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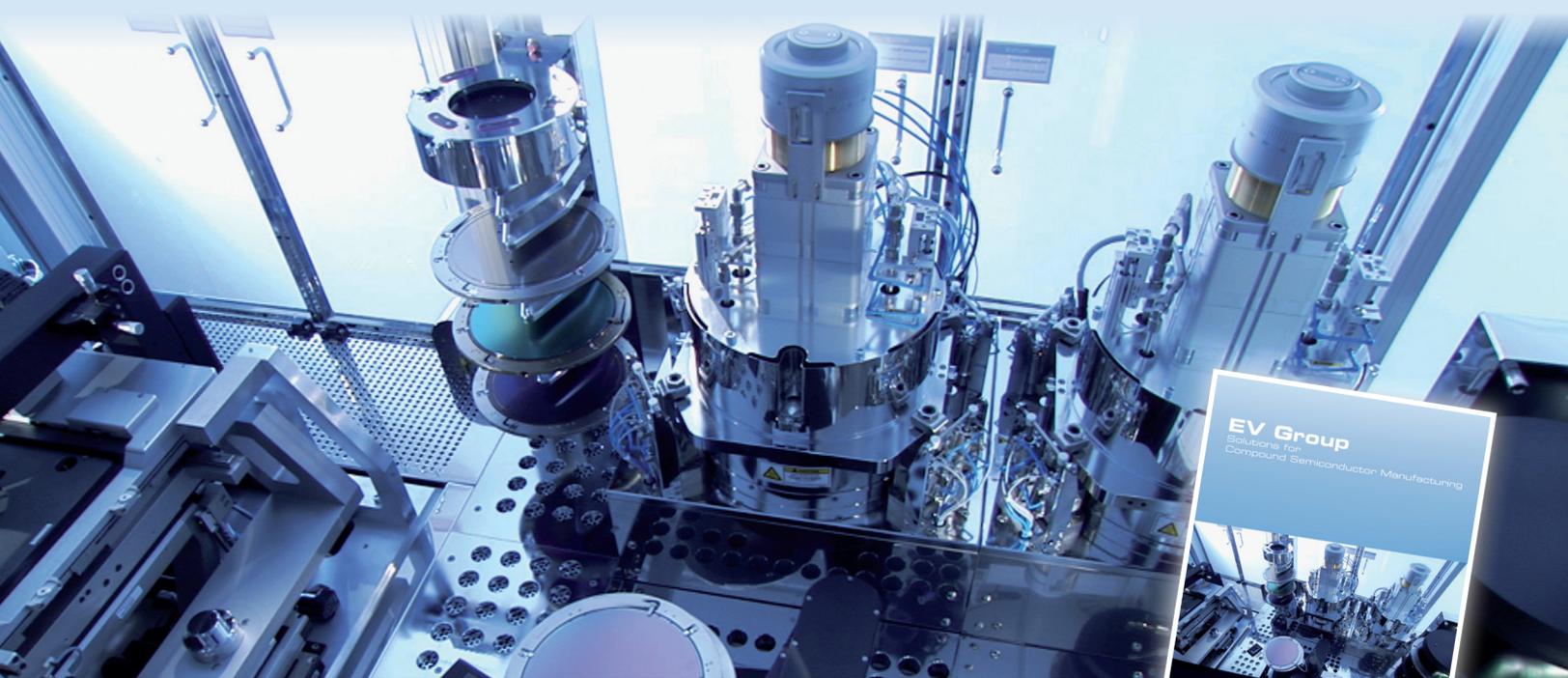
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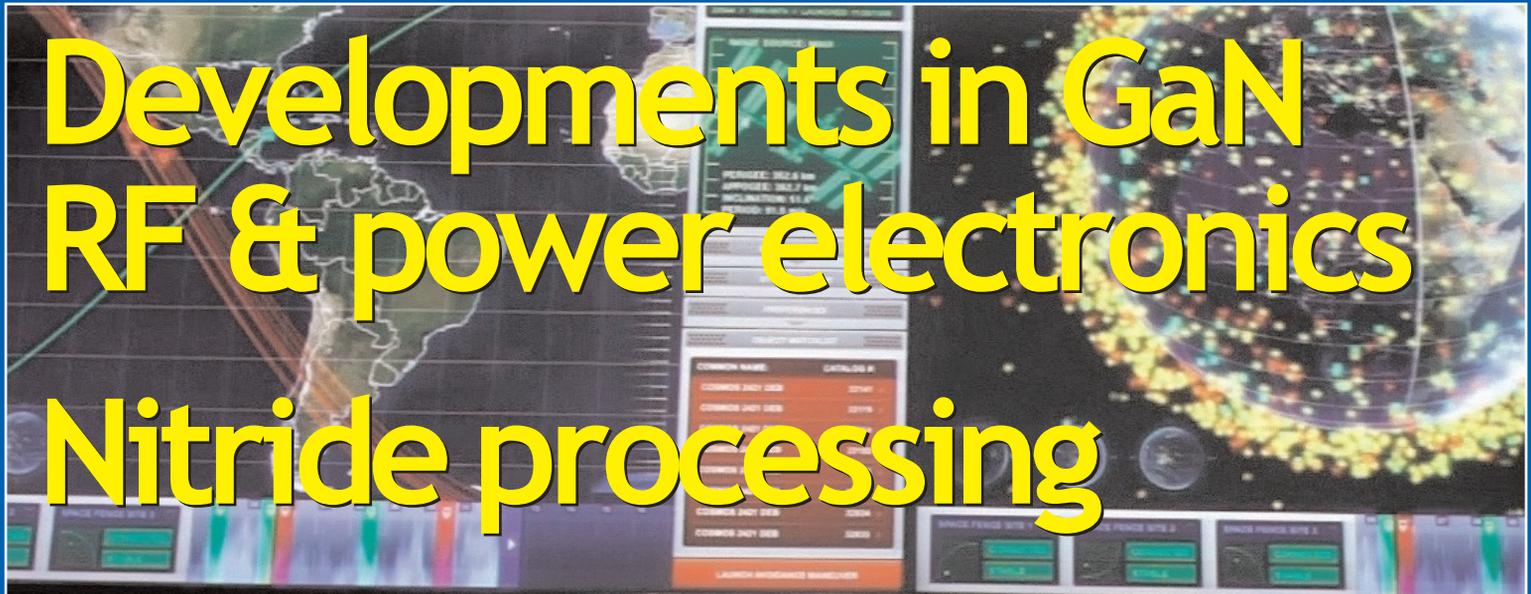
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# semiconductor TODAY

COMPOUNDS & ADVANCED SILICON

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PowerAmerica calls for projects • Bruker buying Jordan Valley  
Panasonic unveils 4.5W blue-violet laser • SWDM Alliance formed



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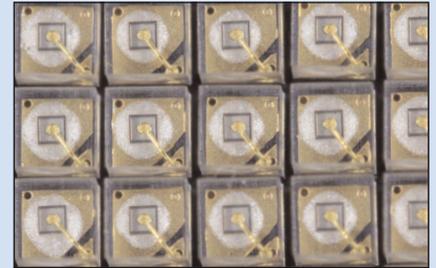
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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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**p36** Plessey's chip-scale-packaged dotLEDs, shortlisted in the Elektra Awards' Design Team of The Year category.



**p44** Trumpf has opened a new subsidiary in Berlin for the engineering of high-power diode lasers.



**p66** China's CNBM has broken ground on construction of a solar module production plant that will use CIGS technology from Germany's Avancis.



Cover: Wolfspeed has partnered with Lockheed Martin to provide GaN high-power amplifiers for the US Air Force's Space Fence, which aims to significantly improve the timeliness with which operators can detect space events that could potentially threaten GPS satellites or the International Space Station. **p18**

## Power electronics makes gains

In this issue we focus on the topic of gallium nitride-based electronics, with the feature article on pages 74-77 giving an overview of recent developments by some of the main device makers in commercializing products for both radio-frequency power amplification and high-voltage power switching applications – including by Cree’s new spin-off Wolfspeed, UCSB spin-off Transphorm (which has partnerships with Japan’s Fujitsu and On Semiconductor), GaN Systems and its foundry partner Qorvo (which also sells its own products), Germany’s Infineon (which acquired International Rectifier in January, and in September introduced its first GaN-on-SiC RF power transistors) and its partner Panasonic in Japan.

On pages 88–90, market research firms Yole Développement and KnowMade forecast that the market for GaN power electronics devices will rise at a compound annual growth rate (CAGR) of 93% from just \$10m in 2015 to \$300m in 2020. KnowMade notes that power GaN intellectual property patents are just beginning to be leveraged by companies to negotiate licensing and supply agreements (such as those between Infineon and Panasonic and between Transphorm and Furukawa Electric).

Also, on pages 91–93, Yole notes that, as well as established wide-bandgap semiconductor technology such as silicon carbide (SiC), GaN-on-SiC and more recently GaN-on-Si technology, other wide-bandgap (WBG) semiconductor options such as bulk GaN substrates, aluminium nitride, gallium oxide (Ga<sub>2</sub>O<sub>3</sub>) and diamond are presenting further possibilities.

