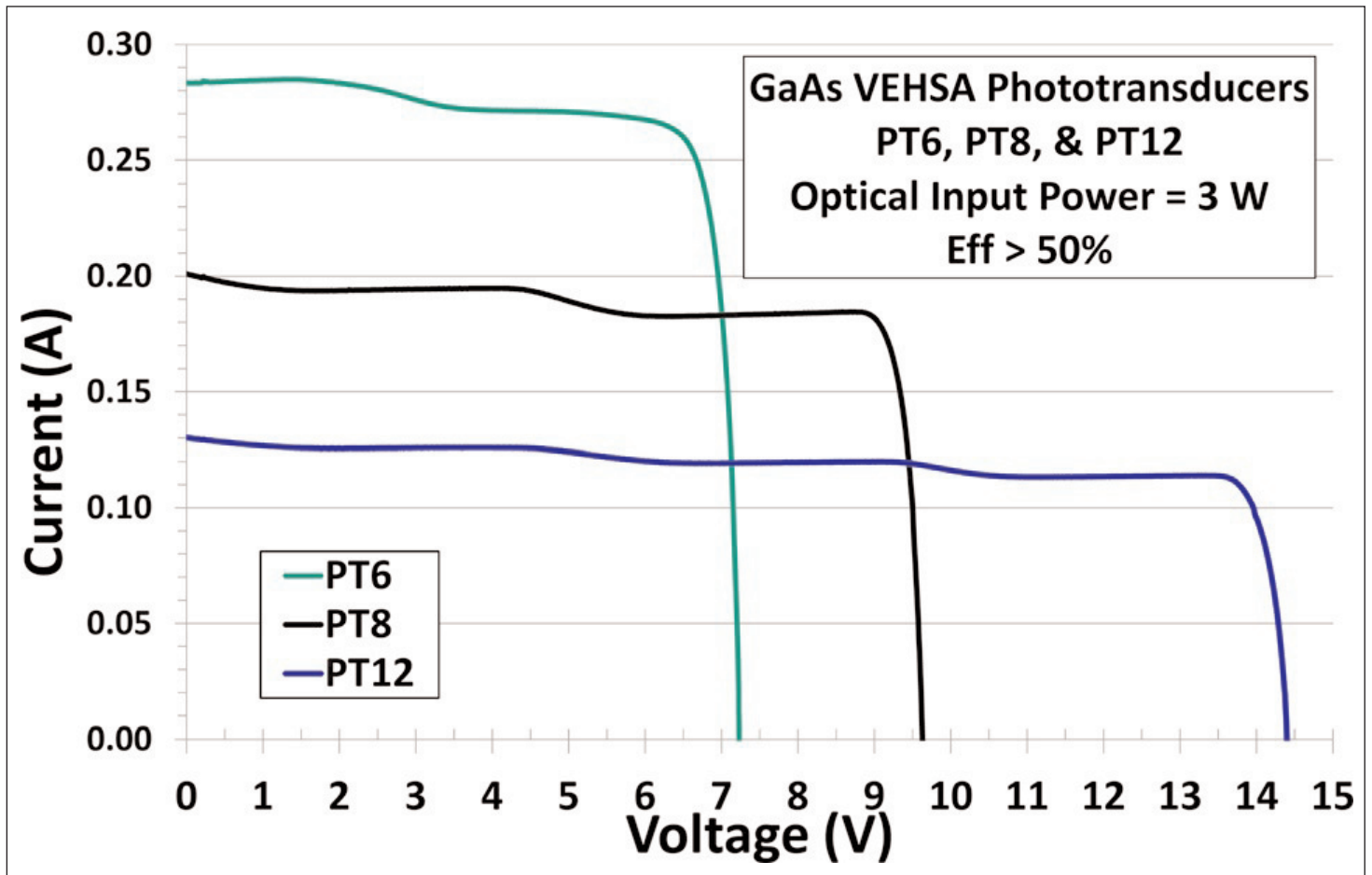


Figure 2. Measured current–voltage curves at 20°C with input at 825nm.

securely microelectronic circuits in many telecommunication, utilities, sensor, and automotive systems, or for controlling more safely neuro-stimulating or biomedical devices.”

Metal-organic chemical vapor deposition (MOCVD) was used to produce heterostructures on 150mm-diameter zinc-doped p-GaAs substrates. Stacks of GaAs n–p junctions were grown on a lattice-matched gallium indium phosphide (GaInP) p-type back surface field. An n-type window layer of lattice-matched GaInP completed the structure.

The n–p junctions were generally connected by high-peak-current  $p^{++}/n^{++}$ -type aluminium gallium arsenide (AlGaAs) tunnel junctions developed by some of the team. The more usual tunnel junction for such connections in concentrated photovoltaic (CPV) devices consists of  $n^{++}$ -GaInP/ $p^{++}$ -AlGaAs. The five-junction (PT5) devices did not use the  $p^{++}$ -AlGaAs/ $n^{++}$ -AlGaAs tunnel junction. PT5 devices were also limited to less than 1W optical input.

The n-GaAs part of the n–p junctions was around 100nm or thinner. The p-GaAs side of the junction was varied in thickness. The 12-junction devices had p-type layers as thin as 44nm.

The heterostructures were designed using a combination of preliminary experiments — photoluminescence and photo-electrical — and simulations. The aim

was, naturally, for close to 100% conversion across the structure.

Silver gridlines formed an ohmic contact with an  $n^{++}$ -GaAs layer on the n-GaInP window.

The devices were designed to operate at longer than 700nm input radiation. The window layer was transparent to this light and the absorption was expected to be important only in the GaAs n–p layers with optimal performance between 805nm and 845nm. An 830nm-wavelength anti-reflection coating was used.

The number of n–p junctions affects the maximum output voltage, with 6.0V for five junctions and 14.6V for 12 (Figure 2). These give about 1.2V open-circuit voltage ( $V_{oc}$ ) per junction.

The researchers comment: “Our test setup with high-power laser diodes having fixed output wavelengths did not allow us at this time to complete the measurements under fully tuned conditions for all the VEHSAs designs. Still, from the modeled and measured optoelectronic properties, we can deduce that the thin individual n/p junctions are each generating ~1.2V of  $V_{oc}$  when illuminated with an average intensity of a few  $W/cm^2$ . We can also deduce that the voltage of the thinner n/p junction can be higher than for the thicker heterostructures by at least ~20mV.” ■

<http://dx.doi.org/10.1063/1.4941240>

Author: Mike Cooke

# Taking the temperature of light-emitting diode external quantum efficiency

Team seeks to disentangle the various effects that impact performance.

**R**esearchers based in Korea and USA have been studying the temperature dependence of external quantum efficiency (EQE) for a range of commercial light-emitting diodes (LEDs) [Jun Hyuk Park et al, J. Appl. Phys., vol119, p023101, 2016]. The team sought to disentangle the various effects that impact LED performance such as non-radiative Shockley–Read–Hall (SRH) recombination and carrier freeze-out.

SRH recombination through mid-gap states reduces efficiency at higher temperatures. By contrast, carrier freeze-out is a low-temperature factor.

The III-nitride compound semiconductors suffer particularly from high activation energies for the acceptor states that create p-type conduction through hole transport (Table 1). These activation energies are more severe in the wide-bandgap semiconductors needed for shorter-wavelength radiation. This factor leads to an imbalance between the hole and electron concentrations.

The team — from Pohang University of Science and Technology (POSTECH), Chonbuk National University, Rensselaer Polytechnic Institute in the USA, and Samsung Electronics — characterized 620nm red alu-

**For the AlGaInP red LEDs, the effect of SRH recombination on EQE is stronger compared to the effect of hole freeze-out. The effect of asymmetry in carrier concentration is relatively smaller for the AlGaInP red LED. In the AlGaN DUV LEDs, the effect of hole freeze-out is stronger than that of SRH recombination due to the larger acceptor activation energy and the resulting larger carrier asymmetry**

minium gallium indium phosphide (AlGaInP), 450nm blue gallium indium nitride (GaInN), and 285nm deep-ultra-violet

aluminum gallium nitride (AlGaN) LEDs.

The epitaxial materials for these devices were derived from metal-organic chemical vapor deposition (MOCVD).

The active regions were multiple quantum wells: 38-period AlGaInP/AlInP, 5-period GaInN/GaN, and 5-period AlGaN/AlGaN.

Characteristics were measured under pulsed current injection to avoid self-heating of the devices.

The EQE was measured

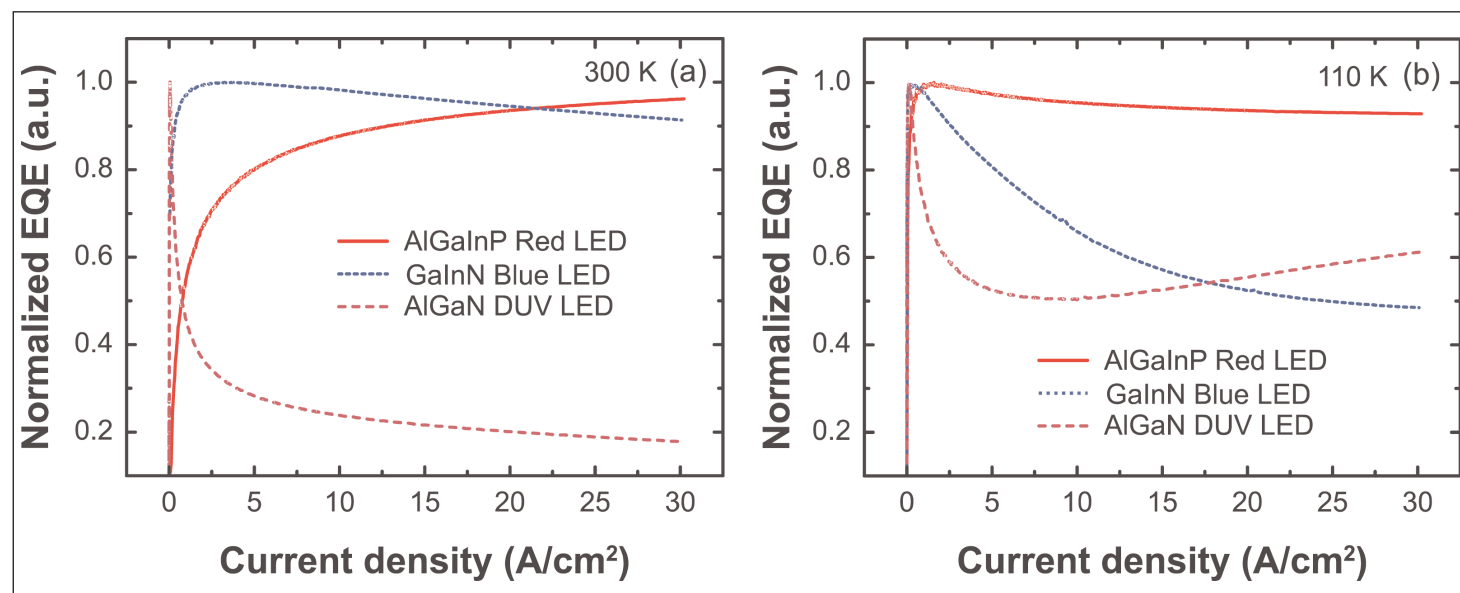


Figure 1. Normalized EQE curves as a function of current density for AlGaInP red LED, GaInN blue LED, and AlGaN DUV LED measured at (a) 300K and (b) 110K.

**Table 1. Typical activation energies for electron donor and acceptor impurities.**

	Donor	Acceptor
AlInP	80meV	76meV
GaN	15meV	170meV
AlN	62meV	630meV

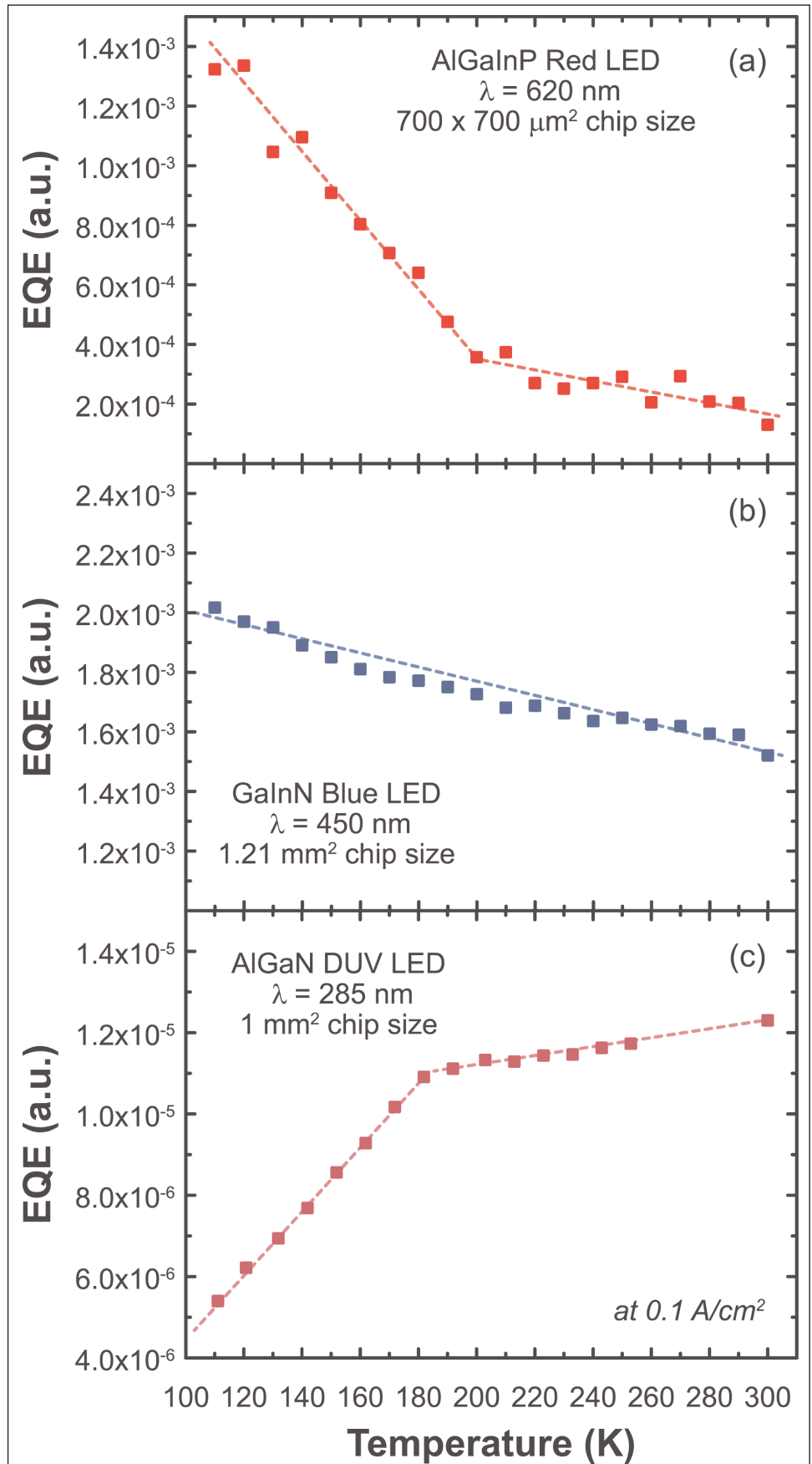
at a range of temperatures. At room temperature (300K), there was no efficiency droop before  $30\text{A}/\text{cm}^2$  for the red device, while the blue and DUV LEDs showed droops of 8.6% and 82.1%, respectively, at  $30\text{A}/\text{cm}^2$  (Figure 1). Lowering the temperature to 110K created a small droop of 7.1% for the red LED. The blue device had an increased droop of 48.8%.

The AlGaIn LED at 110K had a minimum EQE at  $10\text{A}/\text{cm}^2$  and then increased to give a droop of 38.8% on the initial peak at  $30\text{A}/\text{cm}^2$ .

The researchers comment: "The AlGaIn DUV LED has an intrinsically large asymmetry in carrier concentration at cryogenic temperatures, so that the EQE initially decreases (droop), then reaches an EQE minimum point (minimum of 'U-shape'), and then increases again due to the field-ionization of acceptors by the Poole-Frenkel effect."

The Poole-Frenkel effect describes how, under an applied field, acceptor impurities ionize more easily, increasing hole concentration. The DUV LED also had a different temperature behavior under low current injection (Figure 2), with an increase rather than decrease at higher temperature.

The researchers comment: "the experimental data indicate that, for the AlGaInP red LEDs, the effect of SRH recombination on EQE is stronger compared to the effect of hole freeze-out. That is, the effect of asymmetry in carrier concentration is relatively smaller for the AlGaInP red LED. On the contrary, in the AlGaIn DUV LEDs, the effect of hole freeze-out is stronger than that of SRH recombination due to the larger acceptor activation energy and the resulting larger carrier asymmetry." ■



**Figure 2. Temperature-dependent EQE curves for (a) AlGaInP red LED, (b) GaInN/GaN blue LED, and (c) AlGaIn DUV LED measured at  $0.1\text{A}/\text{cm}^2$ .**

<http://dx.doi.org/10.1063/1.4939504>

Author: Mike Cooke

# Improving performance of InGaN LEDs on sapphire substrates

**Mike Cooke** reports on research into semipolar growth, quantum well barrier composition and zinc oxide enhancements.

**C**ommercial indium gallium nitride (InGaN) light-emitting diodes (LEDs) are mostly produced on sapphire substrates, balancing cost versus performance.

Cost can be reduced further by growing III-nitride materials on silicon, but maintaining adequate performance is challenging due to a larger lattice mismatch that generates a higher density of crystal defects.

In the other direction, there are more expensive substrate materials — e.g. silicon carbide and gallium nitride — with smaller lattice mismatches generating higher-quality crystal structures. Further, GaN substrates can be cut in non-standard crystal orientations that allow higher performance LEDs to be created.