Indicating the importance placed on power electronics, PowerAmerica (a private–public partnership between the US Department of Energy, industry and academia) has just released a call for projects to advance wide-bandgap semiconductor manufacturing and to accelerate the adoption of WBG semiconductor power electronics applications (see page 21).

Regarding manufacturing, in this issue we also cover nitride processing, including reducing damage in GaN inductively coupled plasma etch (page 72), a new plasma pre-treatment for chemical-mechanical polishing (CMP) on GaN that avoids creating enlarged etch pits (page 74), and the first application of microwave annealing to the formation of ohmic source–drain contacts to AlGaIn/GaN high-electron-mobility transistors (page 76).

The increasing significance of nitride electronics is also apparent in the activities of metal-organic chemical vapor deposition (MOCVD) system makers Aixtron and Veeco (see their third-quarter 2015 results on pages 28–30). Although influenced predominantly by the large fluctuations in LED demand for display backlighting (particularly related to the slowdown in China) and the delays in adopting new-generation MOCVD systems, other sectors such as lasers, telecoms, memory & logic chips and power electronics assume increased importance. For example, in Q3/2015 Aixtron’s order intake fell 34% from Q2’s \$52.5m to \$34.4m, while Veeco’s orders fell from Q2’s \$124m to just \$52m (pushing the ‘Lighting, Display and Power Electronics’ segment down from 70% to just 23% of Veeco’s total orders). Of Aixtron’s revenues, the proportion related to LEDs fell from 49% in Q1 to 24% in Q2/2015, while the proportion related to Power Electronics rose from 9% to 19%. While demand related to LED lighting remains healthy the firms note, the increasing diversification of such firms and the rise of sectors such as RF & power electronics are gaining in importance.

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- feature articles (technology, markets, regional profiles);
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- event calendar and event previews;
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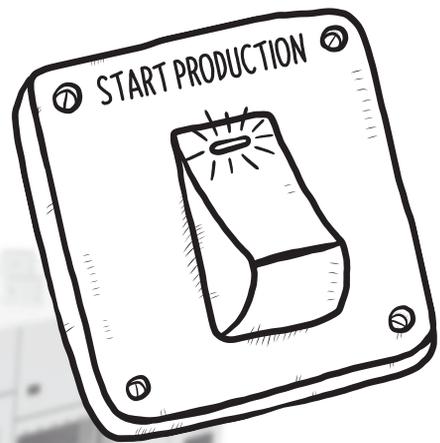
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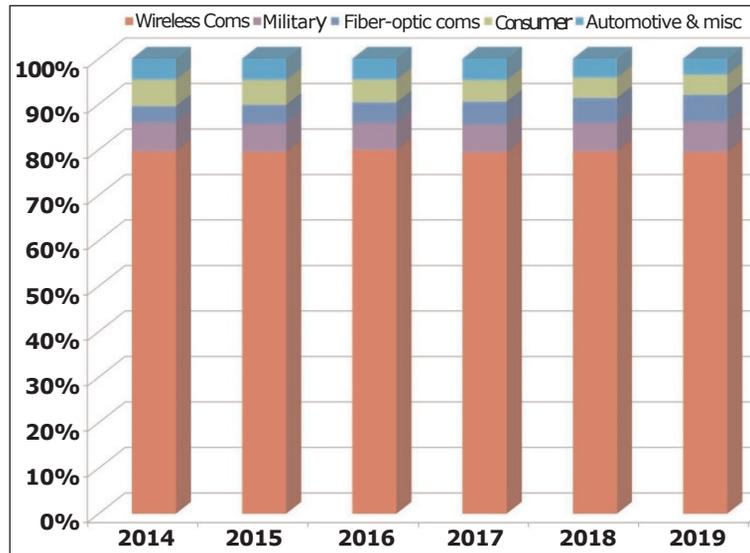


## GaAs RF device revenue to grow from another record of \$7bn in 2015 to peak of \$8bn in 2018

### Rising GaAs content in evolving device and network architectures to offset market share loss to rival technologies

Driven by increasing gallium arsenide content in cellular terminals, the GaAs device market experienced another year of record revenues in 2014 and will break the \$7bn barrier this year then surpass \$8bn by 2019, according to the Strategy Analytics Advanced Semiconductor Applications (ASA) spreadsheet model and report 'GaAs Device Forecast and Outlook: 2014-2019'. The report states that GaAs device revenue will grow even though price erosion and competitive technologies will slow growth.

The report concludes that wireless applications remain the dominant segment of GaAs device market, accounting for just under 80% of all revenue. In particular, the cellular terminal portion of the wireless segment accounts for slightly more than 50% of all GaAs device revenue. New architectures will increase the GaAs content in cellular terminals and, even though CMOS power amplifiers (PAs) will continue capturing market share, the cellular terminal share of the market will grow to slightly more than 55% by the end of the forecast period.



GaAs device revenue market share by application.

In response to price erosion and losing market share to competitive technologies, GaAs device revenue will peak in 2018 at just over \$8bn, before declining by less than 1% in 2019, forecasts the report.

"Despite continuing concern in some quarters about the future of GaAs devices, the market saw its second consecutive year of double-digit growth," notes Eric Higham,

"Defense systems, particularly in radar, communications and EW [electronics warfare] applications, still rely on the performance of GaAs devices," says Asif Anwar, director of Strategy Analytics' Strategic Technologies Practice. "We anticipate these segments will continue to fuel GaAs revenue growth."

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

Strategy Analytics' service director, Advanced Semiconductor Applications. "Other technologies are capturing market share, but evolving device and network architectures need increasing GaAs content and this is offsetting some of the share loss," he adds.

## Laser diode market to grow at 13% to \$11.94bn by 2020

The laser diode market will rise at a compound annual growth rate (CAGR) of 13% to \$11.94bn by 2020, according to a report 'Laser Diode Market by Type, Mode of Operation, Wavelength (Near Infrared, Red, Blue, Green, Others), Application (Communications & Optical Storage, Industrial, Medical, Military & Defense, Instrumentation & Sensor), and Geography— Global Forecast to 2020' from MarketsandMarkets.

There is growing adoption of laser diodes in applications such as com-

munication & optical storage, industrial, medical, military & defense, and instrumentation & sensor. Other applications include automotive, image recording, agriculture, and entertainment.

Segmented by wavelength, the market includes near-infrared, red, blue, green, and others including ultra-violet (UV), violet, and yellow. Near-infrared wavelengths are expected to maintain the greatest market share, while green laser diodes are expected to grow at the

highest CAGR of 16.7% to 2020.

Of the four geographical regions categorized — North America, Europe, Asia-Pacific, and rest of the world (RoW) — the Asia-Pacific (APAC) region is expected to maintain the greatest market share and also to grow the fastest, at a CAGR of 15%. The Americas region is expected to maintain the second-largest share of market.

[www.marketsandmarkets.com/Market-Reports/laser-diode-market-1006.html](http://www.marketsandmarkets.com/Market-Reports/laser-diode-market-1006.html)

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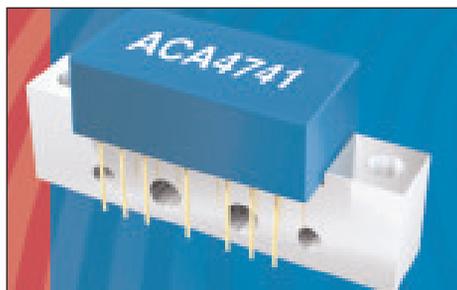
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## Anadigics launches family of DOCSIS 3.1 hybrid line amplifier modules for CATV infrastructure

Anadigics Inc of Warren, NJ, USA has introduced a family of hybrid line amplifier modules optimized for DOCSIS 3.1 infrastructure equipment.

The new ACA47XX line amplifiers integrate the firm's proven surface-mount solutions and passive components in an industry-standard SOT-115J package. Equipment manufacturers can select from push-pull and power doubler configurations, with various gain and output power levels to ensure optimal DOCSIS 3.1 system performance.

"These solutions combine our field-proven, highly linear GaAs technology with a high-power GaN output stage to deliver exceptional output power over the full DOCSIS 3.1 frequency band," says James Martin, senior business development director of Infrastructure Products.



"With global data consumption continuing to rise, our new DOCSIS 3.1 hybrid line amplifier modules stand out as critical enablers for the anticipated major industry-wide infrastructure upgrade."

The ACA47XX hybrid line amplifier modules combine the firm's GaAs-based MESFET and proprietary high-linearity pHEMT technologies with a GaN output stage (power doublers only) in a common, industry-standard SOT-115J package

(providing greater design flexibility across systems) for CATV infrastructure applications. The line amplifiers offer what is claimed to be exceptional composite triple-beat (CTB), composite second-order (CSO), cross-modulation, carrier-to-intermodulation noise (CIN), modulation-error ratio (MER), and bit-error ratio (BER) characteristics for optimal performance in a fully loaded spectrum. Two members of the new product family (the ACA4741 and ACA4788) offer what is reckoned to be record output power to support both analog/digital and completely digital CATV systems. The solutions enable Node+0 system architectures without active components downstream of the fiber or R-MACPHY node.

[www.anadigics.com/products/catv](http://www.anadigics.com/products/catv)

### Anadigics launches hybrid line amplifiers for CATV infrastructure

Anadigics has introduced a family of hybrid line amplifier modules.

Developed specifically as drop-in replacement solutions for system amplifiers, the new ACA27XX hybrid modules include passive components in a pin-compatible SOT-115J package and are optimized to minimize or eliminate tuning requirements.

"Our new hybrid line amplifier modules provide a compelling solution for a wide range of deployed system amplifiers, as well as infra-

structure equipment in production," reckons James Martin, senior business development director of Infrastructure Products, adding that the ACA27XX infrastructure product line is designed specifically to ensure distortion-free video and audio.

Available in push-pull and power doubler configurations, the ACA27XX line amplifiers use the firm's proven GaAs-based MESFET technology — yielding a high mean time to failure (MTTF) — to provide what is claimed to be high output power,

excellent linearity and industry-leading reliability for 1003MHz and 874MHz applications. The hybrid line amplifiers offer what is claimed to be low CTB, CSO and cross-modulation distortion characteristics for optimal performance in a fully loaded spectrum.

The new module family is offered in a wide range of gains and output power levels, while using the industry-standard SOT-115J package to provide greater design flexibility across systems.

## Anadigics adds surface-mount line amplifiers to DOCSIS 3.1 infrastructure portfolio

Anadigics has launched six surface-mount line amplifiers optimized for DOCSIS 3.1 CATV infrastructure applications. The firm's portfolio of DOCSIS 3.1 products includes line amplifiers, reverse path amplifiers, edge QAM amplifiers and gain blocks.

The line amplifiers combine GaAs-based MESFET and high-linearity pHEMT technologies with a GaN

output stage (power doublers only). The new ACA2416, ACA2419, ACA2454, ACA2457, ACA2458 and ACA2463 all offer exceptional CTB, CSO, cross-modulation, CIN, MER and BER characteristics for optimal performance in a fully loaded spectrum, claims the firm.

The ACA2458 joins the ACA2456, ACA4741, and ACA4788 in the new

4X-class product family. These solutions offer four times the power of first-generation GaN line amplifiers. This power, coupled with other performance characteristics, enables Node+0 system architectures without active components downstream of the fiber or R-MACPHY node.

[www.anadigics.com/products/catv](http://www.anadigics.com/products/catv)

## Bastani made senior VP of GlobalFoundries' RF unit

GlobalFoundries of Santa Clara, CA, USA (one of the largest foundries, with over 250 customers and operations in Singapore, Germany and the USA) has appointed Bami Bastani as senior VP of its Radio Frequency (RF) business unit.

With the acquisition of IBM's Microelectronics Division in July, GlobalFoundries says that it has solidified its technology position in wireless front-end module solutions. The firm has significantly broadened its existing high-voltage CMOS and RF MEMS technologies with differentiated RF silicon-on-insulator (RFSOI) and high-performance silicon germanium (SiGe) technologies geared to enable complex RF switches, high-performance power amplifiers, and integrated front-end applications in mobile devices.

With over 35 years of high-tech, semiconductor and RF experience, Bastani will focus on delivering the next generation of GlobalFoundries' RF roadmap, aiming to capture fur-

ther opportunities in the automotive, home and growing Internet of Things (IoT) markets. Bastani will lead a team with a history of providing high-performance solutions that address the increasing complexity of mobile radio devices.

"Bami is an experienced executive with deep knowledge of the RF industry," comments GlobalFoundries' CEO Sanjay Jha. "He brings to GlobalFoundries years of leadership and management capabilities that will enable us to grow our RF business," he adds. "Bami has been part of the semiconductor industry for several decades, and his experience spans beyond RF to wafer manufacturing operations and market growth strategies."

Prior to joining GlobalFoundries, Bastani was president, CEO and board member of global enterprise-grade Wi-Fi networks solution provider Meru Networks from 2012 to earlier this year. He transformed Meru from a hardware company to

a solution provider with emphasis on software, software-defined networks (winning the 2015 SDN Excellence Award) and subscription cloud offering (WaaS). He brought a vertical market strategic focus to the company, allowing it to broaden its offerings and customer base.

Before that, Bastani served in president & CEO as well as board member roles in the mobility, consumer, and broadband markets. These include president and CEO roles at Trident Microsystems Inc and Anadigics Inc. Bastani also served in executive positions at Fujitsu Microelectronics, National Semiconductor and Intel Corp.

Bastani earned his Ph.D. and MSEE in Microelectronics at Ohio State University. He holds three US patents, has several publications on semiconductor technology, and has given several invited keynotes on topics of innovation and corporate management.

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

## MACOM launches plug-in and surface-mount DOCSIS 3.1-compliant CATV diplex filters

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 launched three families of diplex filters designed for DOCSIS 3.0 and 3.1 infrastructure equipment. Available in plug-and-play vertical and horizontal form factors along with surface-mount configurations, the new diplex filters are suited to use in CATV infrastructure spanning nodes, system amplifiers, line extenders, drop amplifiers and RF-over-glass (RFoG) optical networking unit (ONUs). "MACOM's high-performance pluggable and SMD filter platforms provide network equipment designers with full turnkey solutions that facilitate accelerated amplifier developments"

The new MAFL-0110XX series of diplex filter platforms cover the key industry frequency splits of 42/54, 65/85, 85/105 and 204/258MHz, and operate from 5MHz to 1218MHz. The compact plug-and-play filters provide what is claimed to be superior insertion loss, return loss, rejection and cross-over-isolation performance, and are designed and tested to meet exacting infrastructure quality and reliability requirements. Each filter platform is easily expanded to cover other frequency splits.

The diplex filter platforms are the newest additions to MACOM's portfolio of RF components designed to comply with the DOCSIS 3.1 standard for high-bandwidth data transfer over hybrid fiber-coaxial (HFC) infrastructure. MACOM says that its domain expertise, coupled with a global sales and applications support

network, ensure that designers are afforded the products and support required for accelerated market deployments for DOCSIS 3.1-compliant equipment.

"MACOM's high-performance pluggable and SMD filter platforms provide network equipment designers with full turnkey solutions that facilitate accelerated amplifier developments," says Graham Board, senior director of Carrier Networks at MACOM. "With so much focus on amplifier performance for DOCSIS 3.1 infrastructure it is easy to lose sight of the importance of the filter and passive components in the cascade. MACOM's filters are designed to deliver superior RF performance, thus enabling optimal GaAs or GaN amplifier cascades for network equipment."

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

## Qorvo launches 802.11p power amplifier for wireless car connectivity

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA, a provider of RF solutions for mobile, infrastructure and aerospace/defense applications, has launched two 802.11p solutions optimized for high-performance networking in the connected car. Qorvo's 801.11p power amplifier (PA) enhances car-to-car and car-to-infrastructure communication, analysis, and data exchange, helping manufacturers to develop 802.11 systems and applications that both enhance automotive safety and improve the driving experience.

"Qorvo is leveraging our broad expertise in high-reliability, high-performance RF solutions to enhance next-generation 802.11p automotive connectivity, with advanced product reliability that is essential to the automotive industry," says James Klein, president of Qorvo's Infrastructure and Defense Products group. "Our newest 802.11p connected car solution has been selected by multiple manufacturers to be featured in their next-generation automotive connectivity reference designs."



**The QPA5525Q is the most linear solution on the market, enhancing vehicle-to-vehicle and vehicle-to-roadside data transmission for real-time notifications related to traffic congestion management and collision avoidance.**

The QPA5525Q high-power 802.11p power amplifier module integrates an internally matched three-stage PA, compensated DC biasing circuit, and output power detection. It is claimed to be the most linear solution on the market, enhancing vehicle-to-vehicle and vehicle-to-roadside data transmission for real-time notifications related to

automotive environments and includes a PA that provides high gain at 32dB, what is claimed to be an industry-leading error vector magnitude (EVM) floor, and spectral purity for 802.11p applications. The QPA5525Q is available in sampling quantities and is entering volume production in fourth-quarter 2015.

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

traffic congestion management and collision avoidance.

The QPA5525Q is undergoing Automotive Electronics Council (AEC) based testing — specifically AECQ-100 Grade 2 testing — which measures how the product performs between  $-40^{\circ}\text{C}$  and  $+105^{\circ}\text{C}$ . The QPA5525Q was built for harsh

## Richardson Electronics to distribute Anokiwave's silicon core chips and III-V front-end ICs

Richardson Electronics Ltd of LaFox, IL, USA (a global channel partner for electron devices, power electronics, and RF & microwave components) has announced a global distribution agreement with Anokiwave of San Diego, CA, USA, a provider of highly integrated silicon core chips and III-V front-end integrated circuits that enable emerging millimeter-wave and active electronically scanned array (AESA) markets. Anokiwave says that the agreement aligns with its focus on supporting customers and new opportunities with highly technical support to provide innovative

solutions for the most challenging applications. "This agreement significantly strengthens the technical support we can provide to customers and increases our reach to promote our new products and technology"

"Anokiwave develops highly integrated silicon core chips and compound semiconductor ICs for next-generation markets," says Greg Peloquin, executive VP of Richardson Electronics' Power & Microwave Technologies group. "Our global, highly technical sales team is eager and excited to promote these new products and tech-

nologies to key customers, identify new opportunities and gain design wins," he adds.