Here we report on some recent research work that attempts to improve the performance of LEDs grown on sapphire. This work includes techniques that attempt to implement non-standard crystal orientations, modifying the standard multiple quantum well (MQW) structure, and combining GaN and zinc oxide (ZnO).

## Semipolar growth

Two research groups have reported the growth of semipolar-oriented III-nitride on sapphire, promising more efficient LEDs at reduced cost. Semipolar GaN substrates are typically restricted to very expensive 10mm x 10mm pieces of free-standing or bulk material. Growth of semipolar GaN on sapphire results in low crystal quality in general.

Semipolar devices are attractive for longer wavelengths because electric charge polarization of the GaN chemical bond results in large polarization electric fields that inhibit electron-hole recombination to photons in the MQWs, reducing efficiency in conventional c-plane LEDs. This is often referred to in the literature as the quantum-confined Stark effect (QCSE).

Growth of devices in semipolar or nonpolar directions reduces the polarization electric field and reduces the quantum efficiency decrease, efficiency droop, and the

green and yellow gaps in wavelength coverage associated with QCSEs.

Another advantage of semipolar material is improved incorporation of indium in InGaN layers. High-indium-content InGaN tends to decompose, with indium evaporation, or to segregate into regions of varying compositions, leading to localized states.

## Triangular nanostructures

In one piece of work producing semipolar III-nitride material on sapphire, University of New Mexico (UNM), USA, fabricated triangular-nanostructure core-shell LEDs (TLEDs, Figure 1) on c-plane substrates [Ashwin K. Rishinaramangalam et al, Appl. Phys. Express, vol9, p032101, 2016]. The performance results are described as "preliminary".

The researchers comment: "Upon optimization of these TLEDs to being on par with existing technologies on free-standing GaN, the low cost associated with this approach could potentially become the driving force towards commercial adoption."

By using triangular nanostructures with semipolar sidewalls, the UNM researchers hope to access the advantages for light emission without the non-commercial costs of free-standing substrates.

The researchers prepared a 2µm n-GaN on sapphire template using metal-organic chemical vapor deposition (MOCVD). A 120nm silicon nitride layer was patterned into micron-scale stripes using interferometric lithography. The silicon nitride dielectric also functioned as electrical insulation in the resulting devices. A second lithography step was used to define the device and contact regions. The exposed regions of the silicon nitride were dry etched and the wafer surface cleaned using a 'piranha solution' process before nanostructure growth.

The new growth was carried out with continuous-flow MOCVD. The core was silicon-doped n-GaN. The fast growth of the c-plane leads to emergence of a triangular cross-section with semipolar (10 $\bar{1}$ 1) plane sides.



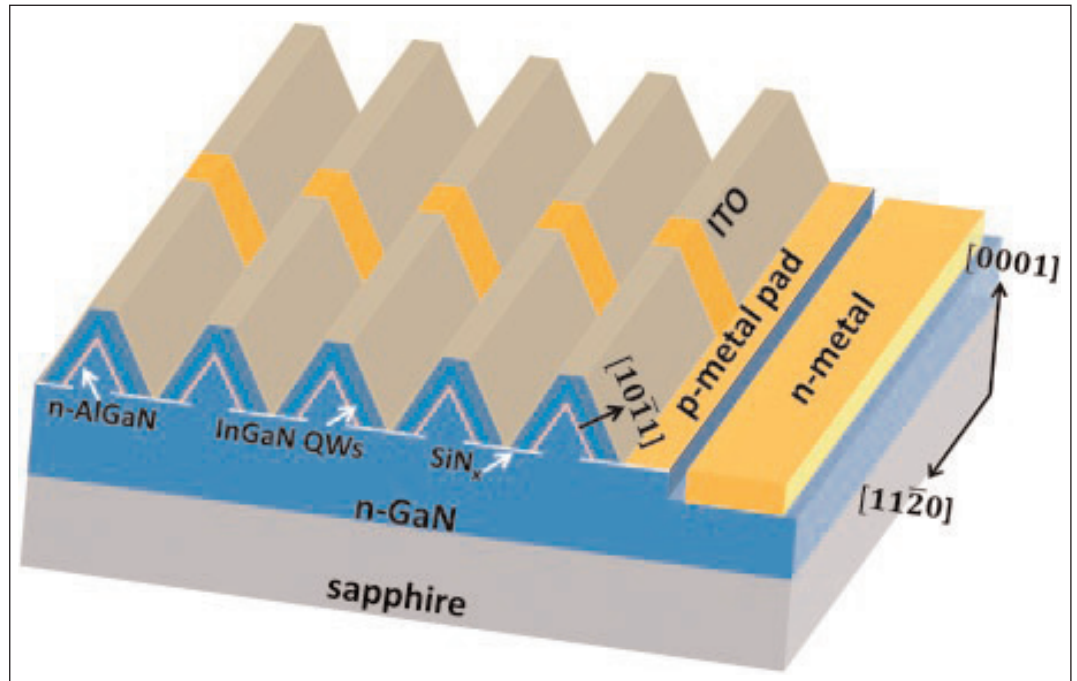
The researchers then applied a thin n-type aluminium gallium nitride (AlGaN) layer to block reverse leakage currents, to getter oxygen impurities, and to fill defects in the silicon nitride mask/insulation.

Further growth consisted of n-GaN electron injection, four InGaN quantum wells (QWs) in GaN barriers (3nm/9nm), and finally a p-GaN contact. The c-plane surfaces on the apex of the triangular cross-section re-emerged during p-GaN growth. The researchers attribute this to the use of hydrogen-rich growth conditions and the faster growth ( $\sim 3\times$ ) of p-GaN on the  $(10\bar{1}1)$  plane, compared with c-plane.

LEDs were fabricated with indium tin oxide (ITO) transparent conducting current-spreading layer, titanium/aluminium/nickel/gold n-electrode, and titanium/gold n- and p-contact pads.

The devices were tested under pulsed currents ( $2\mu\text{s}$ , 2% duty cycle). The electroluminescence (EL) was broadband and significant wavelength blue-shift was seen with increasing current (Figure 2). Wavelength shifts with semipolar devices are usually much smaller than those of c-plane LEDs. Since the peak was to one side of the broadband of emitted radiation, the researchers used the dominant wavelength to characterize the shift. At  $50\text{A}/\text{cm}^2$  current density, the dominant wavelength was  $\sim 465\text{nm}$  compared with a peak at  $\sim 425\text{nm}$ .

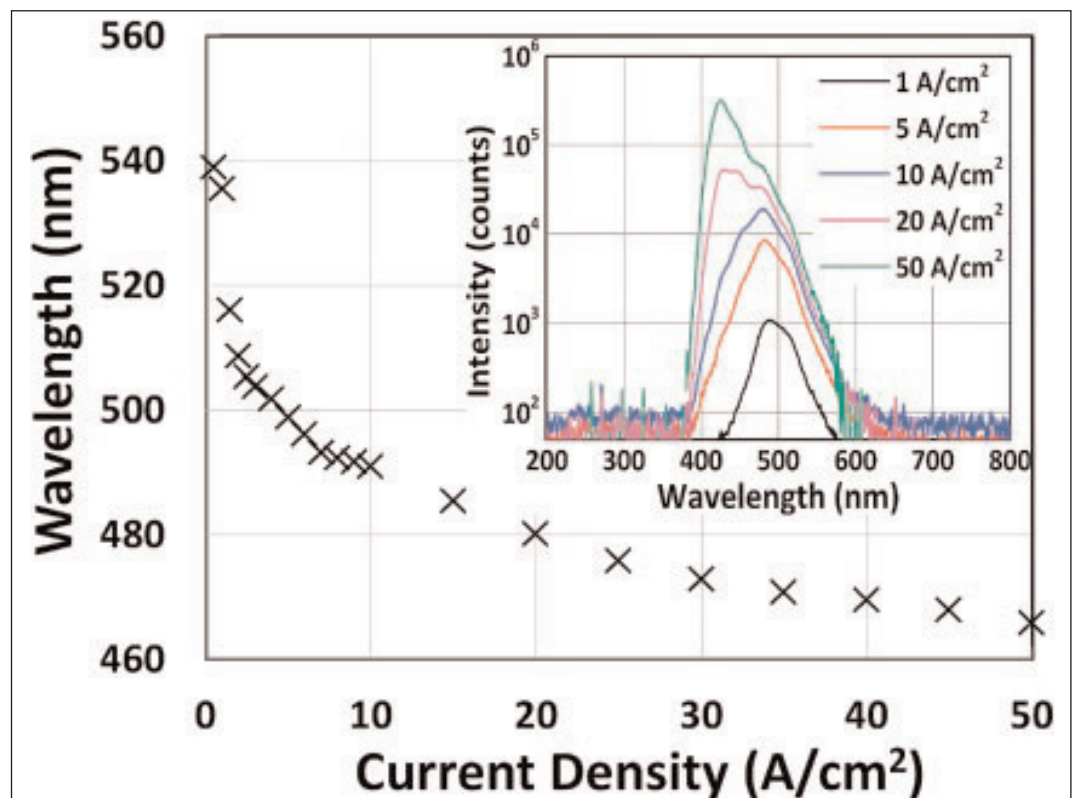
Electron microscope analysis showed the quantum well thicknesses to be non-uniform, thus explaining the broadband emission. The wells were thicker near the apex of the triangular cross-section. The researchers also believe that long-range variation in indium composition of the quantum wells played a role in the broad-



**Figure 1.** Illustration of section of triangular-stripe core-shell nanostructure LED.

band nature of the spectra. Energy dispersive x-ray spectroscopy revealed indium composition 1.5x higher nearer the apex compared with the sidewall.

The researchers explain: "For low injection currents, the path of least resistance is through the thick, high-indium-content QWs near the apex. This results in longer-wavelength emission ( $\sim 480\text{nm}$ ) at low current density, primarily from the QWs near the



**Figure 2.** EL dominant wavelength as function of current density. Inset shows EL spectra.

apexes. As the current density is increased, the current spreading across the nanostructure is improved and a short-wavelength EL peak near 425nm emerges. This peak is attributed to the thin, low-indium-content QWs on the main sidewalls of the triangular stripe. The peak near 425nm shows very small shift in wavelength as a function of current density, as expected for uniform semipolar QWs."

### Overgrowth

University of Sheffield in the UK has also developed semipolar GaN/sapphire, demonstrating its use in long-wavelength InGaN single quantum well (SQW) LEDs [J. Bai et al, Appl. Phys. Lett., vol107, p261103, 2015]. Green to amber devices with peak wavelengths as long as 600nm at 100mA were produced. The researchers describe the EL as "strong" at 100mA.

The Sheffield research developed an overgrowth technique for production of (11 $\bar{2}$ 2) GaN on m-plane sapphire. The team sees applications for solid-state lighting and opto-genetics. Yellow light is particularly useful for controlling the activity of genetically modified cells such as neurons.

The Sheffield group notes that previous semipolar GaN on sapphire devices have been limited to blue and green wavelengths. The researchers comment: "Demonstration of yellow or even longer wavelength such as amber semipolar LEDs with device performance grown on foreign substrates has not yet been reported, as further improvement in growth technologies including crystal quality and enhancing indium incorporation into GaN is requested."

A single layer of (11 $\bar{2}$ 2) GaN was grown by MOCVD on m-plane sapphire using an aluminium nitride (AlN) buffer. The GaN layer was patterned into microrods using photolithographic techniques (Figure 3). The silicon dioxide used as mask was left on top of the GaN microrods.

More MOCVD is then carried out to give an overgrowth (11 $\bar{2}$ 2) GaN template layer about 4 $\mu$ m thick. The silicon dioxide blocks and coalesces defects, reducing dislocation densities to the range 1–4 $\times$ 10<sup>8</sup>/cm<sup>2</sup> and basal stacking fault densities to 1–4 $\times$ 10<sup>4</sup>/cm. X-ray diffraction (XRD) analysis suggests that the process results in a crystal quality approaching that for c-plane GaN on sapphire used for growth of ultra-high bright-

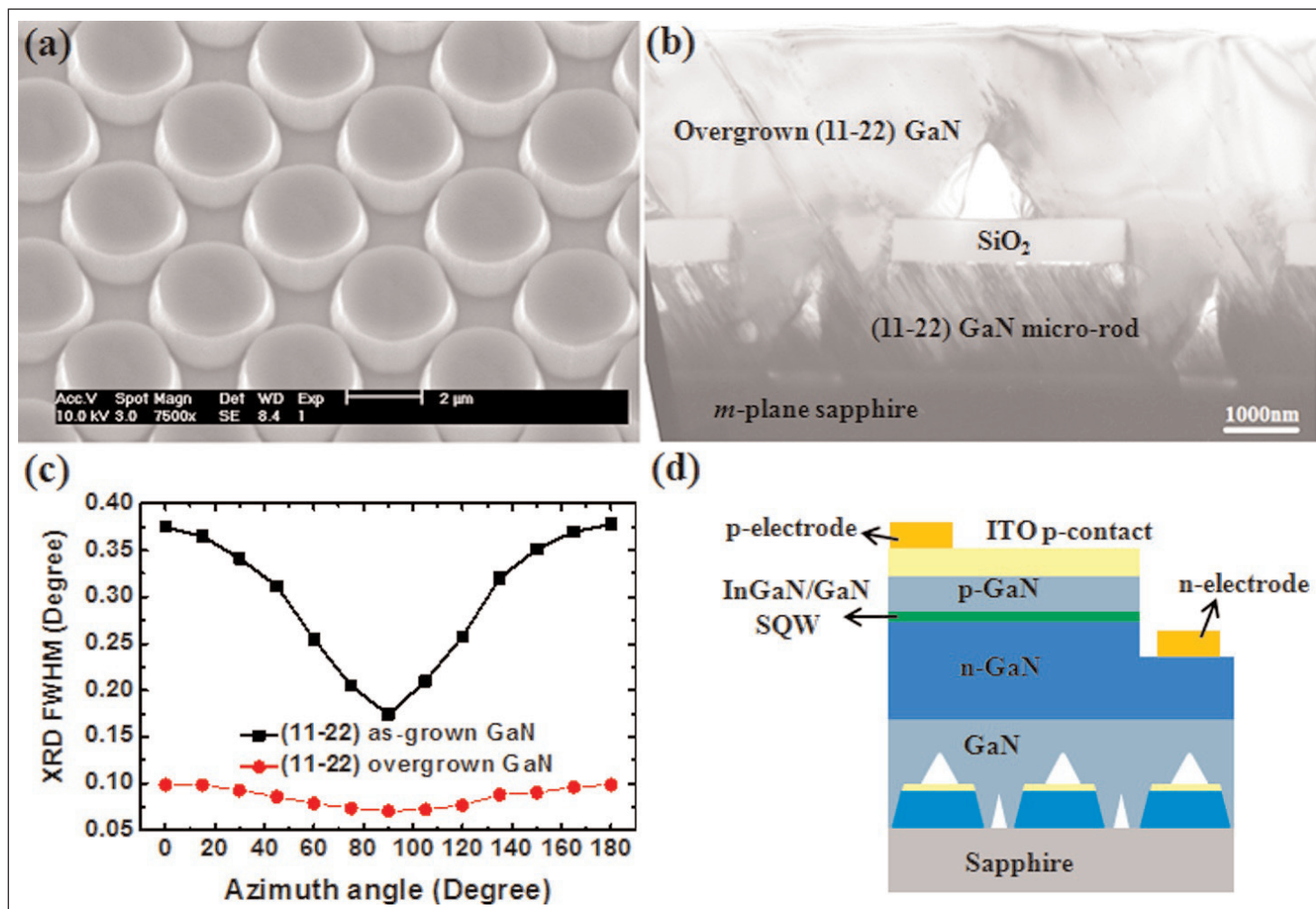
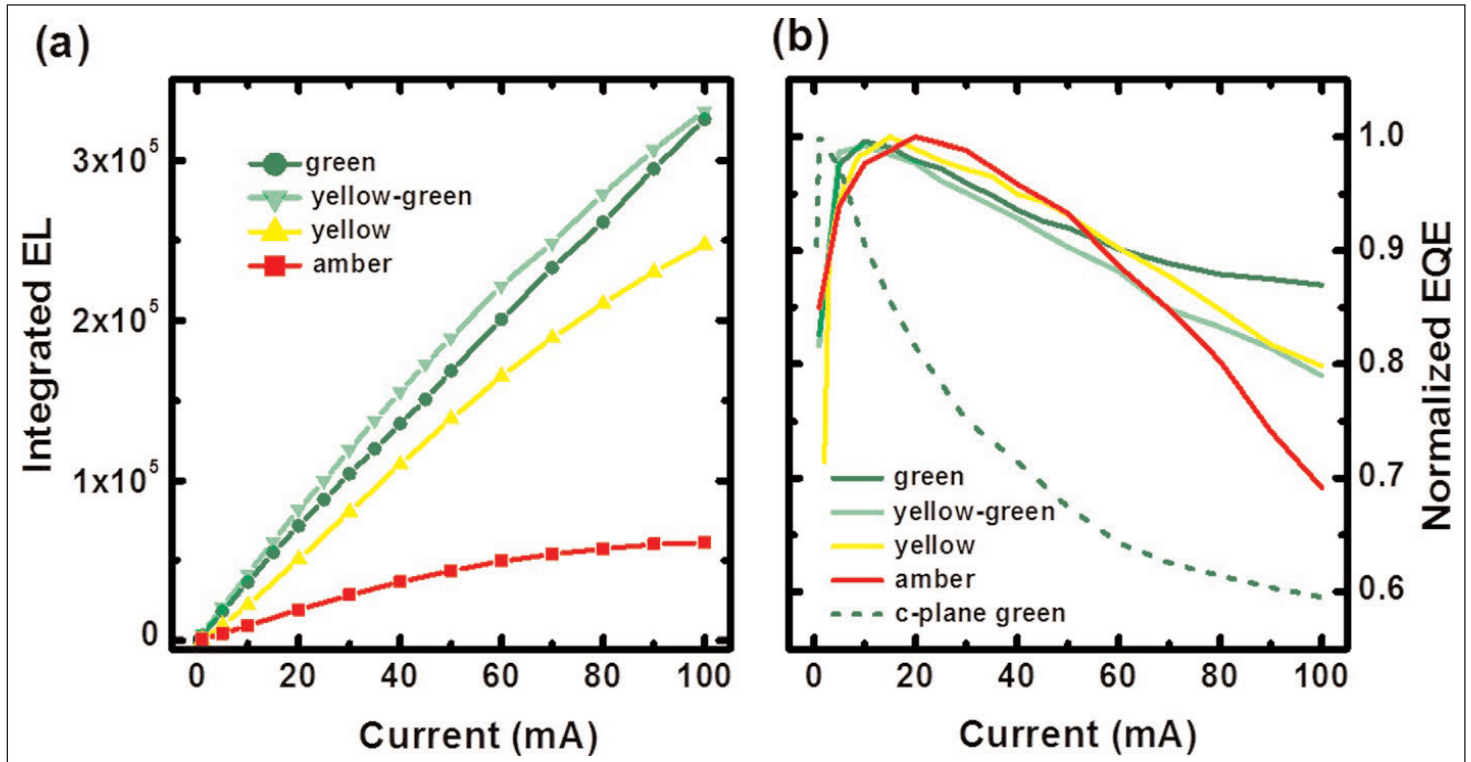


Figure 3. (a) SEM image of micro-rod GaN template; (b) TEM image of (11 $\bar{2}$ 2) GaN overgrown on microrods; (c) XRD full-widths at half maximum (FWHMs) of overgrown (11 $\bar{2}$ 2) GaN and (11 $\bar{2}$ 2) GaN template, measured at azimuth angles ranging from 0° to 180°; (d) schematic of (11 $\bar{2}$ 2) InGaN SQW LED.