"This agreement significantly strengthens the technical support we can provide to customers and increases our reach to promote our new products and technology," comments Anokiwave's CEO Robert Donahue. "Richardson Electronics' extensive global network of sales engineers will help customers select the best-fit products for next-generation millimeter-wave systems."

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

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

## Qorvo launches four highly integrated multiplexers

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA, a provider of RF solutions for mobile, infrastructure and aerospace/defense applications, has launched four multiplexer solutions designed to simplify and accelerate the adoption of carrier aggregation (CA) in 4G LTE-Advanced devices. The firm's first multiplexer solutions leverage its proprietary LowDrift BAW filter technology, which features an intrinsic performance advantage over other acoustic filter technologies and enables dramatically improved mobile data services for users of next-generation smartphones.

"Qorvo's first multiplexers were developed in collaboration with leading chipset suppliers and are qualified on major reference designs," says Eric Creviston, president of Qorvo's Mobile Products group. "Qorvo is expanding our family of multiplexers to accommodate carrier aggregation deployments worldwide, and we are integrating multiplexers into RF Fusion solutions for a single scalable source of best-in-class filtering, switching and amplification."

Qorvo's multiplexers deliver best-in-class insertion loss and high cross-isolation of receive and transmit paths to optimize receive sensitivity and extend smartphone battery life. The firm's first multiplexer solutions are optimized for Europe and the Asia Pacific region and integrate multiple BAW filters to cover the primary band combi-

nations used in CA deployments: bands 1+3 and bands 39+41. The highly compact multiplexer solutions deliver 60% space savings over discrete components.

Qorvo's filters meet or exceed the increasingly stringent requirements related to narrow spacing on receive and transmit bands while delivering consistent performance over temperature, thus enabling better performance in the RF front end.

### Qorvo's Multiplexer solutions

The QM25005 multiplexer features LowDrift transmit and receive filters for FDD-LTE bands 1 and 3 in a highly compact 3.0mm x 2.0mm form factor. Enabling downlink CA, the QM25005 is qualified with leading LTE chipsets and performance-optimized to deliver best-in-class insertion loss and high isolation, resulting in improved receive sensitivity and coverage.

Qorvo is introducing three multiplexers featuring LowDrift BAW filter technology for TDD-LTE bands 39 and 41, each developed in partnership with leading chipset suppliers. With a compact 2.5mm x 2.0mm footprint,

**Qorvo plans to progressively incorporate its multiplexer technology into its RF Fusion line of front-end solutions to provide a single scalable source for the entire cellular front-end**

the QM25001 is designed for global smartphones supporting the full band 41 spectrum for worldwide use. The QM25011 and QM25012 are designed for China domestic smartphones and optimized for China's band 41 narrowband allocation. The QM25011 includes primary transmit and receive filters in a 1.7mm x 1.3mm package, while the complementary QM25012 provides diversity receive filters in an even smaller 1.5mm x 1.1mm footprint. Both products provide at least a 60% space savings over discrete components.

### Inclusion in RF Fusion roadmap

Qorvo plans to progressively incorporate its multiplexer technology into its RF Fusion line of front-end solutions, which combine best-in-class power amplifier efficiency, filtering and switching to provide a single scalable source for the entire cellular front-end.

Qorvo's RF solutions simplify design, reduce product footprint, conserve power and improve overall system performance in smartphones, tablets and other mobile devices. Qorvo offers a unique combination of broad manufacturing scale, deep systems-level expertise and the industry's most comprehensive product and technology portfolio, helping mobile device manufacturers accelerate delivery of next-generation products.

[www.qorvo.com/docs/brochures/qorvo-broadband-docsis-3.1-solutions.pdf](http://www.qorvo.com/docs/brochures/qorvo-broadband-docsis-3.1-solutions.pdf)

## Custom MMIC appoints Special-Ind as technical representative for Italy

Monolithic microwave integrated circuit developer Custom MMIC of Westford, MA, USA has appointed Italy-based Special-Ind as part of its growing network of technical representatives.

"Their extensive knowledge of a number of high-tech industries in

Italy, developed over 60 years, gives them an unparalleled understanding of the opportunities for Custom MMIC in this region," comments Custom MMIC's president & CEO Paul Blount.

Founded in 1955, Special-Ind specializes in advanced technology and

has an established team of high-tech professionals offering components and related technologies for the telecom, automotive, aerospace, industrial and medical industries.

[www.specialind.it](http://www.specialind.it)  
[www.CustomMMIC.com](http://www.CustomMMIC.com)

# Skyworks offers \$2bn to acquire PMC-Sierra

## Storage systems, flash controllers, optical switches and network infrastructure solutions to target hyperscale data-centers

Skyworks Solutions Inc of Woburn, MA, USA has agreed to acquire PMC-Sierra Inc of Sunnyvale, CA, USA (which provides semiconductor and software solutions for storage, optical and mobile networks) for \$10.50 per share in an all-cash transaction valued at about \$2bn.

Skyworks says that the acquisition solidifies its position as a highly diversified analog, RF and mixed-signal semiconductor firm by significantly expanding its product portfolio, customer base and end-market applications. Upon completion of the acquisition, Skyworks expects its annual revenue to be more than \$4bn with gross margin in the 55% range and operating margin exceeding 40%.

"Skyworks will be uniquely positioned to capitalize on the explosive demand for high-performance solutions that seamlessly connect, transport and store Big Data," says Skyworks' chairman & CEO David J. Aldrich. "Specifically, we plan to leverage PMC's innovative storage systems, flash controllers, optical switches and network infrastructure solutions to expand our engagements with some of the world's leading OEMs and ODMs as well as emerging hyperscale data-center customers. At a higher level, this complementary yet highly synergistic acquisition is consistent with

our stated strategy of diversifying into adjacent vertical markets while leveraging our system-level expertise and global scale. PMC enables us to substantially expand our serviceable market within some of the fastest-growing segments in technology including cloud storage and optical networking," he adds. "Financially, we expect this transaction to create further economic value for our shareholders upon closing, with immediate margin expansion and accretion. After we implement \$75m of synergies, we expect at least \$0.75 of incremental non-GAAP diluted earnings per share on an annual basis," Aldrich continues.

"Given Skyworks' deep global sales channels and leadership applications support, underpinned by a world-class supply chain, we could not have found a better partner," comments PMC's president & CEO Greg Lang. "Together, we plan to develop a wider range of leading-edge solutions for our customers, target new growth vectors and enable some of the most exciting networking and storage platforms in the world."

For each share of PMC common stock held at closing, PMC's stockholders will receive \$10.50 in cash (a 37% premium to the close of PMC's stock as of 5 October).

Skyworks intends to fund the acquisition with cash on hand from the combined companies and with new, fully committed debt financing. The closing of the transaction is not subject to financing conditions.

The boards of directors of each firm have approved the transaction, which is expected to close in first-half 2016, subject to PMC shareholder approval, receipt of regulatory approvals and other customary closing conditions.

Excluding any non-recurring acquisition-related charges and amortization of acquired intangibles, Skyworks expects the acquisition to be immediately accretive to non-GAAP earnings post-closing and will finalize estimates of the transaction's financial impact as well as the accounting for the transaction upon deal close.

Based on preliminary results, for fiscal fourth-quarter 2015 Skyworks expects to deliver about \$880m in revenue and \$1.52 of non-GAAP diluted earnings per share. "Skyworks' sustained outperformance is being driven by the growing adoption of our integrated mobile systems and new opportunities across the Internet of Things," states executive VP & chief financial officer Donald W. Palette.

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

## PMC discussing unsolicited rival Microsemi offer of \$11.35 per share

On 19 October, PMC-Sierra received an unsolicited proposal from Microsemi Corp of Aliso Viejo, CA, USA (which designs and makes analog and RF devices, mixed-signal integrated circuits and subsystems for communications, defense & security, aerospace and industrial markets) to acquire it for \$8.75 in cash plus 0.0736 of a Microsemi share for each share of PMC common stock (amounting to \$11.35

per share, or \$2.2bn including PMC's net cash balance as of 27 June).

PMC's board of directors believes, after consultation with its financial advisors and outside legal counsel, that the Microsemi proposal would reasonably be expected to lead to a superior proposal, and that failure to participate in discussions with Microsemi would be inconsistent with the board's fiduciary duties. It has hence determined to engage

in discussions with Microsemi. It adds that there can be no assurances that any definitive agreement or transaction will result from the Microsemi proposal or PMC's discussions with Microsemi.

PMC's board continues to recommend the merger agreement with Skyworks to its stockholders, and is not making any recommendation regarding Microsemi's proposal.

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

# ACCO starts mass production of CMOS multi-mode multi-band power amplifier for 3G/LTE smartphones

## Standard CMOS integrates front-end PAs and controllers into single die in 5mm x 5mm MMPA

ACCO Semiconductor Inc of Sunnyvale, CA, USA, a fabless provider of RF front-end component manufactured using standard high-volume bulk CMOS processes, has announced mass production of the AC26120, a CMOS multi-mode multi-band power amplifier (MMPA) in a low-profile (0.69mm-high) LGA package for thin smartphone handset designs and Internet of Things (IoT) applications.

ACCO notes that CMOS power amplifiers have so far had limited success, mainly in 2G and single-band 3G handsets. However, designed for global handsets and IoT applications with support for quad-band GSM/EDGE and 12-band 3G/LTE (covering frequency bands 1, 2, 3, 4, 5, 8, 20, 23, 25, 26, 27, 34 and 39), the AC26120 is claimed to be the first and most integrated (5mm x 5mm) MMPA fabricated using a standard, low-cost CMOS processes, providing the cost, design and supply-chain advantages of CMOS integration combined with competitive performance.

ACCO has developed and patented what it claims is a unique transistor design that delivers the performance of typical gallium arsenide (GaAs) power amplifiers yet uses standard CMOS fabrication processes.

"ACCO's technology drives the integration of all the PAs and controllers into a single die, eliminating complex manufacturing techniques that use unreliable and expensive gold bonding wires," says ACCO's CEO Greg Caltabiano. "In addition, the consistent CMOS fabrication process enables the replacement of 50+ individual discrete components with a single integrated passive device," he adds.

The use of standard CMOS processing brings the advantages of Moore's Law to the RF front-end, the final non-silicon 'holdout' in the phone. This allows the entire smartphone to ride the same decreasing cost curve while increasing functionality and reliability, as experienced in the rest of the electronics industry, says ACCO.

"CMOS power amplifiers (PAs) have so far had difficulty matching

the performance and features of GaAs-based PAs in LTE mobile devices," notes Christopher Taylor, director of RF & Wireless Components at market research firm Strategy Analytics. "However, we have always held that CMOS has great potential in terms of production cost, integration and consistency, and will eventually win a significant share of the growing LTE PA market, which we estimate will soon exceed \$3bn per year," he adds. "By addressing the shortcomings of earlier CMOS PAs from the phone manufacturers' perspective, ACCO is leading the way to wider use in LTE devices," he believes.

ACCO is ramping up AC26120 production into various brands of LTE smartphones that are now shipping in multiple countries throughout Asia and Europe. The firm says that it will continue to leverage its patented technology to develop new CMOS solutions for the RF front-end of mobile communications products.

[www.acco-semi.com](http://www.acco-semi.com)

## TowerJazz to receive \$30m advance payment from customer for capacity expansion

Specialty foundry TowerJazz (which has fabrication plants at Tower Semiconductor Ltd in Migdal Haemek, Israel, and at its subsidiaries Jazz Semiconductor Inc in Newport Beach, CA, USA and TowerJazz Japan Ltd) has signed a definitive agreement with one of its customers to receive \$30m advance payment which would be used for capacity expansion in its worldwide fabs. TowerJazz will provide secured capacity to support current and fore-casted customer manufacturing needs.

"We are seeing through customers' forecasts, purchase orders, and our sales and marketing channels a very high demand, exceeding our current manufacturing capabilities, primarily in our analog 0.18µm technology processes," says TowerJazz's CEO Russell Ellwanger. "Hence, we are implementing a four-pronged, proactive strategy as follows:

(i) we are rapidly cross qualifying our Israeli, US and Japanese fabs for manufacture of products and technology platforms originating in

our US and Israeli fabs, (ii) we are investing in capacity to enable quick ramp up of more products, (iii) we are continuously exploring M&A opportunities and (iv) we are engaging in customer funded programs for customers who need capacity reservation and/or new capabilities and capacity. This signed definitive agreement is an example of the latter. We continue to execute on all fronts in parallel."

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

## Ascatron and LPE cooperate on 150mm SiC epitaxy for power electronics

Silicon carbide power semiconductor device developer Ascatron AB of Kista, Stockholm, Sweden (which was spun out of research institute Acreo in 2011, and supplies SiC epitaxial material) and LPE SpA of Milan, Italy, which designs and makes epitaxial reactors for power electronics, have entered into a cooperation agreement to develop SiC epi material for volume production on 150mm substrates. The first results demonstrating what is said to be outstanding uniformity are being presented at the 16th International Conference on Silicon Carbide and Related Materials (ICSCRM) in Catania, Sicily, Italy.

At its production fab, Ascatron has installed a new LPE SiC epitaxy reactor system with 150mm wafer

capability. The PE106 model is a new development from LPE and was recently launched on the market. What is claimed to be the industry's shortest cycle time and smallest footprint makes it optimal for the production of Ascatron's epi material for high-voltage power devices, it is reckoned.

"The new production equipment from LPE is key to scale up Ascatron advanced epitaxy processes to state-of-the-art 150mm SiC wafers," says Ascatron's CEO Christian Vieider. "We are now ready to provide our customers with n-type doped epi wafers with thicknesses from 0.1µm up to 100µm," he adds.

"The new PE106 will further enhance Ascatron unique epitaxy-

based SiC technology, which is set to gain worldwide acceptance among device makers because of its superior features," reckons LPE's CEO Franco Preti. "The cooperation with Ascatron enables LPE to strengthen our position on the market," he adds.

"The single-wafer concept of the LPE reactor is ideal to optimize growth parameters for a wide range of processes," comments Ascatron's chief technology officer Adolf Schöner. "We are now able to establish our unique growth processes for embedded pn junctions and 3D structures on this 150mm wafer platform, which is a crucial step towards cost-effective production of next-generation SiC power devices".

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

[www.lpe-epi.com](http://www.lpe-epi.com)

## SDK shipping very low-defect-density SiC epiwafers

Tokyo-based Showa Denko K.K. (SDK) will this month start commercial shipments of a new grade of 4" (100mm)- and 6" (150mm)-diameter silicon carbide (SiC) epitaxial wafers with very low defect density, under the trade name HGE (High-Grade Epi) for power devices.

Compared with mainstream silicon-based semiconductors, SiC-based power devices can operate under high-temperature, high-voltage, and high-current conditions while substantially reducing energy loss, notes SDK. These features enable the production of smaller, lighter and more energy-efficient power control modules. SiC power devices are already used as power sources for servers in data centers, distributed power supply systems for new energies, and in subway railcars. Demand is expected to grow further as plans have been announced to use SiC power devices in vehicles. Furthermore, efforts are under way to develop SiC-based ultra-high-voltage (10kV-class) devices for use in

power generation/transmission systems.

Power modules for high-voltage, high-current applications mainly contain devices with a Schottky barrier diode (SBD) structure and transistors with a MOSFET (metal-oxide-semiconductor field-effect transistor) structure. While SiC is increasingly used in SBDs, it is difficult to use SiC in MOSFETs. As a MOSFET's oxide film — formed on the surface of an epitaxial wafer — is used in device operations, finer surface defect (SD) and various types of crystal defects, including basal plane dislocation (BPD), considerably affect the yield and product quality.

For automotive applications meanwhile, large chips (measuring around 10mm square) are fabricated from epiwafers. This is because one device needs to handle a current as high as 100A. To prevent deterioration in the production yield of such large chips, the epiwafer's defect density should be controlled within 0.1/cm<sup>2</sup>.

In the new product HGE, SDK has controlled the density of surface defects to within 0.1/cm<sup>2</sup> (one-third the existing level of SDK's conventional product) and the density of basal plane dislocations to within 0.1/cm<sup>2</sup> (one-hundredth or less compared with the conventional product). As a result, it is now possible to almost eliminate device defects attributable to BPDs (assuming the use of a 10mm square chip). SDK hence believes that the new product will greatly contribute to the commercialization and market expansion of 'full SiC' power modules that combine SiC-SBDs and SiC-MOSFETs.

Using the HGE technology, SDK has also produced SiC epiwafers with a film thickness of 100µm or more, together with low defect density and good uniformity. SDK plans to start commercial shipments of these SiC epiwafers for use in power generation/transmission systems.

[www.sdk.co.jp](http://www.sdk.co.jp)

# Quadrivio and Como Venture acquires 16.7% stake in Ascatron as part of A-round fundraising

## Ascatron takes 28.8% stake in PileGrowth, targeting SiC-on-Si MOSFETs

As part of its A-round fundraising, silicon carbide (SiC) power semiconductor device developer Ascatron AB of Kista, Stockholm, Sweden (which was spun out of research institute Acreo in 2011) has signed an investment agreement with the Italy-based Quadrivio (through its venture capital fund TTVenture) and Como Venture, which together have received a 16.7% stake in Ascatron.

The aim is to continue to support Ascatron in creating industrializing next-generation power semiconductors based on wide-bandgap material such as silicon carbide (SiC) and gallium nitride (GaN), for which the market is reckoned to be rising rapidly at an annual growth rate of 54% to \$2bn in 2020.