**Figure 4. Light output (a) and normalized EQE (b) of the four LEDs as function of current from 1mA to 100mA. Commercial c-plane green LED (dashed line) reference.**

ness blue LEDs.

InGaN SQW structures were grown on the templates. The n-GaN and p-GaN layers were 1  $\mu\text{m}$  and 150nm, respectively. Lateral LEDs on 0.33mm x 0.33mm mesas were fabricated with 100nm indium tin oxide transparent conducting p-contact. The n-contact consisted of titanium/aluminium/titanium/gold. The contact pads were titanium/gold.

LEDs with four different color spectra were produced: green, green-yellow, yellow, and amber. As the wavelength of the light increases, the peaks become broader. In the case of the amber LED, the 600nm peak has a shoulder centered on 630nm at 100mA injection. The researchers say that this behavior is indicative of increasing indium separation at the higher compositions needed for longer wavelengths.

The peak wavelength underwent a blue-shift to shorter wavelengths with increasing current. The amount of shift was greatest with the longer-wavelength devices with high indium content. The green, green-yellow and yellow LEDs shifted 8nm, 15nm, and 19nm, respectively, between 1mA and 100mA. In c-plane green LEDs the corresponding shift is typically 13nm.

The researchers comment: "This suggests that the QCSEs in our (11 $\bar{2}$ 2) LEDs are effectively suppressed."

The amber devices had an even greater shift that could indicate significant segregation effects with lower-energy localized states being populated at low current injection. These state fill up at higher currents forcing shorter-wavelength transitions, accounting for the large  $\sim 50\text{nm}$  shift. In fact, in the lower current

injection range less than 20mA one could consider the LED to be emitting red light (620–740nm).

Problems with fabrication also increased the turn-on voltage of the amber devices ( $\sim 4\text{V}$  at 20mA). In particular, the p-GaN layer had to be grown at a lower temperature than normal to avoid damage to the InGaN single quantum well. The 20mA voltage for the other devices was in the range 3.0–3.4V, which is standard for InGaN LEDs.

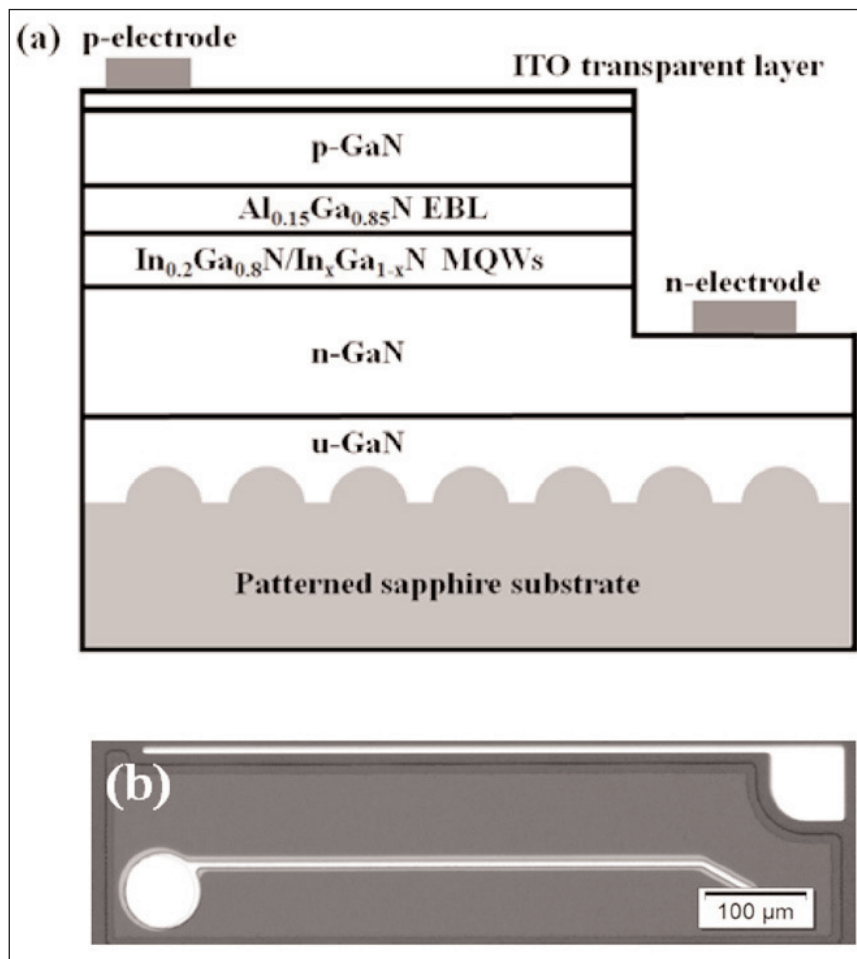
The amber device also suffers from lower light output (Figure 4). All devices have better external quantum efficiency (EQE) performance in terms of droop, compared with commercial c-plane devices. The EQEs at 100mA relative to the maximum were 87%, 80%, 79% and 69% for the corresponding green, green-yellow, yellow and amber devices. The conventional c-plane device in the figure had an EQE at 49% of the maximum ( $\sim 3\text{mA}$ ).

### Barrier enhancement

South China University of Technology has shown improved power and efficiency performance for InGaN LEDs with 1.2% indium-content multiple-quantum-well (MQW) barriers [Zhiting Lin et al, J. Phys. D: Appl. Phys., vol49, p115112, 2016].

The purpose of the research was to study the effect of indium in MQW barriers. Most commercial MQW designs use pure GaN barriers (i.e. 0% indium).

The epitaxial heterostructures were grown by MOCVD on 2-inch (0001) patterned sapphire (Figure 5). The undoped buffer layer was 4  $\mu\text{m}$ . The n-GaN contact was



**Figure 5. (a) Epitaxial structure of as-grown LEDs; (b) optical micrograph of chip.**

3  $\mu\text{m}$ . The electron-blocking layer (EBL) and p-contact were 20nm and 150nm, respectively.

The MQW region consisted of seven 3nm wells separated by 14nm barriers. The wells had 20% indium content. The variation in indium content in the barriers was achieved through changing the trimethyl-indium

precursor flux. The indium content was evaluated using XRD analysis.

Standard InGaN LED chips were fabricated with 250nm indium tin oxide (ITO) transparent conductor, and chromium/platinum/gold n- and p-electrodes. The chip dimensions were 750  $\mu\text{m}$  x 220  $\mu\text{m}$ .

The highest light output power above 20mA injection current was achieved with 1.2%-In barriers (Figure 6) — at 70mA the increase over pure GaN barriers was 15.4%. The light output decreased significantly when the indium content in the barriers exceeded 2%.

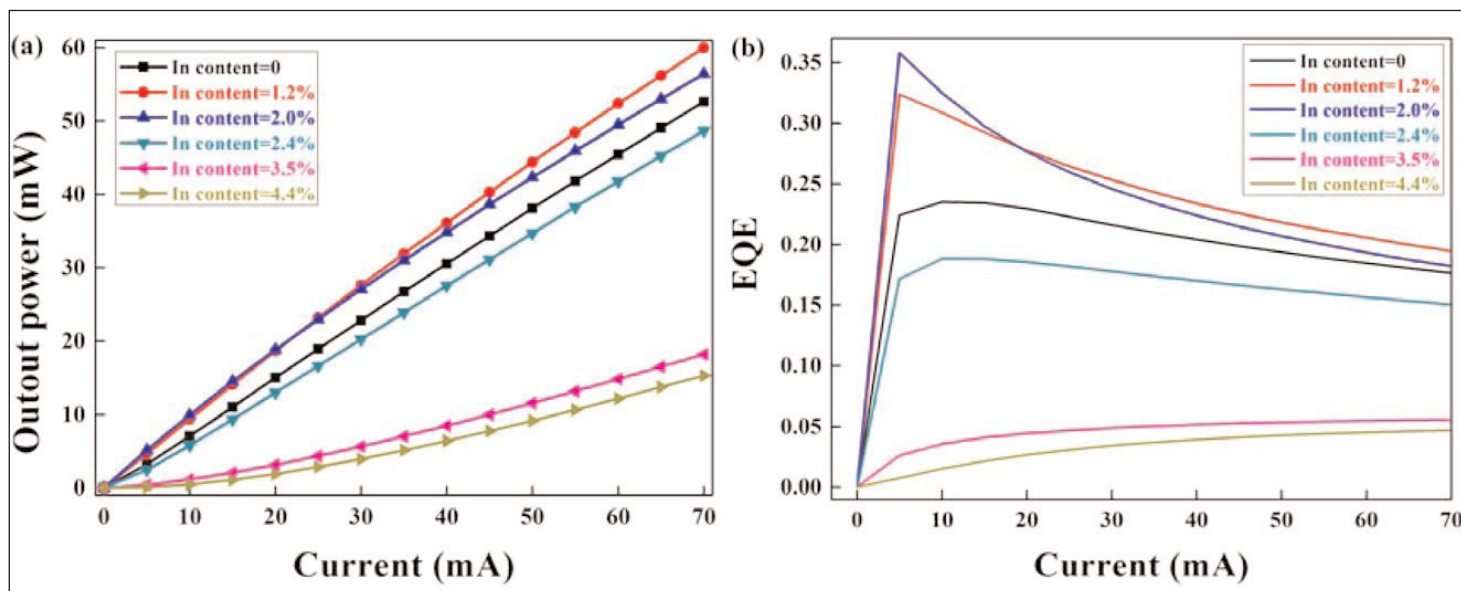
Although the 2.0%-In barrier gave the highest peak external quantum efficiency (EQE), the 1.2%-In barrier was better at reducing the droop effect at higher injection current. At 70mA, the 2.0%- and 1.2%-In barriers gave EQE values 3.3% and 10.3% better than for pure GaN barriers, respectively.

The researchers therefore consider 1.2% indium to be the optimal content for InGaN barriers. X-ray analysis suggested that problems with increased indium content included increasing roughness of the well/barrier interface and degraded crystal quality.

One cause of such problems could be the increased lattice mismatch between the barrier and the underlying GaN lattice constant. The thinner wells should be less affected by crystal quality degradation,

despite the higher indium content. However, the reduced crystal quality of the barriers and the interface roughness do have their effect on the quality of subsequent well growth, inducing the creation of non-radiative recombination centers.

Photoluminescence analysis showed a slight reduction



**Figure 6. (a) Light output power versus current and (b) EQE versus current.**

in intensity for 1.2%-In barriers, compared with pure GaN. As the indium content was increased beyond 1.2%, the photoluminescence decreased sharply.

The researchers used simulations to suggest that a positive effect of increasing indium content in the barriers was to increase carrier concentrations in the MQW structure. "We propose that the gain on carrier concentration and the crystalline quality degradation are a pair of opposite influential factors as the indium content of InGaN barriers increases," they write.

The calculations also suggest that the increase in indium increases the potential barrier for electrons while reducing that for holes.

### Ultraviolet light from ZnO

Jilin and Zhengzhou universities in China have increased the EL of zinc oxide/gallium nitride (ZnO/GaN) heterojunction light-emitting diodes (LEDs) by growing the crystal layers with oxygen/nitrogen polarities [Junyan Jiang et al, Appl. Phys. Lett., vol108, p063505, 2016].

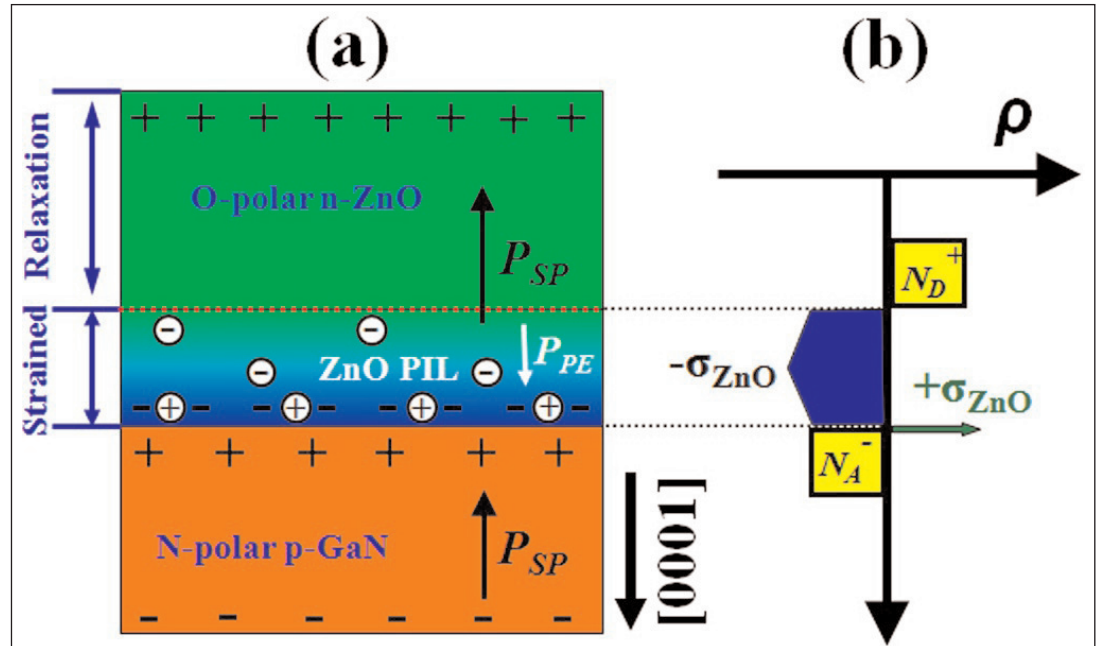
The change from the more usual zinc/gallium polarity shifts the depletion layer of the p-n GaN-ZnO junction from the interface region into the ZnO, where recombination through excitons can lead to efficient production of ultraviolet (UV) photons. ZnO has a particularly strong  $\sim 60\text{meV}$  exciton binding of electron and holes. Also the direct bandgap is  $3.37\text{eV}$ .

The excitons in GaN have bindings around  $20\text{meV}$ , which is comparable to room temperature thermal effects ( $\sim 26\text{meV}$ ). ZnO p-n junctions are extremely difficult to realize because p-type material cannot be fabricated in a repeatable/reliable manner. There have been hopes of combining n-ZnO and p-GaN, but usually the EL is weak or undetectable from the ZnO side.

The LED materials were grown on c-plane sapphire ( $\text{Al}_2\text{O}_3$ ) substrates in an Aixtron CCS 3x2-inch flip-top MOCVD reactor.

The N-polar p-GaN layer had a hole concentration of  $2.4 \times 10^{17}/\text{cm}^3$ . The O-polar n-ZnO layer was produced in a two-step photo-assisted MOCVD process, using diethyl-zinc and oxygen precursors in argon carrier.

The two ZnO steps consisted of a  $450^\circ\text{C}/6\text{Torr}$  buffer,



**Figure 7. (a) Schematic of O-polar n-ZnO/N-polar p-GaN heterostructure with polarization-induced inversion layer. Fixed charges induced by spontaneous and piezoelectric polarization are also displayed. (b) Spatial distribution of fixed polarization charges and ionized dopants in O-polar n-ZnO/N-polar p-GaN heterostructure.**

followed by a  $650^\circ\text{C}/12\text{Torr}$   $450\text{nm}$  layer. The electron concentration was  $2.7 \times 10^{17}/\text{cm}^3$ . Sputtered nickel/gold and gold were used as p-GaN and n-ZnO contacts for the LEDs.

Naively one expects the depletion region of a p-n junction to be mostly in the region with lowest carrier concentration. However, the chemical bonds of both ZnO and GaN have a large ionic component, resulting in charge polarization effects (Figure 7).