Using its 3DSiC technology, Ascatron provides active doping structures based on epitaxy, enabling material quality and device performance unattainable through existing methods, it is claimed. With 10 staff in Sweden, the firm fabricates epitaxial material in-house and outsources the processing of device wafers and chip packaging. Prototype fabrication is performed in the Electrum Laboratory in Kista-Stockholm. Target markets range from high-temperature applications for harsh environments to high-voltage applications for wind, traction and data-centers markets, as well as volume markets for solar and automotive applications.

"This is a first investment from international investors," notes Ascatron's CEO Christian Vieider. "The money will be used to bring the Buried Grid technology for next-generation high-performance SiC power electronic devices to the market."

As part of the agreement, Ascatron acquired 28.8% of the shares of PileGrowth Tech, an Italian start-up based in Milan. PileGrowth has developed a process for growing

different semiconductor materials such as SiC on silicon. The material technology enable Ascatron to also address volume consumer markets.

"The development of MOSFET transistors based on cubic SiC grown on silicon is an exciting challenge,

with potential to compete in the 300–1000V market with other semiconductors such as GaN," notes Ascatron's chief technology officer Adolf Schöner.

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

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

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For more information please contact [sales@norstel.com](mailto:sales@norstel.com), [www.norstel.com](http://www.norstel.com)

## Wolfspeed launches surface-mount 1700V SiC MOSFET

Wolfspeed has launched what it says is the first 1700V SiC MOSFET in an optimized surface-mount (SMD) package designed for commercial use in auxiliary power supplies in high-voltage power inverter systems. The higher blocking voltage enables design engineers to replace lower-rated silicon MOSFETs with the new SiC MOSFETs, delivering higher efficiency, simplified driver circuitry, and lower thermal dissipation, and resulting in lower total system costs, says the firm.

The new SMD package, specifically designed for high-voltage MOSFETs, has a small footprint with a wide creepage distance (7mm between drain and source). This is made possible by the small die size and high blocking capability of Wolfspeed's SiC planar MOS technology. The new package also includes a separate driver source connection, which reduces gate ringing and provides clean gate signals.

"Our new 1700V SiC MOSFET provides power electronics engineers with significant design advantages, particularly in flyback topologies," claims Edgar Ayerbe, marketing manager for power MOSFETs.

"Due to the lower switching losses of silicon carbide, the devices operate at much lower junction temperatures. This enables customers to directly mount the devices onto the PCB with no additional heat-sinks, which greatly reduces the manufacturing costs and improves the reliability of the systems," he adds. "The result is a smaller, lighter power supply with a lower system cost than is possible using silicon devices."

Use of the 1700V SiC MOSFET is anticipated in auxiliary power supplies within high-power inverters — such as solar power inverters, motor drives, uninterruptible power supply (UPS) equipment, wind-energy converters, and traction power systems — which typically

buck down DC voltages to operate system logic, protection circuitry, displays, network interface, and cooling fans. They can also be used in the power supplies of three-phase e-meters, or in any converter application that requires high blocking voltages and low capacitance.

Designated the C2M1000170J, the new 1700V SiC MOSFET features an avalanche rating greater than 1800V, and an  $R_{DS(on)}$  on-resistance of 1 $\Omega$ . These characteristics ensure reliable performance in flyback converter circuits, including those in noisy electrical environments such as those found in high-power inverters. By enabling the design of single-switch flyback topologies from input voltages spanning 200V to 1000V, the 1700V SiC MOSFET simplifies the complex drive and snubber circuit elements required for silicon devices.

The C2M1000170J is fully qualified and available for sampling now.

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

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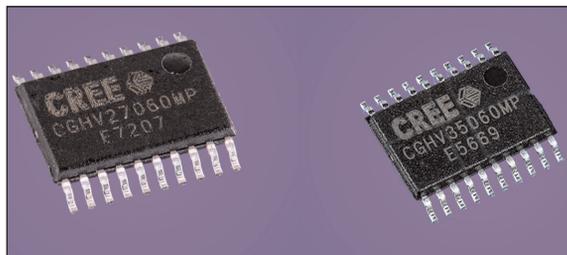
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## Wolfspeed launches 50V plastic-packaged GaN HEMTs

Wolfspeed of Raleigh, NC, USA has launched two plastic-packaged 50V/60W gallium nitride on silicon carbide (GaN-on-SiC) high-electron-mobility transistor (HEMT) devices that provide power and bandwidth in a low-cost package platform. Supplied in miniature (4.5mm x 6.5mm) surface-mount (SMT) packages, the new devices are suitable for LTE, small-cell base transceiver station (BTS), radar, public safety radio, and other communications applications.

The CGHV27060MP is a 50V/60W broadband GaN HEMT with circuits for both linear and pulsed applications and no internal input or output match, allowing it to support a wide range of frequencies spanning UHF through 2.7GHz. Tested at 2.5GHz, the new GaN HEMT is suited to LTE micro base-station amplifiers with 10–15W average power and high-efficiency topologies, such as Doherty or Class A, B and F amplifiers. Utilizing an S-band radar circuit, the 50V device provides 16.5dB gain, 70% drain efficiency and 80W output power at pulsed PSAT with a 100µs pulse width and 10% duty cycle.



**Wolfspeed's new 50V/60W plastic-packaged GaN HEMTs.**

At 14W PAVE, the device delivers 18.5dB gain and 35% efficiency. This plastic-packaged transistor is also capable of 65W of continuous wave (CW) output power when used in high-efficiency amplifier designs.

Internally pre-matched on input and unmatched on output, the CGHV35060MP is a 50V/60W broadband GaN HEMT designed for operation at 2.7–3.5GHz. Tested at 3.3GHz, the device exhibits 14.5dB gain with 67% drain efficiency, and is optimized for S-band applications, including weather, air traffic control, marine, port surveillance, and search & rescue radar applications.

Additionally, both of the new 50V GaN HEMTs are compatible with industry-standard digital pre-distortion (DPD) correction methods to increase amplifier efficiency, and their miniature 4.5mm x 6.5mm plastic overmold packaging makes them an economical solution for higher-volume

applications, says Wolfspeed.

Fabricated on a SiC substrate with a 0.4µm process, Wolfspeed's GaN-on-SiC HEMTs exhibit what are claimed to be superior performance characteristics compared to silicon (Si) and gallium arsenide (GaAs), including higher breakdown voltage, saturated electron drift velocity, and thermal conductivity. The firm's GaN HEMTs also offer greater power density and wider bandwidths than Si, GaAs, and GaN-on-Si transistors, it adds.

The distributors Mouser and Digi-Key are currently taking orders, and products will be available to ship by December.

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

## Wolfspeed presents RF foundry services and components at MILCOM

Wolfspeed exhibited at the MILCOM 2015 (military communications) conference and exhibition in Tampa, FL, USA (26–28 October).

Wolfspeed's RF Foundry — which is claimed to be the largest dedicated, commercial wide-bandgap production device facility — presented its US Department of Defense (DoD) manufacturing readiness level (MRL8+) and Category 1A Trusted Foundry services, in addition to several new Wolfspeed RF components, including a miniature, plastic-packaged 50V/60W broadband GaN HEMT for military communications applications as well as what is claimed to be one of the highest-power Ku-band MMICs on the market.

Supplied in a small 4.5mm x 6.5mm surface-mount plastic package,

Wolfspeed's new, inherently wide-band CGHV27060MP delivers 70% efficiency, 75W of power, and 17dB of large-signal gain over frequency bands spanning UHF to 2.7GHz. Booth visitors saw the high-power, high-efficiency device mounted in an active 2.5–2.7GHz application circuit, and view static examples of Wolfspeed's CMPA1D1E025F 40V/30W two-stage, 50Ω Ku-band GaN MMIC high-power amplifier (HPA), which covers the 13.5–14.75GHz commercial satcom band, delivers satcom measured performance of 20dB linear gain at 42dBm average output power, and enables higher-power, more efficient Ku-band solutions than incumbent traveling-wave tube (TWT) or gallium arsenide (GaAs) solutions. "Communications play a crucial

role in military readiness and operations, so it's critical that these systems are developed, from inception to completion, with the most effective, efficient, and reliable components available," says foundry program manager Ryan Fury. "Wolfspeed not only delivers industry-leading GaN-on-SiC RF technology especially designed to enable next-generation communications systems, but also provides world-class design assistance, proven fabrication processes, testing and support to help customers realize their specifications, and has a proven track record of doing with faster cycle times, higher first-pass design successes, and greater reliability than our competitors."

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

# Wolfspeed GaN high-power amplifiers meet reliability goals for Lockheed Martin's Space Fence program

Wolfspeed of Raleigh, NC, USA, a Cree Company that supplies gallium nitride on silicon carbide (GaN-on-SiC) high-electron-mobility transistors (HEMTs) and monolithic microwave integrated circuits (MMICs), has partnered with security and aerospace company Lockheed Martin of Bethesda, MD, USA to provide GaN high-power amplifiers (HPAs) for the US Air Force's Space Fence, which aims to significantly improve the timeliness with which operators can detect space events that could potentially threaten GPS satellites or the International Space Station.