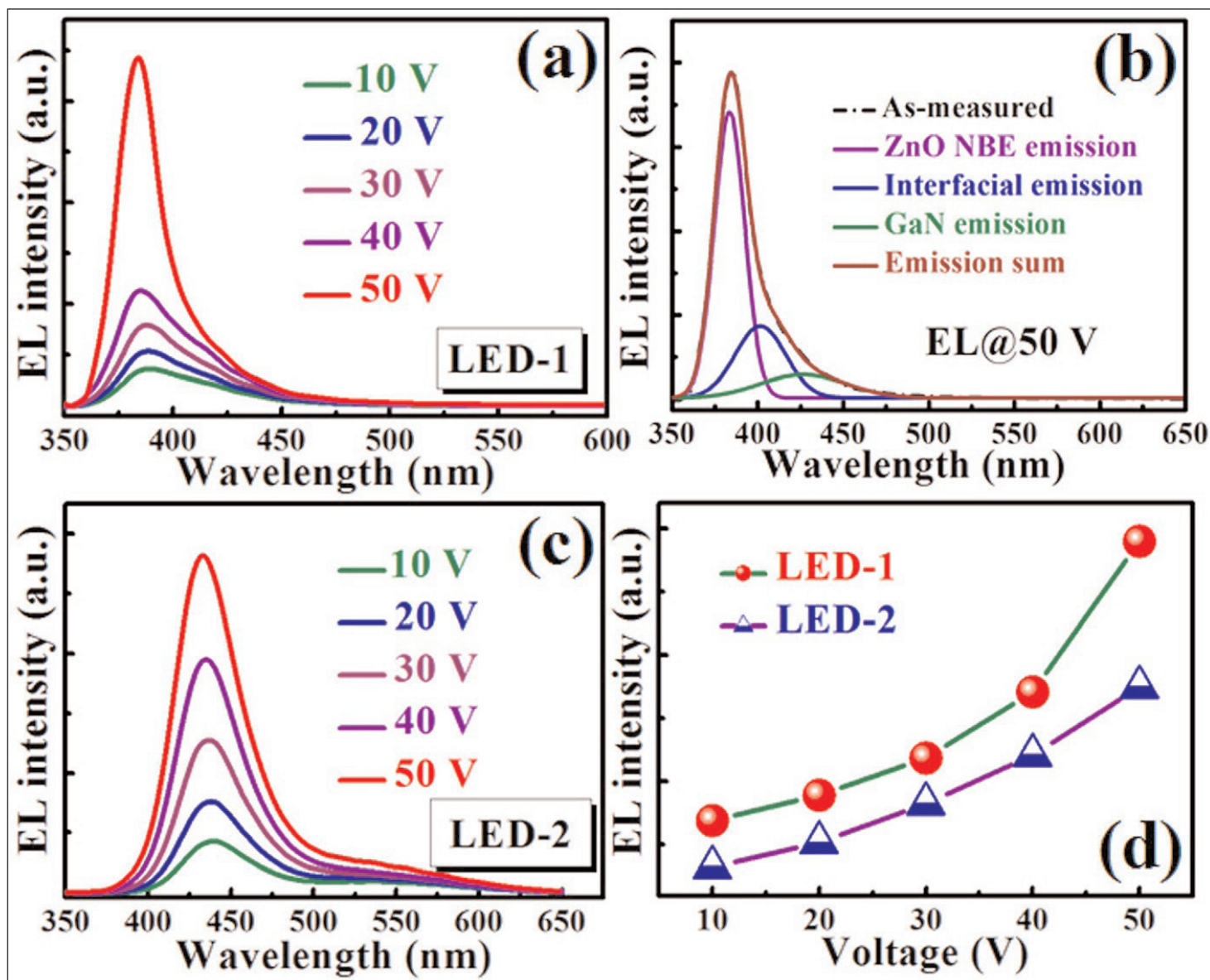
The different polarizations of ZnO and GaN give rise to charge dipole layers at interfaces and electric fields in the bulk of the material. There are both spontaneous and strain-dependent/piezoelectric polarization effects.

The early part of the ZnO layer is under compressive strain due to a 1.8% lattice mismatch with GaN. The compression relaxes later on in the growth. This leads to a polarization interface charge and a distributed charge from the varying strain as the ZnO relaxes.

In O-polar n-ZnO/N-polar p-GaN the depletion layer is shifted into the ZnO layer by a polarization-induced inversion layer (PIL). This gives rise to hopes that the electron-hole recombination will occur on the ZnO side, giving highly efficient UV emission based on excitons.

The LEDs had a turn-on voltage around  $3\text{V}$  and demonstrated rectifying behavior. The researchers observed "strong" UV EL centered at  $\sim 385\text{nm}$  (Figure 8). A Gaussian fit of the  $50\text{V}$  spectrum gave three peaks at  $383\text{nm}$ ,  $402\text{nm}$ , and  $430\text{nm}$ .

The researchers associated the strong  $383\text{nm}$  UV emission with ZnO near-band edge (NBE) transitions



**Figure 8. (a) EL spectra of LED-1 (O-polar/N-polar) under various forward bias voltages ranging from 10V to 50V. (b) Gaussian deconvolution of a representative EL spectrum from LED-1 measured at 50V. (c) EL spectra of LED-2 (Zn-polar/Ga-polar) under various forward bias voltages ranging from 10V to 50V. (d) Relationship between integrated EL intensity and voltage of two LEDs.**

from free and bound excitons. The 430nm blue emission was attributed to transitions in the p-GaN to the magnesium acceptor level. The researchers add: "The blue emission at 402nm is from the interfacial recombination of the electrons from n-ZnO and the holes from p-GaN."

The researchers also produced a comparison LED-2 with Zn-polar n-ZnO and Ga-polar p-GaN. The p-GaN hole concentration was  $\sim 2 \times 10^{17}/\text{cm}^3$ . The EL emission from this device was broad and centered on 435nm (blue). The researchers interpret this as indicating that the depletion region is primarily on the p-GaN side. By contrast, the team believes the depletion region for the O-polar n-ZnO/N-polar p-GaN combination for LED-1 is completely on the ZnO side.

The group comments: "If the PIL of ZnO film is thick enough, the injected electrons and holes could be

effectively confined into ZnO side, producing UV emission from ZnO. More importantly, it is found that the light output power of LED-1 is relatively higher than that of LED-2 under the same test conditions."

At 50V, the O-polar n-ZnO/N-polar p-GaN LED-1 intensity exceeded that of LED-2 by 66%.

LED-1's full-width at half maximum became narrower with higher voltage: 48nm at 10V and 24nm at 50V. "As the forward bias changes from 10 to 50V, the intensity of ZnO NBE emission increases much faster than other two components. And it plays a dominant role when the forward bias is higher than 30V." The narrow NBE emission's increasing dominance reduces the FWHM value. ■

*The author Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.*

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# Hybrid MOCVD/MBE growth of III-nitride tunnel junctions

Molecular beam epitaxy has been used to apply n-type layers on metal-organic chemical vapor deposition grown p-type GaN

University of California Santa Barbara (UCSB) in the USA has been developing a hybrid technique to create III-nitride tunnel junctions (TJs) using a combination of metal-organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE) [Erin C. Young et al, Appl. Phys. Express, vol9, p022102, 2016].

Efficient tunnel junctions could replace indium tin oxide (ITO) current-spreading layers with n-type gallium nitride (GaN) in light-emitting diodes and lasers. Tunnel junctions could also be used in multi-junction solar cells based on III-nitride absorbing layers.

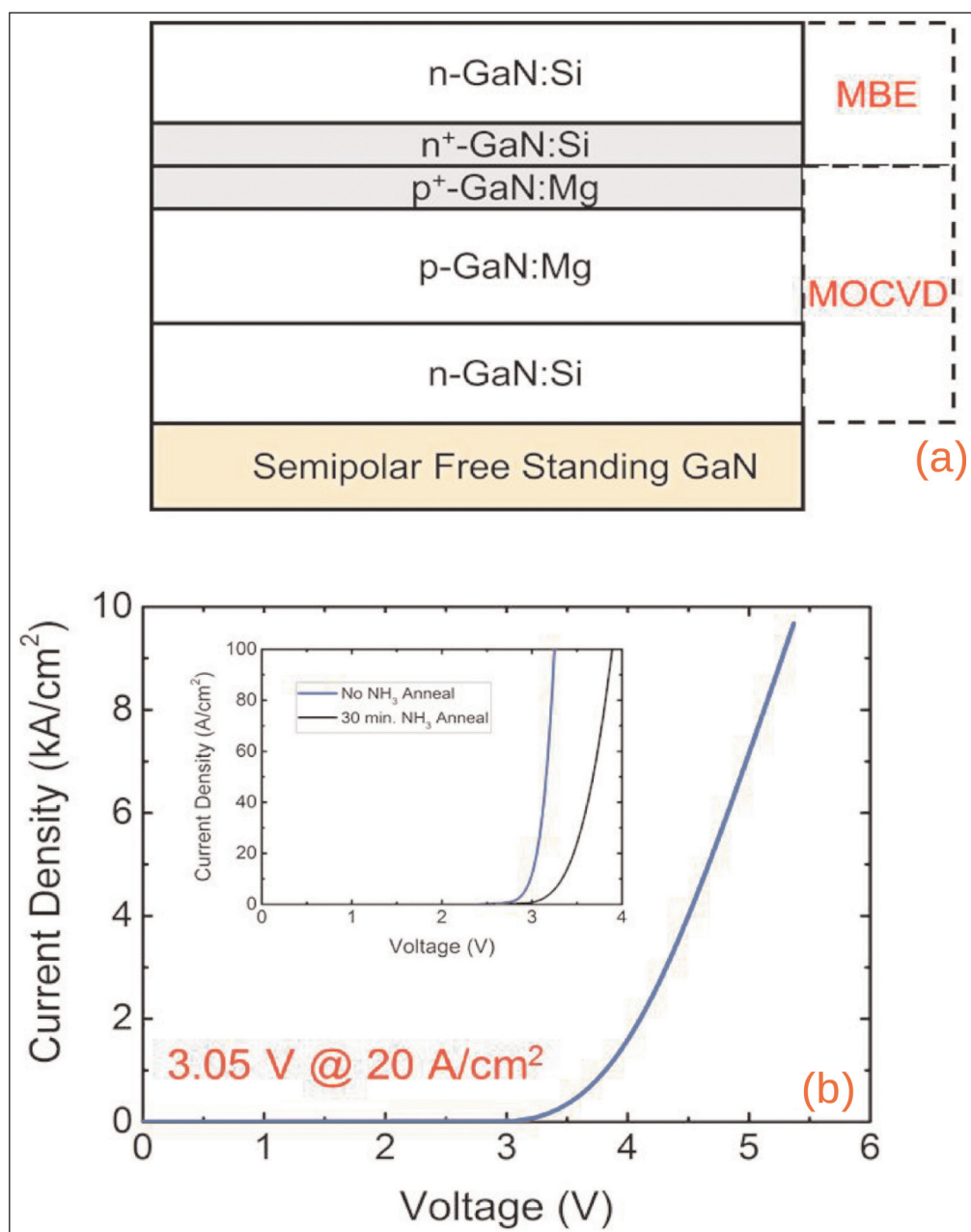
Tunnel junctions are based on flow across very thin depletion layers in p-n junctions. Unfortunately, the wide bandgap of  $\sim 3.4\text{eV}$  for GaN leads to relatively large 20nm depletion layers when the doping levels are around  $1 \times 10^{19}/\text{cm}^3$ . Such a thick depletion layer chokes off the tunneling current. Increasing the doping level in GaN can be tricky, particular for p-GaN. The difficulties with p-GaN mean that device designs usually place it last in the growth sequence.

Most development of tunnel junctions so far has involved MBE, but MOCVD is the preferred technology in commercial production.

The n-type side of the tunnel junction was grown by ammonia ( $\text{NH}_3$ ) MBE on MOCVD GaN p-n and light-emitting diode devices on free-standing semi-polar GaN supplied by Mitsubishi Chemical.

The MBE n-GaN material consisted of a thin heavily doped layer followed by a thicker current-spreading

layer. The optimum combination of electrical and optical characteristics – low resistance and high trans-



**Figure 1. (a) Schematic of test structure with MOCVD p-n diode and re-grown MBE n-GaN. (b) I-V characteristics (a) up to current density of 10kA/cm<sup>2</sup>, for devices with 25µm radius. Inset: effect of in-situ NH<sub>3</sub> annealing prior to MBE re-growth on same devices. Annealed sample showed a higher turn-on voltage and differential resistance compared with unannealed sample.**



parency — for the heavily doped layer was found with a carrier concentration of  $\sim 1 \times 10^{20}/\text{cm}^3$ .

Before MBE the samples were cleaned in solvent. During the 15-minute ramp-up to the 750°C MBE re-growth temperature, the top p-GaN layers were activated. Annealing processes for activating p-GaN generally remove hydrogen, which passivates magnesium doping. Since  $\text{NH}_3$  was used in the MBE process, it was important to start the re-growth with low ammonia flow to avoid reintroducing hydrogen into the p-GaN interface. The researchers note that the hydrogen level in ammonia MBE is several orders of magnitude lower than that found in MOCVD growth processes.

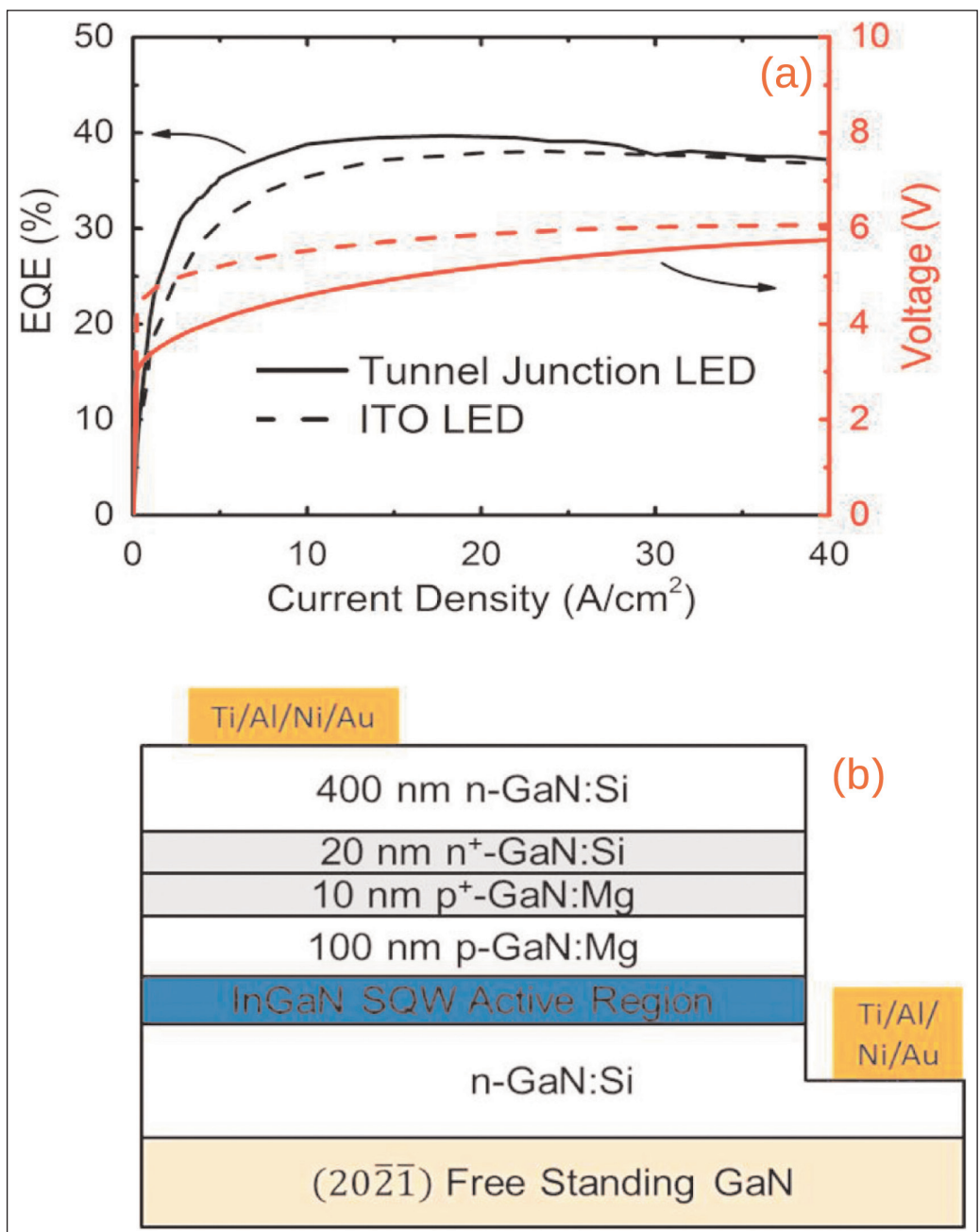
The team also found that the presence of oxygen at the interface could enhance performance. They comment: "The development of a controllable procedure for introducing oxygen at this interface will be a key to ensuring the repeatability of TJ device characteristics."

The oxygen was detected using atom probe tomography (APT). The researchers comment: "The strong overlap of the Mg and O suggests that a donor-acceptor complex such as  $\text{ON-2MgGa}$  could have formed at the interface, effectively preventing free surface Mg from incorporating into the n-side of the TJ during regrowth."

Such an effect could lead to a more abrupt drop-off in magnesium concentration, improving the tunneling through the depletion layer.

The material was used to create devices with titanium/gold contacts to the n-GaN material. Reference devices without the tunnel junction were produced with palladium/gold p-contacts. Contacts with ITO were chromium/nickel/gold.

The researchers created tunnel junction on p-n diodes with total differential resistivity between  $7\text{kA}/\text{cm}^2$  and  $10\text{kA}/\text{cm}^2$  of  $1.5 \times 10^{-4} \Omega\text{-cm}^2$ , including contact resistance (Figure 1). The voltages at  $20\text{A}/\text{cm}^2$  and  $5\text{kA}/\text{cm}^2$  were 3.05V and 4.67V, respectively.



**Figure 2. (a) External quantum efficiency and voltage versus current density for TJ LED (solid lines) and ITO reference LED (dotted line) and (b) schematic of TJ LED. Device area was  $0.1\text{mm}^2$ .**

The team comments: "We consider this to be among the lowest resistivity and voltage characteristics reported for any III-nitride TJ."

Comparing blue LEDs with tunnel junction and indium tin oxide (ITO) current-spreading layers (Figure 2), the researchers found that the tunnel junction device had a lower voltage of 5.2V at 20mA, compared with 5.87V for the ITO LED. These voltages were on the high side for such devices – the researchers blame unoptimized n-contacts with Schottky, rather than ohmic, behavior.

The tunnel-junction LED also had improved external quantum efficiency (EQE) in the low-current range. ■

<http://doi.org/10.7567/APEX.9.022102>

Author: Mike Cooke

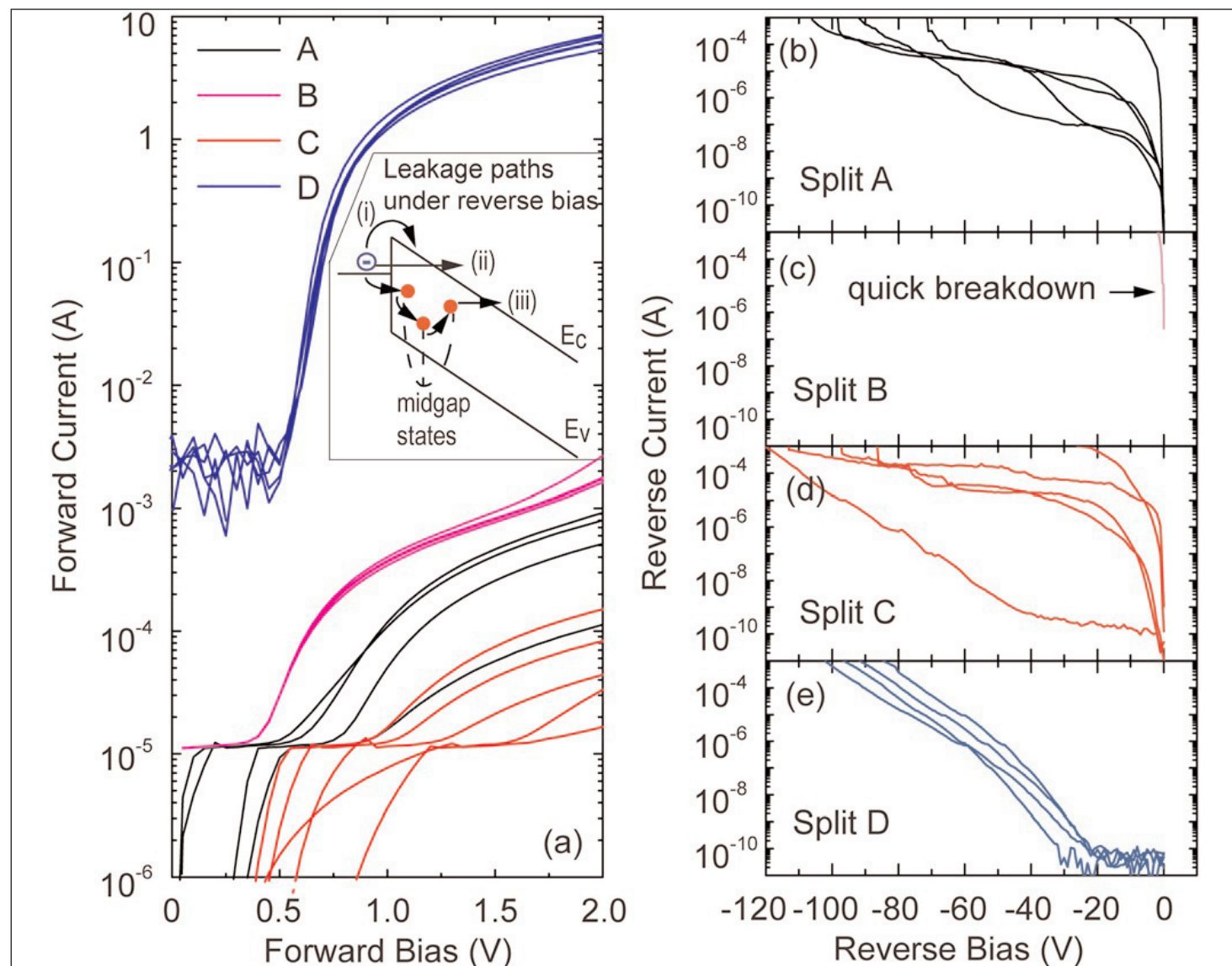
# HRL creates low-carbon gallium nitride layers for Schottky barrier diodes

Devices achieve 0.77V turn-on and more than 800V breakdown.

**H**RL Laboratories LLC in the USA has been developing vertical gallium nitride (GaN) Schottky barrier diodes (SBDs) with low turn-on voltages of 0.77V and breakdown at more than 800V [Y. Cao et al, Appl. Phys. Lett., vol108, p062103, 2016].

Vertical GaN structures have recently been studied with a view to high-voltage/power/frequency electronics,

based on the material's high critical field for breakdown. Vertical current flow can push the peak field into the material, avoiding premature breakdown through surface states and passivation effects. A number of groups have reported on vertical p-n diodes on free-standing and bulk GaN, but these have high turn-on voltages around 3V. SBDs should have much lower



**Figure 1.** Plot of forward (a) and reverse current in diodes layers grown according to parameters (b) A, (c) B, (d) C and (e) D as function of bias voltage. Inset (a) shows three leakage paths under reverse bias.

turn-on voltages, reducing conduction losses during operation.

The researchers first studied the effect of different metal-organic chemical vapor deposition (MOCVD) growth conditions on carbon incorporation by creating a stack of GaN layers separated by AlGaIn spacers on free-standing GaN. The carbon concentration varied between less than  $3 \times 10^{15}/\text{cm}^3$  and  $3 \times 10^{19}/\text{cm}^3$  (see Table 1).

Carbon arises from the metal-organic precursors of the MOCVD process. The effect of carbon incorporation in GaN is various, and more than eight different trap states have been associated with the impurity and its incorporation at Ga or N sites.

The same growth conditions were used to produce separate GaN layers on free-standing GaN. The surface roughness of the highest-carbon-concentration layer was more than 1nm root mean square (RMS). The RMS roughness of the other layers was less than 1nm. X-ray analysis also showed that the high-carbon layer had a high density of screw dislocations.

A nickel/gold 1.8mmx1.8mm Schottky contact was created on each GaN layer. The backsides of the wafers were coated with titanium/gold to form the other ohmic contact. There was no isolation.

The on-current of the devices was low, except for the low-carbon device (D, Figure 1). The researchers explain: "This means most free electrons are trapped in GaN when the concentration of carbon is at  $8 \times 10^{16}/\text{cm}^3$  or higher." Device D had a turn-on voltage of 0.7V. Device D also had lower leakage under reverse bias, with 1mA being reached beyond 80V. The other SBDs reached 1mA leakage before 70V.

The growth parameters D were used to create a  $6\mu\text{m}$  lightly silicon-doped n-GaN drift layer with low carbon concentration. The n-type doping was around  $10^{16}/\text{cm}^3$ . SBDs were fabricated with ion-implant edge termination and  $0.8\text{mm} \times 0.8\text{mm}$  Schottky contacts. The overlap between the edge termination and contact was  $10\mu\text{m}$ .

The resulting SBD achieved a breakdown of more than 800V for  $1\text{mA}/\text{mm}^2$  ( $0.64\text{mA}$ ) reverse leakage (Figure 2). The forward current at +2V was close to  $1.6\text{A}$

**Table 1. Growth conditions for different carbon concentrations. Temperature around  $1040^\circ\text{C}$  for all layers.**

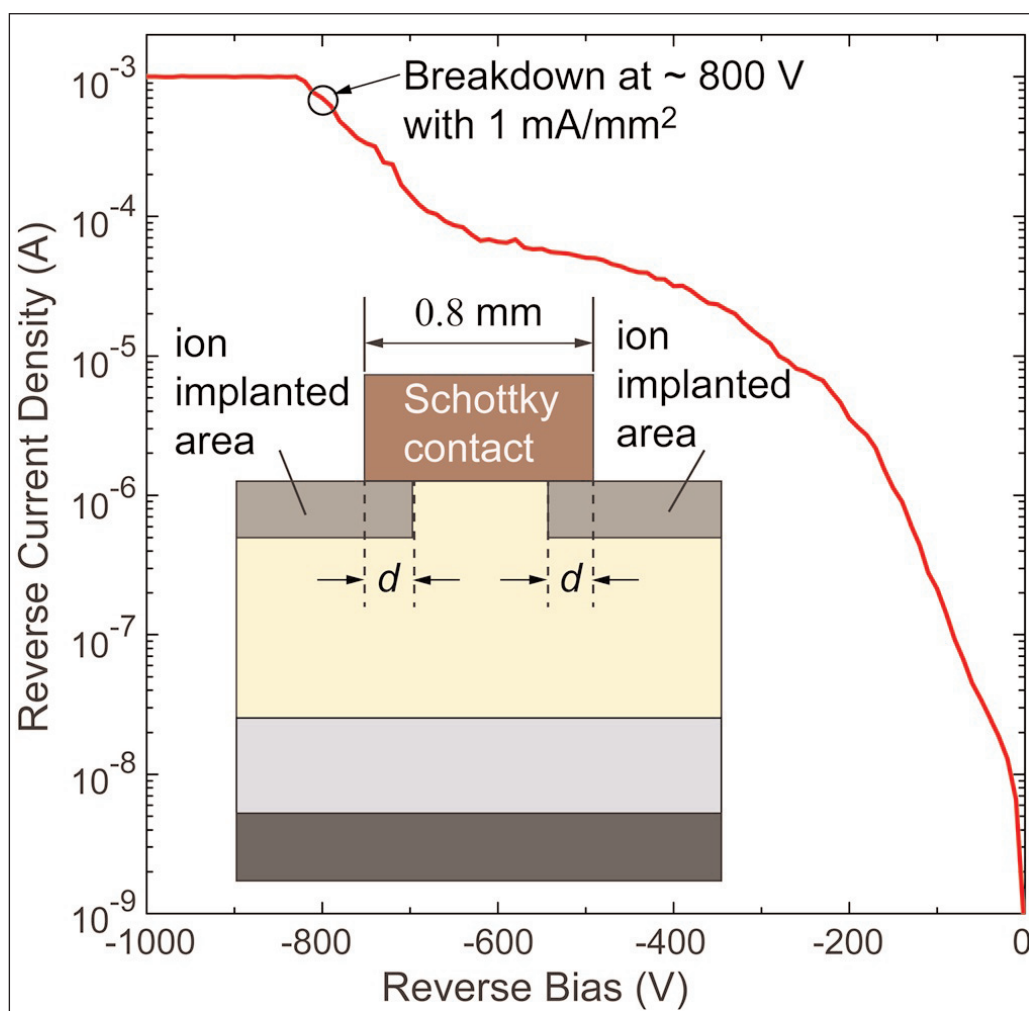
Layer	Pressure (Torr)	V/III ratio	Growth rate ( $\text{\AA}/\text{s}$ )	Carbon ( $/\text{cm}^3$ )
A	50	954	6.99	$3 \times 10^{19}$
B	100	1717	7.14	$8 \times 10^{17}$
C	100	3981	3.76	$8 \times 10^{16}$
D	300	4777	2.19	$3 \times 10^{15}$

and the specific on-resistance was around  $5\text{m}\Omega\text{-cm}^2$ . The researchers claim the 0.77V turn-on voltage as among the lowest so far for GaN vertical diodes.

Through capacitance-voltage analysis, the researchers find a maximum electric field at breakdown of  $1.38 \times 10^6\text{V}/\text{cm}$  at the Schottky/GaN interface. This value falls short of the theoretical value of  $3.3 \times 10^6\text{V}/\text{cm}$ . "This means the breakdown is limited by the leakage through the barrier and could be further improved by enhancing the barrier height by surface treatment," the researchers comment. ■

<http://dx.doi.org/10.1063/1.4941814>

Author: Mike Cooke



**Figure 2. Plot of reverse leakage current in diode with  $6\mu\text{m}$  GaN drift layer as a function of bias. Inset: schematic of diode structure with isolation.**

# Aluminium ion implants for lateral gallium nitride transistors

**Process reduces off-current leakage with little degradation of on-current.**

**R**esearchers in China have been studying the potential of aluminium (Al) ion implantation for creating back-barriers and device isolation in gallium nitride (GaN) metal-insulator-semiconductor high-electron-mobility transistors (MISHEMTs) on silicon substrates [Shichuang Sun et al, Appl. Phys. Lett., vol108, p013507, 2016].

The team from Huazhong University of Science and Technology and Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO) comments that, with optimization, Al ion implantation offers a great potential method for creating high-performance AlGaN/GaN HEMTs.

The resulting devices showed much reduced off-current with only a small impact on the on-current. GaN transistors are being developed for high-voltage switching and high-frequency power amplification.

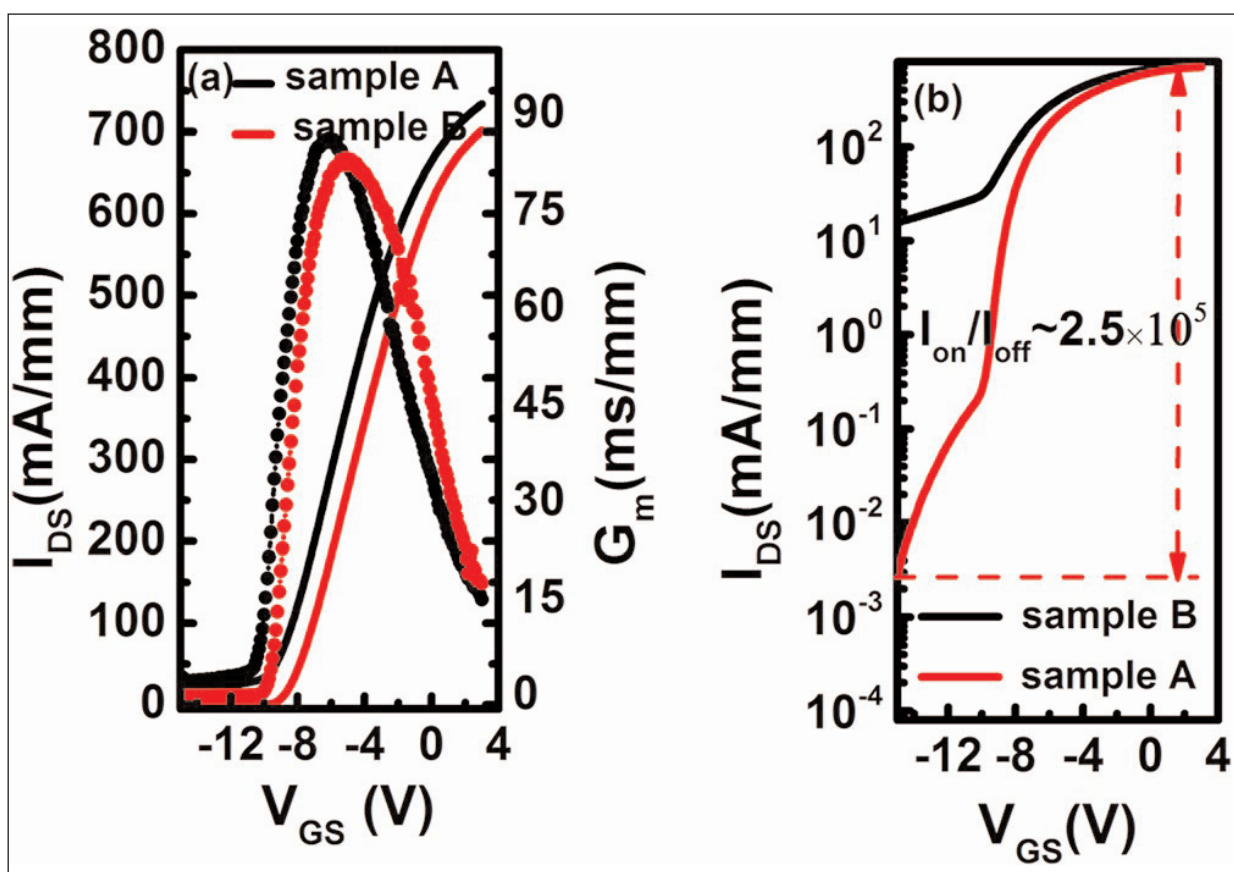
The 600nm resistive GaN buffer was grown on (111) silicon with an AlGaN/AlN transition layer by metal-organic chemical vapor deposition (MOCVD). The aluminium implant was carried out at two energies (140keV/90keV) to give a uniform ion profile.

The templates were cleaned and thermally treated before MOCVD re-

growth. The thermal process consisted of a 12 minute ramp up to 1050°C in ammonia/hydrogen and then maintaining the temperature for a further 5 minutes. The treatment aimed to repair lattice damage from the ion implant. The thermal process was carried out in the MOCVD chamber.

The re-growth sequence was 100nm undoped GaN, a 1nm AlN interlayer, a 20nm Al<sub>0.25</sub>Ga<sub>0.75</sub>N barrier, and a 3nm GaN cap. The researchers claim that there was no observable damage at the interface with the ion-implanted template.

The Hall resistance and carrier concentration in the two-dimensional electron gas (2DEG) channel region were 350Ω/square and 1.07x10<sup>13</sup>/cm<sup>2</sup>, respectively. A wafer subjected to the same process apart from the



**Figure 1. Transfer characteristics of AlGaN/GaN MISHEMTs on sample A and B templates.**

ion implant had  $315\Omega/\text{square}$  resistance and  $1.3 \times 10^{13}/\text{cm}^2$  carrier concentration.