Due to go online from Kwajalein Atoll in the Marshall Islands in 2018, Space Fence will accurately track the estimated 500,000 objects — such as spent rocket boosters, stray hardware, and other debris — that are floating in the same space as the satellites on which modern technology depends. Developed by Lockheed Martin in partnership with Space Military Command and the US Air Force Life Cycle Management Center/Space Command Control and Surveillance Division, Space Fence incorporates a scalable, solid-state S-band radar with a high frequency that is capable of detecting much smaller objects than the current system, and should thus improve accuracy, quicken response time, and expand surveillance coverage.

Having completed the critical design review and begun construction, Lockheed Martin's Space Fence team is currently focused on the production of technology that will bring the system online, and has recently reached a major design milestone by confirming the long-term reliability of Wolfspeed's GaN HPA technology, which is integral to meeting the project's



Photo Courtesy of Lockheed Martin

efficiency and availability requirements and will allow Space Fence to track 10 times more space junk than the current system. After more than 5000 hours (nearly seven months) of accelerated stress testing, Lockheed Martin has demonstrated greater than 99% confidence that Wolfspeed's GaN HPAs will meet the long-term reliability goals for the Space Fence program.

"These test results represent the culmination of more than a decade of shared investment in GaN technology," says Steve Bruce, vice president, Advanced Systems at Lockheed Martin Mission Systems and Training.

"GaN HPAs provide significant advantages for active phased-array radar systems like Space Fence, including higher power density, greater

efficiency, and improved reliability over previous technologies," he adds.

"Our high-performance commercial GaN products have been fielded for many years in a variety of military and commercial applications, and the successful completion of this most recent reliability milestone further validates that GaN technology has matured enough to support the mission-critical 24/7/365 coverage required by the Space Fence system," says Wolfspeed's RF and microwave director Jim Milligan.

In addition, Wolfspeed also offers a variety of catalogue S-band GaN radar devices, such as the CMPA2735075F, which is a two-stage GaN HEMT high-power MMIC amplifier that provides saturated RF output power of 75W over 2.7–3.5GHz with power gain of 20dB in a small package (0.5" x 0.5") and was the first S-band GaN HEMT MMIC on the market to offer 60% typical power-added efficiency (PAE) with RF pulse widths of 300µs and a 20% duty cycle.

[www.lockheedmartin.com/us/products/space-fence.html](http://www.lockheedmartin.com/us/products/space-fence.html)  
[www.wolfspeed.com/RF/Products/SBand-XBand-CBand/Packaged-MMICs/CMPA2735075F](http://www.wolfspeed.com/RF/Products/SBand-XBand-CBand/Packaged-MMICs/CMPA2735075F)

**GaN HPAs provide significant advantages for active phased-array radar systems like Space Fence, including higher power density, greater efficiency, and improved reliability over previous technologies**

## Lockheed Martin-led team awarded \$784m contract to build GaN-based ballistic missile defense radar

The US Missile Defense Agency (MDA) has awarded a team led by Lockheed Martin a contract to develop, build and test the Long Range Discrimination Radar (LRDR), which will support a layered ballistic missile defense strategy to protect the USA from ballistic missile attacks.

The nine-year contract (with options) will have potential contract value of about \$784m. Work will be primarily performed in New Jersey, Alaska, Alabama, Florida, and New York.

LRDR is a high-powered S-band radar incorporating gallium nitride components and will be capable of discriminating threats at extreme distances. LRDR is a key part of the Ballistic Missile Defense System (BMDS), which will provide acquisition, tracking and discrimination data to enable separate defense systems to lock on and engage

missile threats, a capability stemming from Lockheed Martin's experience in creating ballistic missile defense systems for the US and allied governments.

"The US has a limited number of ground-based interceptors to detect threats, yet the number of potential missile threats — and counter-measures used to hide those threats — is growing," says Carl Bannar, VP of Lockheed Martin's Integrated Warfare Systems and Sensors business. "Our offering meets the MDA's vision for LRDR by pairing innovative radar discrimination capability with proven ballistic missile defense algorithms."

Lockheed Martin says the MDA award builds on the US government's long-term investment in S-band radar, ground-based radar, and systems integration. Since 2012,

the firm has offered solid-state ground-based S-band radar utilizing an Open GaN Foundry model that leverages relationships with strategic suppliers.

"Our mature, scalable, GaN-based S-band technology was ideally suited for this high-performance ballistic missile defense application," says Bannar. "LRDR represents the latest evolution in ground-based radar and ballistic missile defense."

When constructed, LRDR will consist of a solid-state, active electronically scanned antenna (AESA) and the facility to house and operate this radar antenna. Lockheed Martin's proposed LRDR system will be built on an aggressive timeline ready for operational testing in Clear Air Force Station, Alaska by 2020.

[www.lockheedmartin.com/lrdr](http://www.lockheedmartin.com/lrdr)

## Raytheon's GaN-based 360° AESA Patriot radar moves toward production readiness

Using funding from Raytheon Company of Waltham, MA, USA, an upgrade to the combat-proven Patriot Air and Missile Defense System's radar that provides 360° of protection from threats such as drones, aircraft and cruise and ballistic missiles (attacking simultaneously from multiple directions) will soon be production ready, due to a recently completed series of engineering milestones.

Involving upgrading the Patriot radar main array with GaN-based active electronically scanned array (AESA) technology, Raytheon (currently constructing a GaN-based AESA full-size main panel radar array) is hence on track to having a full-scale main array demonstrator operational in early 2016.

"The Raytheon-developed GaN-based AESA radar builds on the more than \$150m invested in GaN technology, and will be a simple

upgrade for the more than 220 Patriot fire units fielded by the USA and the 12 other Patriot partner nations," says Ralph Acaba, VP of Integrated Air and Missile Defense at Raytheon's Integrated Defense Systems business. "This upgrade is approved for export to all current Patriot partners and a number of future Patriot partner nations such as Poland," he adds. "It enables 360° of protection, while retaining Patriot's mobility and reducing operation and maintenance cost by as much as 50%."

The Raytheon-built GaN-based AESA Patriot uses three antenna arrays mounted on a mobile radar shelter to provide 360° of radar coverage. The main AESA array is a bolt-on replacement antenna for the existing GaAs-based antenna. The GaN-based array measures about 9' wide x 13' tall, and is oriented toward the primary threat.

Patriot's new rear-panel arrays are a quarter the size of the main array and let the system look behind and to the sides of the main array, enabling Patriot to engage threats in all directions.

Earlier this year, Raytheon built a GaN-based AESA Patriot rear-panel array, integrated it with the current Patriot radar using the existing, recently modernized, back-end processing hardware and software, and tracked targets of opportunity to seamlessly create a 360° view.

Raytheon's GaN-based AESA Patriot radar will work with future open architecture as an Integrated Air and Missile Defense Battle Command System and retains backwards compatibility with the existing Patriot Engagement Control Station. It is also fully interoperable with NATO.

[www.raytheon.com/capabilities/products/patriot](http://www.raytheon.com/capabilities/products/patriot)

## Qorvo combines GaN-on-SiC with advanced packaging to cut cost, boost bandwidth, save board space for DOCSIS 3.1

Qorvo Inc, a provider of core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications, has announced a series of innovations intended to speed the deployment of high-speed cable TV DOCSIS 3.1 networks while providing cable designers greater flexibility in product design. The firm says that its newest multi-chip module (MCM) packaging, thermal sensing pins and GaN-on-SiC integration capabilities enable CATV product designers to lower costs, increase bandwidth and reduce board space.

Qorvo reckons that its MCM packaging helps to reduce board space by up to 50% and enables up to 30% cost savings versus traditional SOT115J packaging. The MCM packaging includes temperature-sensing pins, which ensure proper assembly and provide optimal thermal management. To facilitate the

use of its newest MCM capabilities, Qorvo also offers PCB layout and thermal design support services.

Qorvo says that multi-system operators (MSOs) can leverage the output and gain performance of its GaN-on-SiC technology to upgrade equipment within existing product footprints, saving installation time and cost while enhancing performance. Additionally, the GaN-on-SiC technology helps to reduce overall power consumption by up to 20% with associated features such as adjustable current control.

Qorvo's new DOCSIS 3.1 products include the RFCM3316 and -3326 GaN-based power doubler amplifiers and are available in miniaturized 9mm x 8mm MCM packaging.

Qorvo's DOCSIS 3.1 forward-path amplifiers operate from 45MHz to 1.2GHz with very high output (capable of 74dBmV composite

power), distortion lower than 70dBc and input and output return loss of -20dB (typical). The reverse-path amplifiers operate up to 300MHz with integrated attenuator and power-down function.