The transistor fabrication began with low-pressure CVD of 20nm silicon nitride for gate insulation. Annealed source/drain contacts consisted of titanium/aluminium/nickel/gold. Device isolation was achieved through more ion implantation. The gate electrode consisted of nickel/gold. The gate was  $4\mu\text{m}$  long and  $100\mu\text{m}$  wide. The distances from gate to drain and source were  $16\mu\text{m}$  and  $4\mu\text{m}$ , respectively.

The device built on the sample without ion implantation (A) did not achieve pinch-off and the on/off current ratio was very low at 46 (Figure 1). The ion-implanted device (B) was much better with "excellent pinch-off", according to the researchers. The on/off current ratio was  $2.5 \times 10^5$  with an off-current of  $2.8 \times 10^{-3} \text{mA}/\text{mm}$ .

The maximum drain current at 3V gate potential was  $701 \text{mA}/\text{mm}$ . The peak transconductance was  $83 \text{mS}/\text{mm}$ . The researchers say that there was little degradation in these parameters, compared with sample A.

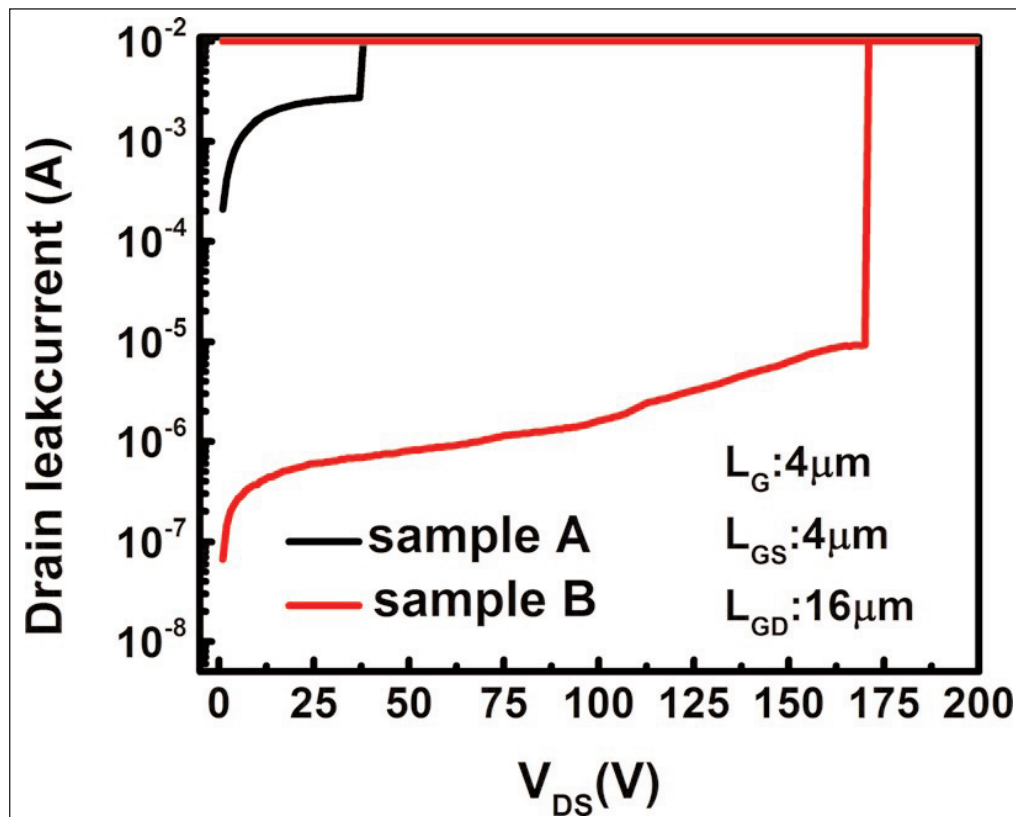
The improvement in switching capability of sample B came from the much reduced off-current (Figure 2). The off-current was reduced by three orders of magnitude and the breakdown voltage increased by 5x, compared with sample A.

AlGaN back-barriers have also been used to improve

off-currents. However, the 2DEG carrier concentration tends to be impacted more severely due to the charge polarization contrast of the AlGaN and GaN chemical bonds. Typical AlGaN back-barriers use around 5% Al content, giving a conduction-band offset of 0.06eV. The researchers estimate that the offset from the Al implantation is 0.07eV, equivalent to an  $\text{Al}_{0.058}\text{Ga}_{0.942}\text{N}$  layer. ■

<http://dx.doi.org/10.1063/1.4939508>

Author: Mike Cooke



**Figure 2. Measured breakdown voltage of AlGaN/GaN MISHEMTs on sample A and B templates.**

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# Going beyond gallium nitride transistor state-of-the-art performance

imec presents enhancement-mode p-GaN high-electron-mobility devices on silicon at IEDM.

The imec research center in Belgium claims beyond state-of-the-art performance for a p-type gallium nitride (p-GaN) high-electron-mobility transistor (HEMT) on silicon operating in enhancement-mode (normally-off). The threshold voltage was +2V. Low on-resistance of  $7\Omega\text{-mm}$  enabled high drive current of  $0.4\text{A/mm}$  at 10V drain bias. imec presented its results at the IEEE International Electron Devices Meeting in Washington DC, USA (8 December 2015)

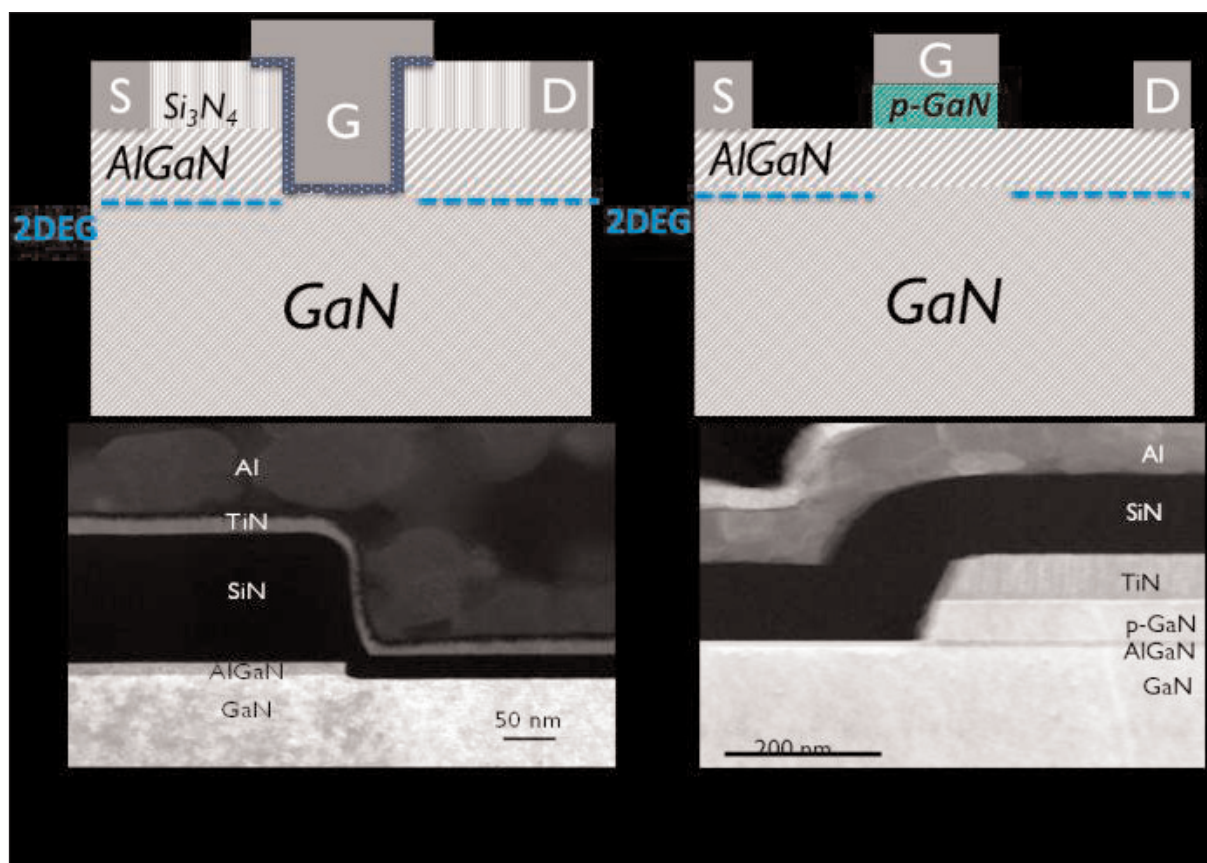
in sessions 16.2 and 35.4. imec claims that the p-GaN HEMT outperforms metal-insulator-semiconductor (MISHEMT) counterparts.

imec has been working on the p-GaN HEMT structure (Figure 1) for some time [[www.semiconductor-today.com/news\\_items/2015/sep/imec\\_020915.shtml](http://www.semiconductor-today.com/news_items/2015/sep/imec_020915.shtml)].

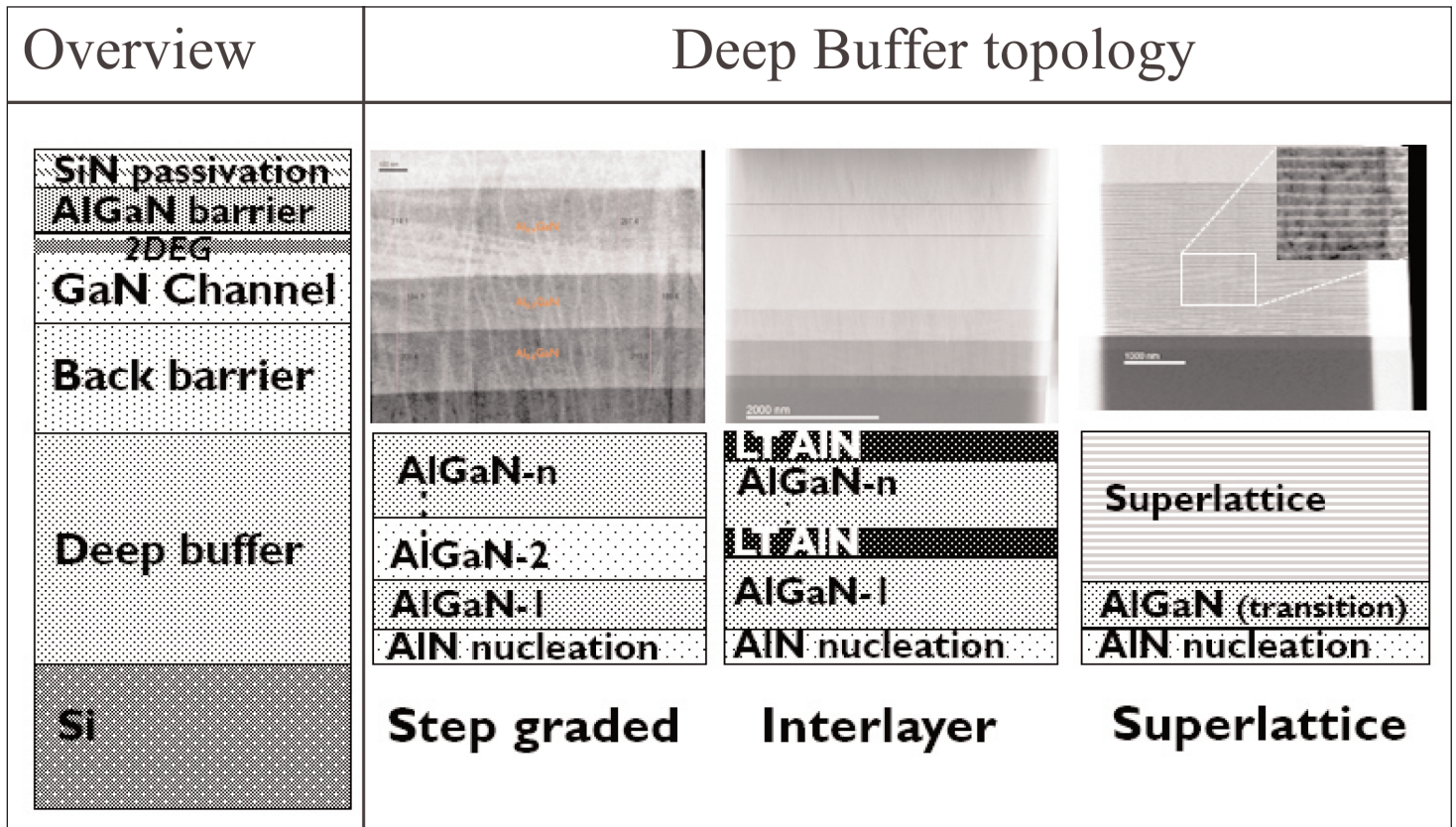
Normally-off/ enhancement-mode operation is preferred for power efficiency and fail safety. Conventional GaN HEMTs, produced without special measures such as fluoride plasma treatment of the gate region, tend to be depletion-mode/normally-on. Producing GaN devices on silicon should lead to production cost savings, but device performance can be impacted by crystal defects arising from the larger lattice mismatch, compared

with silicon carbide (SiC) or free-standing/bulk GaN substrates.

One team of imec researchers focused on improving the interface between the 200mm-diameter substrate and the overlying GaN buffer with the aim of reducing dispersion/current collapse. Dispersion occurs in pulse-mode/switching operation. One cause of this is trap states in the buffer layer that adversely affect performance compared with DC characterization. Three types of high-voltage buffer/silicon interface were compared: step-graded, low-temperature AlN interlayer, and superlattice (Figure 2). Using a 'design of experiments' methodology, the researchers conclude that "a superlattice buffer can achieve simul-



**Figure 1. Schematic cross section (upper figures) and transmission electron micrographs (TEMs) of gate region (lower figures) of (a) recessed-gate MISHEMT and (b) p-GaN HEMT.**



**Figure 2. Schematic overview of AlGaIn/GaN buffer and constituent parts. Schemes of three different deep buffer topologies are shown and illustrated with TEM cross sections of epi buffers.**

taneously low dispersion and leakage under negative bulk bias”.

In their optimization efforts, the teams targeted low dispersion/current collapse, leakage and breakdown voltage over a wide temperature range and bias conditions. Another team of researchers also optimized the epitaxy process for the p-GaN layer, which contains the two-dimensional electron gas (2DEG) channel near the

top aluminium gallium nitride (AlGaIn) barrier layer.

imec says that it is working towards industrialization and is offering a complete 200mm CMOS-compatible 200V GaN process line that features excellent specs on enhancement-mode devices. ■

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# Increasing gallium nitride MOSFET threshold voltage

Researchers claim record high value of 7.6V for aluminium oxide dielectric gate insulator.

University of Electronic Science and Technology of China claims a record high threshold voltage of +7.6V for an aluminium oxide/gallium nitride ( $\text{Al}_2\text{O}_3/\text{GaN}$ ) metal-oxide-semiconductor field-effect transistor (MOSFET) [Qi Zhou et al, IEEE Electron Device Letters, published online 22 December 2015]

GaN transistors tend to be normally-on with negative threshold voltages without special measures designed to increase the threshold for normally-off operation. These measures tend to negatively impact other factors such as reducing on-current and/or increasing off-current/leakage.

Normally-off operation is particularly desired for power applications where fail-safety and power efficiency are important considerations. In particular, a threshold above 6V and a gate swing greater than 10V are often needed to avoid faulty turn-on induced by electromagnetic interference in power switching applications.

MOSFETs tend to have more positive thresholds compared with Schottky gate high-electron-mobility transistors (HEMTs). However, the dielectric/semiconductor interface in a MOSFET can create a positive fixed charge in trap states, impeding normally-off operation. Fixed charges can also act as scattering centers that reduce the field-effect mobility, increasing on-resistance.

The researchers fabricated their MOSFETs (Figure 1) on a commercial 4-inch AlGaIn/GaN-on-silicon wafer

from Enkris Semiconductor ([www.enkris.com](http://www.enkris.com)). The metal-organic chemical vapor deposition (MOCVD) heterostructure consisted of a  $3.5\mu\text{m}$  GaN buffer, 1nm AlN spacer, 23nm AlGaIn barrier, and 2nm GaN cap. The specifications of the two-dimensional electron gas (2DEG) were  $1.05 \times 10^{13}/\text{cm}^2$  carrier density,  $1500\text{cm}^2/\text{V}\cdot\text{s}$  mobility, and  $400\Omega/\text{square}$  sheet resistance.

The ohmic contacts were fabricated before mesa isolation etching. The 100nm silicon nitride ( $\text{SiN}_x$ ) passivation was applied using inductively coupled plasma chemical vapor deposition (ICP-CVD).

The  $\text{SiN}_x$  was also used as a hard mask for a two-step gate recess etching with inductively coupled plasma and a low-damage digital process. The 5Å digital etch cycle consisted of oxygen plasma oxidation and dilute hydrochloric acid rinse for oxide removal.

Using 15 cycles of the digital etch resulted in a recess depth of about 30nm into the heterostructure, around 4nm over-etch into the buffer/2DEG layer. The recess root mean square (RMS) surface roughness was 0.54nm, according to atomic force microscopy.

The gate stack consisted of 18nm of atomic layer deposition (ALD) aluminium oxide ( $\text{Al}_2\text{O}_3$ ) and nickel/gold. Annealing at 400°C in nitrogen was applied either post-dielectric (PDA) or post-gate (PGA) deposition.

The threshold voltage for  $1\mu\text{A}/\text{mm}$  current ( $V_{\text{TH}}$ ) at 10V drain bias was -1.9V without annealing. This normally-on behavior was shifted to normally-off +2.7V

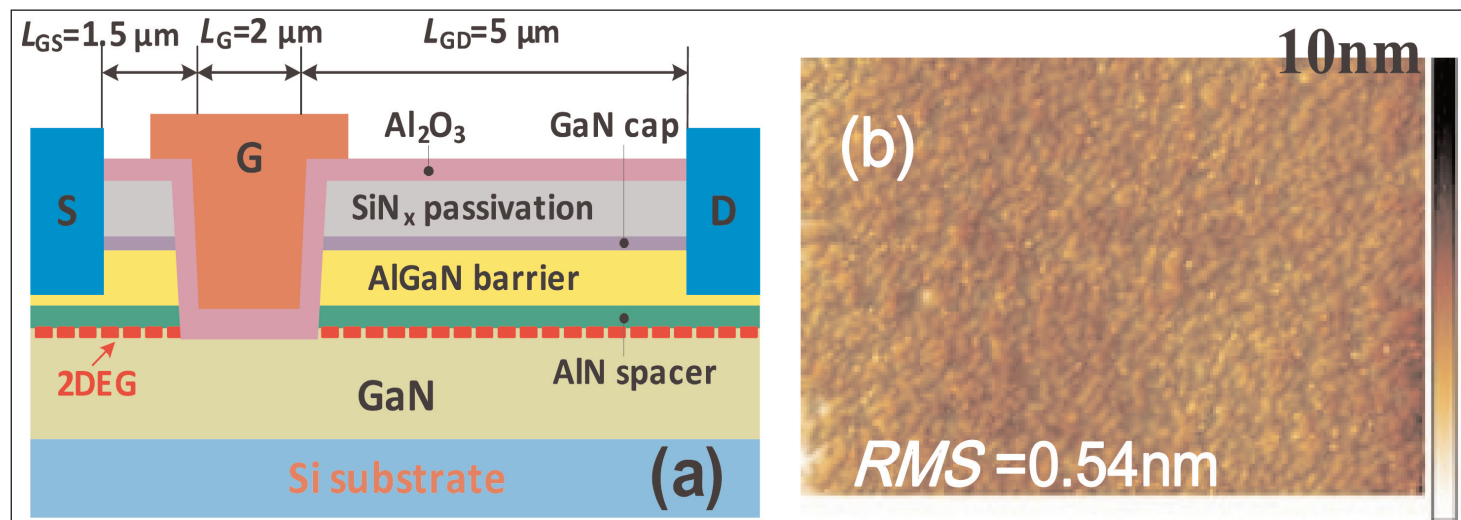


Figure 1. (a) Schematic cross section of normally-off  $\text{Al}_2\text{O}_3/\text{GaN}$  MOSFETs and (b) surface morphology of recessed gate region.



with PGA. PDA devices had an even higher threshold of +5.2V.

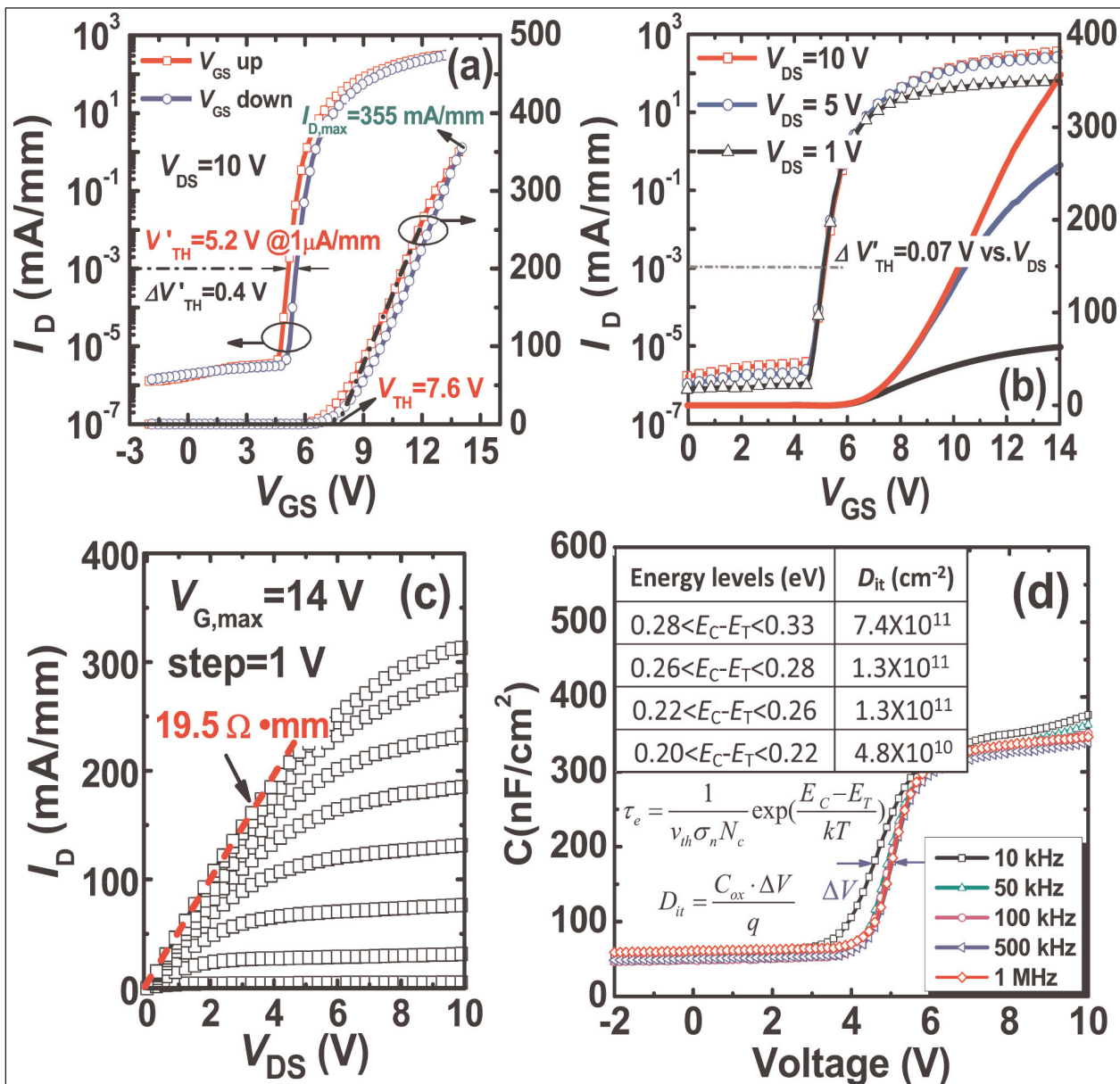
Capacitance-voltage measurements were consistent with  $\text{Al}_2\text{O}_3/\text{GaN}$  interface trap densities of  $1.44 \times 10^{13}/\text{cm}^2$ ,  $5 \times 10^{12}/\text{cm}^2$ , and  $3 \times 10^{12}/\text{cm}^2$  for no annealing, PGA, and PDA, respectively.

The team believes the interface traps result in positive charges that shift the threshold downwards: "The presence of interface positive charges can be explained by two possible scenarios. (1) The GaN surface is metal (Ga)-face, the oxygen atoms of  $\text{Al}_2\text{O}_3$  attach to

Ga substituting for N (ON) and forming Ga-O bond at  $\text{Al}_2\text{O}_3/\text{GaN}$  interface due to the low formation energy of ON. The ON is likely to act as a shallow donor in GaN and positively charged (ON+). (2) The Ga dangling bonds (DBs) could be generated during gate recessing and act as the positive charge centers."

The team suggests that the nitrogen from the annealing more easily reaches the interface if applied post-dielectric rather than post-gate. This nitrogen fixes the ON and DB problems.

A PDA device with  $2\mu\text{m}$  gate length demonstrated a threshold voltage ( $V_{\text{TH}}$ ) for the linear region of +7.6V (Figure 2). The gate-source and gate-drain distances and gate width were, respectively,  $1.5\mu\text{m}$ ,  $5\mu\text{m}$ , and  $50\mu\text{m}$ . The gate had an overhang of  $0.5\mu\text{m}$  on either side. The maximum drain current of  $355\text{mA}/\text{mm}$  was



**Figure 2. (a) Measured transfer curves in linear- and log-scale, (b) transfer curves versus drain bias ( $V_{\text{DS}}$ ), (c) output curves and (d) frequency-dependent capacitance-voltage (C-V) curves of PDA device. Inset: extracted interface state energy levels and corresponding state density ( $D_{it}$ ). Sweep rate 0.25V/s.**

achieved at +14V gate potential.

The researchers comment: "These values are the highest reported for normally-off GaN devices with  $V_{\text{TH}} > 5\text{V}$  up to date. The device features an excellent pinch-off at  $V_{\text{GS}}$  of  $\sim +4.6\text{V}$ , and delivers a low off-state leakage current of  $1.8\text{nA}/\text{mm}$  at  $V_{\text{GS}} = 0\text{V}$ . The  $V_{\text{TH}}$  also exhibits good stability versus drain bias voltage."

The researchers also point out that the +5.2V value for the more stringent  $V_{\text{TH}}$  criterion is remarkable. Other groups with normally-off devices have reported only up to +2.7V for this  $V_{\text{TH}}$  criterion, according to a comparison table assembled by the team. The same table gives a maximum  $V_{\text{TH}}$  of +7.2V for the other groups. ■

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Author: Mike Cooke

# Non-alloyed contacts for gallium arsenide devices

A zinc oxide interlayer and sulfur hexafluoride have been used to avoid metal-induced gap and interface trap states.

Researchers in South Korea have been developing improved non-alloyed contacts for gallium arsenide (GaAs) complementary metal-oxide-semiconductor (CMOS) and high-electron-mobility transistors (HEMTs) [Seung-Hwan Kim et al, IEEE Electron Device Letters, 3 February 2016]. Four universities were involved: Korea University, Hanyang University, Sungkyunkwan University, and Inha University.

Source-drain contacts for GaAs devices are usually alloyed to reduce contact resistance. However, the high temperatures involved significantly increase surface roughness, and reliable devices then need large source-drain separations, which blocks attempts to scale to smaller dimensions. Also, surface roughness causes problems in gate fabrication.

To avoid contact metal alloying, the researchers have developed a zinc oxide (ZnO) interlayer to avoid metal-induced gap states (MIGS) and sulfur hexafluoride ( $\text{SF}_6$ ) plasma passivation to deal with interface traps.

The researchers used an n-GaAs wafer doped with silicon  $\sim 2 \times 10^{18}/\text{cm}^3$ . The wafer was cleaned to remove organics and native oxides. The passivation of interface trap states consisted of either aqueous ammonium sulfide ( $(\text{NH}_4)_2\text{S}$ ) solution treatment or plasma  $\text{SF}_6$ .

Atomic layer deposition (ALD) at  $250^\circ\text{C}$  was used to apply zinc oxide from diethyl zinc precursor and water vapor reactant. The non-alloyed metal contacts consisted of 30nm titanium and 40nm gold, produced through electron-beam evaporation.

The ZnO interlayer metal-interlayer-semiconductor (MIS) structure was designed to block MIGS penetration, which induces Fermi pinning to the charge neutrality level (CNL), creating a Schottky barrier rather than ohmic contact. ZnO was chosen for its wide bandgap and small conduction band offset to GaAs, compared with alternatives such as aluminium oxide, silicon nitride or hafnium dioxide.

The  $\text{SF}_6$  passivation produced 36x higher current than non-passivated metal-semiconductor (MS) contact samples without ZnO interlayer (Figure 1). The performance was also much better than sulfur passivation from  $(\text{NH}_4)_2\text{S}$  solution. The optimum process time for the  $\text{SF}_6$  process was found to be 10 seconds.

"These results signify that the proposed passivation method can effectively reduce the interface trap states on the GaAs surface," the researchers write.

X-ray photoelectron spectroscopy (XPS) suggested that 10 seconds was sufficient for the formation of Ga-S passivation bonds, while avoiding a  $\text{GaF}_3$

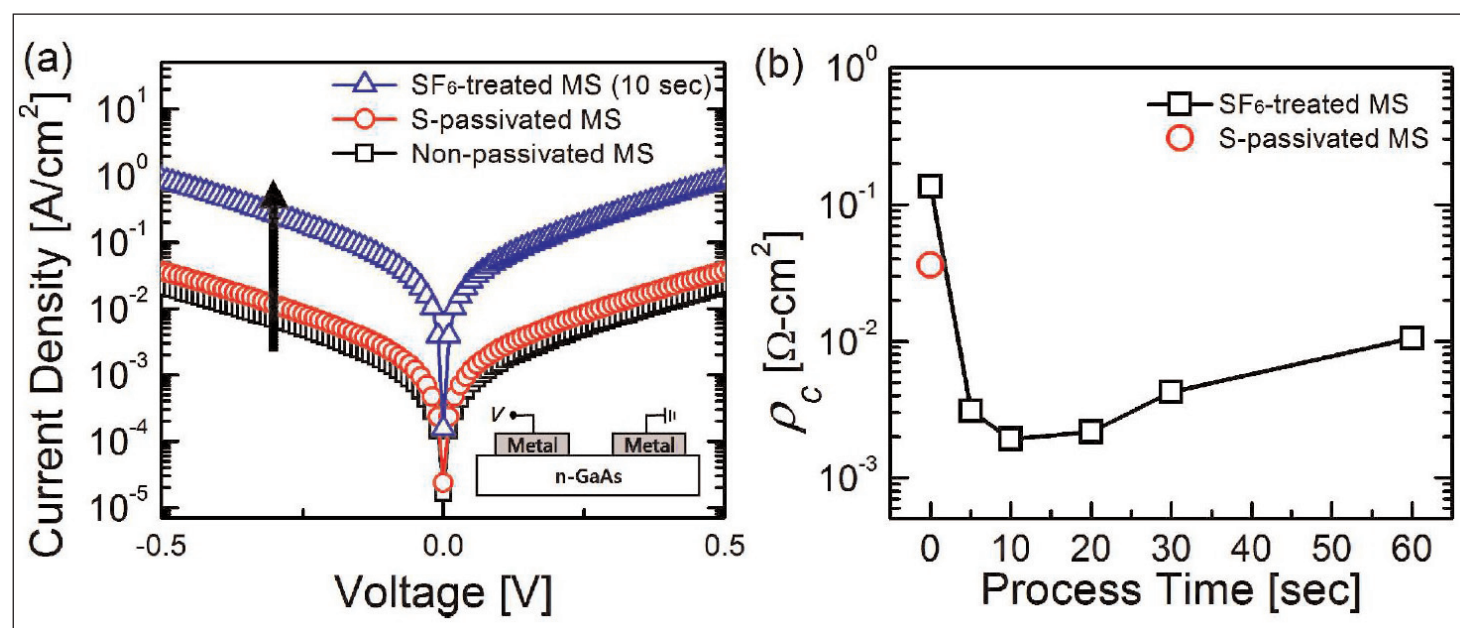
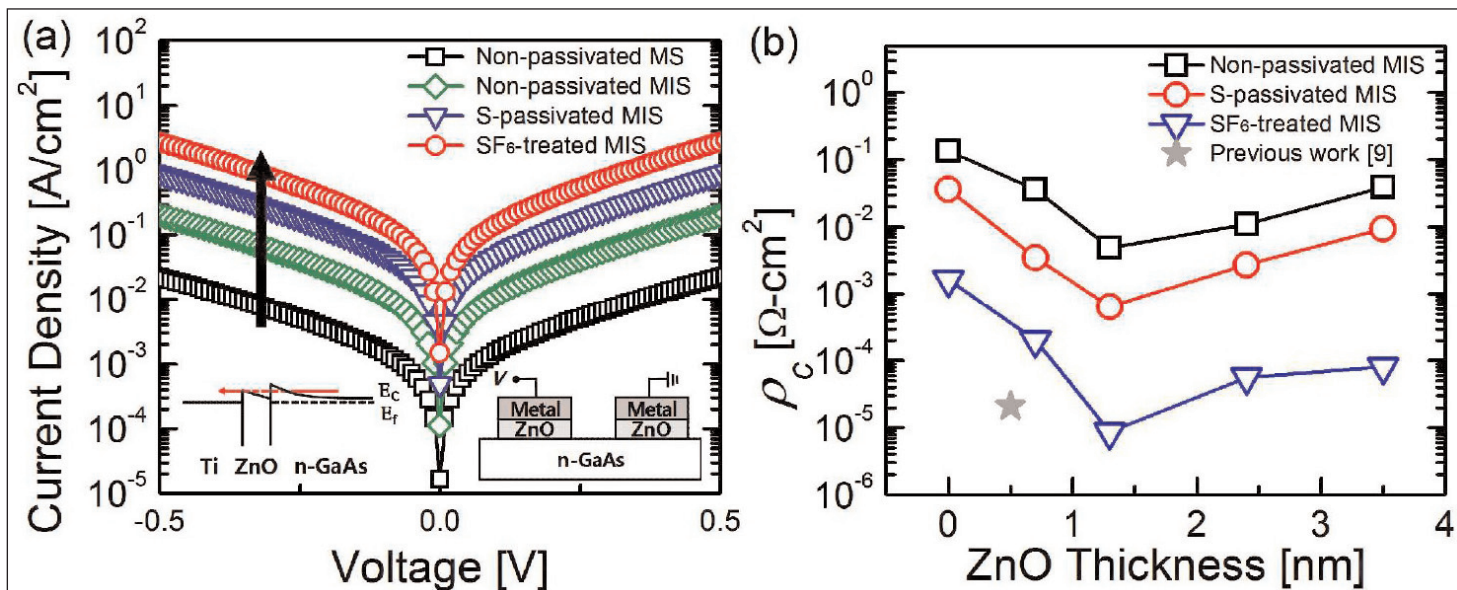


Figure 1. (a) Current-voltage characteristics and (b) specific contact resistivity for titanium on  $\text{SF}_6$ -treated n-GaAs as function of plasma process time. Inset in (a) shows schematic of electrical measurements of MS contact.



**Figure 2. (a) Current–voltage characteristics and (b) specific contact resistivity for MS contact and MIS contacts. Insets in (a) show the band diagram of MIS contact (left) and schematic of electrical measurements of MIS contact (right).**

electron tunneling barrier layer with 9.8eV bandgap and large conduction band offset.

Atomic force microscopy (AFM) showed that surface roughness increased negligibly from 0.357nm to 0.572nm root-mean-square.

The MIS samples with ZnO interlayer and  $SF_6$  passivation had currents 4x and 15x that of sulfur- and non-passivated MIS structures, respectively. The optimum thickness of ZnO was found to be 1.3nm. Above this, tunneling resistance becomes significant. The lowest MIS specific contact resistivity ( $\rho_c$ ) was  $\sim 8 \times 10^{-6} \Omega\text{-cm}^2$

for 1.3nm ZnO and 10-second  $SF_6$  passivation (Figure 2).

The researchers say that this is around a  $10^{-4}$  reduction on the non-passivated titanium-GaAs MS contact. They add: "This  $\rho_c$  value is also lower than that of the Ge-passivated MIS contact in our previous work."

The MIS contact with  $SF_6$  also had almost the same electrical characteristics after annealing at 450°C for two hours. ■

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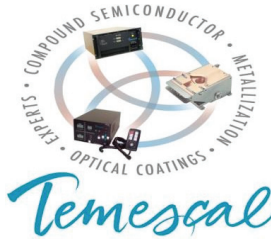
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Fax: +44 (0)1954 786818  
[www.cambridge-fluid.com](http://www.cambridge-fluid.com)

**CS CLEAN SYSTEMS AG**

Fraunhoferstrasse 4,  
Ismaning, 85737,  
Germany  
Tel: +49 89 96 24 00 0  
Fax: +49 89 96 24 00 122  
[www.cscleansystems.com](http://www.cscleansystems.com)

**SAES Pure Gas Inc**

4175 Santa Fe Road,  
San Luis Obispo,  
CA 93401,  
USA  
Tel: +1 805 541 9299  
Fax: +1 805 541 9399  
[www.saesgetters.com](http://www.saesgetters.com)

**11 Process monitoring  
and control****k-Space Associates Inc**

2182 Bishop Circle  
East, Dexter,  
MI 48130,  
USA  
Tel: +1 734 426 7977  
Fax: +1 734 426 7955

[www.k-space.com](http://www.k-space.com)

k-Space Associates Inc specializes in  
in-situ, real-time thin-film process  
monitoring tools for MBE, MOCVD,  
PVD, and thermal evaporation.  
Applications and materials include  
the research and production line  
monitoring of compound  
semiconductor-based electronic,  
optoelectronic, and photovoltaic  
devices.

**KLA-Tencor**

One Technology Dr,  
1-2221I, Milpitas, CA 95035, USA  
Tel: +1 408 875 3000  
Fax: +1 408 875 4144  
[www.kla-tencor.com](http://www.kla-tencor.com)

**LayTec AG**

Seesener Str.  
10-13,  
10709 Berlin,  
Germany  
Tel: +49 30 89 00 55 0  
Fax: +49 30 89 00 180

[www.laytec.de](http://www.laytec.de)

LayTec develops and manufactures  
optical in-situ and in-line metrology  
systems for thin-film processes  
with particular focus on compound  
semiconductor and photovoltaic  
applications. Its know-how is  
based on optical techniques:  
reflectometry, emissivity corrected  
pyrometry, curvature  
measurements and reflectance  
anisotropy spectroscopy.

**WEP (Ingenieurbüro Wolff  
für Elektronik- und  
Programmentwicklungen)**

Bregstrasse 90, D-78120  
Furtwangen im Schwarzwald,  
Germany  
Tel: +49 7723 9197 0  
Fax: +49 7723 9197 22

[www.wepcontrol.com](http://www.wepcontrol.com)

## 12 Inspection equipment

### **Bruker AXS GmbH**

Oestliche Rheinbrueckenstrasse 49,  
Karlsruhe, 76187,  
Germany

Tel: +49 (0)721 595 2888  
Fax: +49 (0)721 595 4587

[www.bruker-axs.de](http://www.bruker-axs.de)

## 13 Characterization equipment

### **J.A. Woollam Co. Inc.**

645 M Street Suite 102,  
Lincoln, NE 68508, USA

Tel: +1 402 477 7501  
Fax: +1 402 477 8214

[www.jawoollam.com](http://www.jawoollam.com)

### **Lake Shore Cryotronics Inc**

575 McCorkle Boulevard,  
Westerville, OH 43082,  
USA

Tel: +1 614 891 2244  
Fax: +1 614 818 1600

[www.lakeshore.com](http://www.lakeshore.com)

## 14 Chip test equipment

### **Keithley Instruments Inc**

28775 Aurora Road,  
Cleveland, OH 44139,  
USA

Tel: +1 440.248.0400  
Fax: +1 440.248.6168

[www.keithley.com](http://www.keithley.com)

## 15 Assembly/packaging materials

### **ePAK International Inc**

4926 Spicewood Springs Road,  
Austin, TX 78759,  
USA

Tel: +1 512 231 8083  
Fax: +1 512 231 8183

[www.epak.com](http://www.epak.com)

### **Gel-Pak**

31398 Huntwood Avenue,  
Hayward, CA 94544, USA

Tel: +1 510 576 2220  
Fax: +1 510 576 2282

[www.gelpak.com](http://www.gelpak.com)

### **Wafer World Inc**

(see section 3 for full contact details)

### **Materion Advanced Materials Group**

2978 Main Street,  
Buffalo, NY 14214,  
USA

Tel: +1 716 837 1000  
Fax: +1 716 833 2926

[www.williams-adv.com](http://www.williams-adv.com)

## 16 Assembly/packaging equipment

### **Ismeca Europe Semiconductor SA**

Helvetie 283, La Chaux-de-Fonds,  
2301, Switzerland

Tel: +41 329257111  
Fax: +41 329257115

[www.ismeca.com](http://www.ismeca.com)

### **Kulicke & Soffa Industries**

1005 Virginia Drive,  
Fort Washington,  
PA 19034,  
USA

Tel: +1 215 784 6000  
Fax: +1 215 784 6001

[www.kns.com](http://www.kns.com)

### **Palomar Technologies Inc**

2728 Loker Avenue West,  
Carlsbad, CA 92010,  
USA

Tel: +1 760 931 3600  
Fax: +1 760 931 5191

[www.PalomarTechnologies.com](http://www.PalomarTechnologies.com)

### **TECDIA Inc**

2700 Augustine Drive, Suite 110,  
Santa Clara, CA 95054,  
USA

Tel: +1 408 748 0100  
Fax: +1 408 748 0111

[www.tecdia.com](http://www.tecdia.com)

## 17 Assembly/packaging foundry

### **Quik-Pak**

10987 Via Frontera,  
San Diego, CA 92127, USA

Tel: +1 858 674 4676  
Fax: +1 8586 74 4681

[www.quikicpak.com](http://www.quikicpak.com)

## 18 Chip foundry

### **Compound Semiconductor Technologies Ltd**

Block 7, Kelvin Campus,  
West of Scotland, Glasgow,  
Scotland G20 0TH,  
UK

Tel: +44 141 579 3000  
Fax: +44 141 579 3040

[www.compoundsemi.co.uk](http://www.compoundsemi.co.uk)

### **United Monolithic Semiconductors**

Route departementale 128,  
BP46, Orsay, 91401,  
France

Tel: +33 1 69 33 04 72  
Fax: +33 169 33 02 92

[www.ums-gaas.com](http://www.ums-gaas.com)

## 19 Facility equipment

### **MEI, LLC**

3474 18th Avenue SE,  
Albany, OR 97322-7014,  
USA

Tel: +1 541 917 3626  
Fax: +1 541 917 3623

[www.marlerenterprises.net](http://www.marlerenterprises.net)

## 20 Facility consumables

### **W.L. Gore & Associates**

401 Airport Rd, Elkton,  
MD 21921-4236,  
USA

Tel: +1 410 392 4440  
Fax: +1 410 506 8749

[www.gore.com](http://www.gore.com)

## 21 Computer hardware & software

### **Ansoft Corp**

4 Station Square, Suite 200,  
Pittsburgh, PA 15219, USA

Tel: +1 412 261 3200  
Fax: +1 412 471 9427

[www.ansoft.com](http://www.ansoft.com)

### **Crosslight Software Inc**

121-3989 Henning Dr.,  
Burnaby, BC, V5C 6P8, Canada

Tel: +1 604 320 1704  
Fax: +1 604 320 1734

[www.crosslight.com](http://www.crosslight.com)



**Semiconductor Technology Research Inc**

10404 Patterson Ave., Suite 108,  
Richmond, VA 23238,  
USA  
Tel: +1 804 740 8314  
Fax: +1 804 740 3814  
[www.semitech.us](http://www.semitech.us)

**22 Used equipment****Class One Equipment Inc**

5302 Snapfinger Woods Drive,  
Decatur, GA 30035, USA  
Tel: +1 770 808 8708  
Fax: +1 770 808 8308  
[www.ClassOneEquipment.com](http://www.ClassOneEquipment.com)

**23 Services****Henry Butcher International**

Brownlow House, 50-51

High Holborn, London WC1V 6EG,  
UK

Tel: +44 (0)20 7405 8411  
Fax: +44 (0)20 7405 9772  
[www.henrybutcher.com](http://www.henrybutcher.com)

**M+W Zander Holding AG**

Lotterbergstrasse 30,  
Stuttgart,  
Germany  
Tel: +49 711 8804 1141  
Fax: +49 711 8804 1950  
[www.mw-zander.com](http://www.mw-zander.com)

**24 Consulting****Fishbone Consulting SARL**

8 Rue de la Grange aux Moines,  
78460 Choisel,  
France  
Tel: + 33 (0)1 30 47 29 03  
E-mail: [jean-luc.ledys@neuf.fr](mailto:jean-luc.ledys@neuf.fr)

**25 Resources****AI Shultz Advertising Marketing for Advanced Technology Companies**

1346 The Alameda,  
7140 San Jose, CA 95126, USA  
Tel: +1 408 289 9555  
[www.alshultz.com](http://www.alshultz.com)

**SEMI Global Headquarters**

3081 Zanker Road,  
San Jose, CA 95134, USA  
Tel: +1 408 943 6900  
Fax: +1 408 428 9600  
[www.semi.org](http://www.semi.org)

**Yole Développement**

45 rue Sainte Geneviève,  
69006 Lyon, France  
Tel: +33 472 83 01 86  
[www.yole.fr](http://www.yole.fr)

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**4–7 April 2016**

## **SPIE Photonics Europe 2016**

SQUARE Brussels Meeting Centre, Brussels, Belgium

**E-mail:** [info@spieeurope.org](mailto:info@spieeurope.org)

**http://**[spie.org/SPIE-PHOTONICS-EUROPE-conference](http://spie.org/SPIE-PHOTONICS-EUROPE-conference)

**7 April 2016**

## **2D Materials Processing Technology Workshop**

Alan Turing Building — National Graphene Centre, University of Manchester, UK

**www.oxford-instruments.com/2dworkshop**

**13–16 April 2016**

## **LED Taiwan 2016 and Taiwan International Lighting Show**

Taiwan World Trade Center, Taipei, Taiwan

**E-mail:** [sluo@semi.org](mailto:sluo@semi.org)

**www.ledtaiwan.org**

**17–21 April 2016**

## **SPIE Defense + Commercial Sensing 2016 (DCS), incorporating:**

**SPIE Defense + Security (Conference on Sensors, Imaging, and Optics)**

**SPIE Commercial + Scientific Sensing and Imaging (Conference on Advanced Technologies and Applications)**

Baltimore Convention Center, Baltimore, MD, USA

**E-mail:** [customerservice@spie.org](mailto:customerservice@spie.org)

**http://**[spie.org/SPIE-DCS-conference](http://spie.org/SPIE-DCS-conference)

**http://**[spie.org/SPIE-DCS-Defense+Security](http://spie.org/SPIE-DCS-Defense+Security)

**http://**[spie.org/SPIE-DCS-Commercial-Sensing](http://spie.org/SPIE-DCS-Commercial-Sensing)

**25–27 April 2016**

## **12th International Conference on Concentrator Photovoltaics (CPV-12)**

Freiburg, Germany

**E-mail:** [info@cpv-12.org](mailto:info@cpv-12.org)

**www.cpv-12.org**

**26–28 April 2016**

## **SEMICON Southeast Asia (SEMICON SEA)**

Penang, Malaysia

**E-mail:** [skoh@semi.org](mailto:skoh@semi.org)

**www.semiconsea.org**

**6 May 2016**

## **31st annual Reliability Of Compound Semiconductors (ROCS) Workshop 2016**

Hyatt Regency Miami, FL, USA

**E-mail:** [rocs@jedec.org](mailto:rocs@jedec.org)

**www.jedec.org/home/gaas**

**16–19 May 2016**

## **2016 CS MANTECH (International Conference on Compound Semiconductor Manufacturing Technology)**

Hyatt Regency Miami, FL, USA

**E-mail:** [conferencechairman@gaasmantech.org](mailto:conferencechairman@gaasmantech.org)

**www.csmantech.org**

**24–25 May 2016**

## **Imec Technology Forum Brussels (ITF2016 Brussels)**

SQUARE Brussels Meeting Centre, Belgium

**E-mail:** [Annouck.Vanrompay@imec.be](mailto:Annouck.Vanrompay@imec.be)

**www.itf2016.be/brussels**

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**5–10 June 2016**

**CLEO 2016:**

**Conference on Lasers and Electro-Optics**

San Jose Convention Center, CA, USA

**E-mail:** info@cleoconference.org

[www.cleoconference.org](http://www.cleoconference.org)

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**7–9 June 2016**

**SEMICON Russia 2016**

Moscow, Russia

**E-mail:** esuvorov@semi.org

[www.semiconrussia.org](http://www.semiconrussia.org)

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**13–17 June 2016**

**2016 Symposia on VLSI Technology & Circuits**

Hilton Hawaiian Village, Honolulu, HI, USA

**E-mail:** vlsi@vlsisymposium.org

[www.vlsisymposium.org](http://www.vlsisymposium.org)

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**22–24 June 2016**

**Intersolar Europe**

Messe München, Germany

**E-mail:** info@intersolar.de

[www.intersolar.de](http://www.intersolar.de)

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**26–30 June 2016**

**Compound Semiconductor Week 2016**

(CSW2016), including:

**43rd International Symposium on Compound Semiconductors (ISCS2016);  
28th International Conference on Indium Phosphide and Related Materials (IPRM2016)**

Toyama International Conference Center, Japan

**E-mail:** secretary2016@csw-jpn.org

[www.csw-jpn.org](http://www.csw-jpn.org)

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**10–15 July 2016**

**18<sup>th</sup> International Conference on Metal Organic Vapor Phase Epitaxy (ICMOVPE XVIII)**

Sheraton San Diego Hotel & Marina, CA, USA

**E-mail:** info@mrs.org

[www.mrs.org/icmovpe-xviii](http://www.mrs.org/icmovpe-xviii)

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**11 July 2016**

**ITF2016 USA**

San Francisco Marriott Marquis, CA, USA

**E-mail:** Annouck.Vanrompay@imec.be

[www.itf2016.be/page.aspx/2217](http://www.itf2016.be/page.aspx/2217)

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**11–13 July 2016**

**IEEE Photonics Society's 2016 Summer Topicals Meeting Series – 'Emerging Technologies for Green Photonics'**

Newport Beach Marriott Hotel, CA, USA

**E-mail:** i.donnelly@ieee.org

[www.sum-ieee.org](http://www.sum-ieee.org)

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**11–14 July 2016**

**Intersolar North America (co-located with  
ees North America and SEMICON West)**

San Francisco, CA, USA

**E-mail:** info@intersolar.us

[www.intersolar.us](http://www.intersolar.us)

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**12–14 July 2016**

**SEMICON West 2016**

Moscone Center, San Francisco, CA, USA

**E-mail:** semiconwest@xpressreg.net

[www.semiconwest.org](http://www.semiconwest.org)

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**28 August – 1 September 2016**

**SPIE Optics + Photonics 2016**

San Diego Convention Center, CA, USA

**E-mail:** customerservice@spie.org

<http://spie.org/optics-photonics1>

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**6–7 September 2016**

**2nd International Forum on Sapphire Market & Technologies**

**E-mail:** veyrier@yole.fr

[www.i-micronews.com/events/yole-events/eventdetail/142/-/2nd-int-forum-on-sapphire-market-technologies.html](http://www.i-micronews.com/events/yole-events/eventdetail/142/-/2nd-int-forum-on-sapphire-market-technologies.html)  
alongside:

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**6–9 September 2016**

**18th China International Optoelectronic Exposition (CIOE 2016)**

Shenzhen Convention & Exhibition Center (SZCEC), China

**E-mail:** cioe@cioe.cn

[www.cioe.cn/en](http://www.cioe.cn/en)

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**7–9 September 2016**

**SEMICON Taiwan 2016**

Taipei Nangang Exhibition Center, Taiwan

**E-mail:** semicontaiwan@semi.org

[www.semicontaiwan.org](http://www.semicontaiwan.org)

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**12–15 September 2016**

**25th International Semiconductor Laser Conference (ISLC 2016)**

Kobe Meriken Park Oriental Hotel, Kobe, Japan

**E-mail:** islc2016@ics-inc.co.jp

[www.islc2016.org](http://www.islc2016.org)

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**19–22 September 2016**

**LED China 2016**

Shanghai New International Expo Centre (SNIEC), China

**E-mail:** led-trust@ubm.com

[www.LEDChina-sh.com](http://www.LEDChina-sh.com)

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**2–6 October 2016**

**29th IEEE Photonics Conference (IPC 2016 )**

Waikoloa, Hawaii, USA

**E-mail:** c.c.scott@ieee.org

[www.ipc-ieee.org](http://www.ipc-ieee.org)

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