Qorvo's DOCSIS 3.1 products are available in MCM, SOT-115J and standard monolithic microwave integrated circuit (MMIC) packages, including QFN, SOT89 and SOIC. The MMIC products include gain amplifiers, low equivalent input noise current (EINC) trans-impedance amplifiers, attenuators, switches, filters and complete optical receivers for RF-over-glass (RFoG) and passive optical network (PON) applications. The DOCSIS 3.1 solutions use process technologies including GaN HEMTs, delivering high linearity, output power and reliability.

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

### Qorvo launches hybrid power doubler amplifier for DOCSIS 3.1

Qorvo has announced availability of the RFPD3580 power doubler amplifier, offering what is claimed to be the lowest power consumption and highest output capability for cable TV DOCSIS 3.1 systems.

Featuring both GaN-on-SiC and GaAs process technologies, the hybrid power doubler amplifier module is said to provide high output capability for 45MHz-1.218GHz CATV amplifier systems, excellent linearity and superior return loss performance with robust reliability. The RFPD3580 also operates at what Qorvo claims is an industry-best 18W power consumption, and is unconditionally stable under all terminations.

"DOCSIS 3.1 increases bandwidth to 1.218GHz, supports higher data rates and more digital content," notes Kellie Chong, director of CATV and Broadband Access products. "A new DOCSIS 3.1 hybrid fiber coaxial (HFC) architecture, fiber

deep (Node+0) is designed to reduce the number of PAs [power amplifiers], but puts higher performance demands on the power doubler amplifier. The high-performance RFPD3580 power doubler is designed to meet output requirements for this new architecture at the lowest power consumption."

Having shipped over 2 million CATV GaN units to date, Qorvo is further expanding its portfolio of DOCSIS 3.1 solutions to help cable operators and MSOs optimize available spectrum and increase throughput across their networks to better support increasing subscriber demand for new and improved broadband services.

The firm's DOCSIS 3.1 product portfolio includes over 60 products, including power doubler amplifiers, push-pull amplifiers, pre-driver gain blocks, attenuators, and switches. Its DOCSIS 3.1 forward-

path amplifiers operate from 45MHz to 1.2GHz, with high output (capable of 74dBmV composite power); distortion levels of under 70dBc; and input and output return loss of -20dB (typical). Its reverse-path amplifiers operate up to 300MHz with integrated attenuator and power down function. The firm's DOCSIS 3.1 solutions use process technologies including GaN HEMTs, which deliver superior linearity, output power and reliability needed to equip high-speed cable infrastructure networks.

Qorvo's DOCSIS 3.1 products are available in SOT-115J, MCM and standard MMIC packages, including QFN, SOT89 and SOIC. The MMIC products include gain amplifiers, low equivalent input noise current (EINC) trans-impedance amplifiers (TIA), attenuators, switches, filters and complete optical receivers for RF-over-glass (RFoG) and passive optical network (PON) applications.

## PowerAmerica calls for projects for DOE-funded program on wide-bandgap manufacturing development

PowerAmerica — a private–public partnership between the US Department of Energy, industry and academia — has released a new call for projects to advance wide-bandgap (WBG) semiconductor manufacturing and to accelerate the adoption of WBG semiconductor power electronics applications.

Issued on 2 October, the call for projects requests participation on:

- Projects that lower the cost and increase the availability of wide-bandgap power electronic devices by increasing gallium nitride (GaN) and silicon carbide (SiC) foundry capacity.
- Projects that advance innovative WBG semiconductor devices from design through qualification and accelerate the pathway for devices to reach volume manufacturing.
- Projects that increase the acceptance and adoption of WBG power electronics by advanced packaging

and demonstrating reliability of SiC and GaN devices.

- Projects to accelerate commercialization of WBG power electronics applications in:
  - transportation and energy-constrained mobile systems;
  - renewable energy power conversion and energy exploration;
  - energy efficiency for communications and digital systems; and
  - high-voltage systems and energy-efficient motor drives.
- Education and workforce development for WBG semiconductors and power electronics.

### Technical applications require 1:1 cost sharing.

Led by North Carolina State University (NCSU) and located on its Centennial Campus, PowerAmerica's mission is to develop advanced manufacturing processes to enable cost-competitive, large-scale production of WBG semiconductor-

based power electronics, which allow electronic systems to be smaller, faster and more efficient than power electronics made from silicon. PowerAmerica is a \$146m program, with \$70m provided by the Department of Energy and \$76m provided by industry, state and academia through cost sharing.

"The advantages of WBG are tremendous," says PowerAmerica's deputy director John Muth.

"Compared to silicon, in many applications using WBG power electronics the system can be reduced in size and weight, operate at higher temperatures and cut energy losses in half," he adds.

"This is a great opportunity for US industry to excel and compete with the rest of the world and is a fantastic area for young engineers to further their careers."

[www.poweramericainstitute.org/call-for-projects](http://www.poweramericainstitute.org/call-for-projects)

## Panasonic develops GaN diodes with high-current operations and low turn-on voltage

Japan's Panasonic Corp has developed GaN diodes that can not only operate at a current of 7.6kA/cm<sup>2</sup> (four times greater than that tolerated by conventional silicon carbide diodes with a 1200V rated voltage) but also operate at low voltages by virtue of their lower turn-on voltage (0.8V). Also, on-resistance ( $R_{on}A$ ) is roughly halved, to 1.3mΩcm<sup>2</sup>.

Production of the diodes is enabled by a new hybrid structure composed of separately embedded structure consisting of a low-voltage unit and a high-current-capable unit, in preparation for high-voltage conditions.

Conventional silicon diodes are limited regarding reducing switching losses. On the other hand, diodes based on SiC and GaN require an increased chip area to achieve high-current operation, placing limitations on the reduction of switch-

ing losses and size due to the increased operating frequency.

The new GaN diodes have achieved simultaneous high-current operations and low threshold voltage, and thus can handle high currents even with a small chip area. The capacitance of the chip can therefore be reduced to achieve lower switching losses, allowing the device to operate at higher frequencies. As a result, the use of GaN diodes in the voltage conversion circuits or inverter circuits of automotive or industrial equipment that requires high power can reduce system size due to high-frequency operation.

Panasonic says the hybrid structure of the new diodes was created with a p-type GaN layer in which trenches are formed. The firm developed processing technology that can remove a p-type layer on an n-type

layer in a selective way, to achieve not only high-current operations and a low turn-on voltage but also a breakdown voltage of 1.6kV.

To fabricate the new diodes, Panasonic used low-resistance conductive GaN substrates (which have been used commercially in LEDs and lasers and are expected to be adopted in power devices). The firm has also established technologies for epitaxial growth and processing on a GaN substrate. A structure in which currents flow vertically enables a smaller chip area and lower resistance.

The development was presented at the 47th annual International Conference on Solid State Devices and Materials (SSDM 2015) in Sapporo, Japan (27–30 September). The work was partially supported by Japan's Ministry of Environment.

<http://panasonic.net>

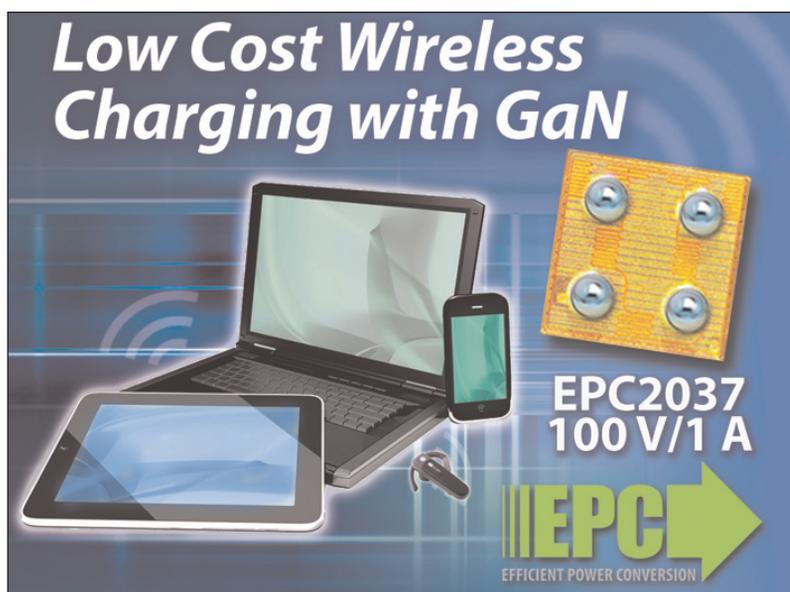
## EPC adds 100V, 1A, 550mΩ E-mode GaN power transistor for wireless charging Class-D and Class-E amplifiers

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, has introduced the EPC2037 as the newest member of its family of enhancement-mode gallium nitride power transistors.

The EPC2037 is a 0.9mm x 0.9mm 100V<sub>DS</sub>, 1A device with a maximum  $R_{DS(on)}$  of 550mΩ with 5V applied to the gate. The GaN transistor delivers what is claimed to be high performance due to its ultra-high-switching frequency, low  $R_{DS(on)}$ , exceptionally low  $Q_G$  and small package. This eGaN FET was designed to be driven directly from a digital logic IC thus eliminating the need for a separate and costly driver IC.

Compared to a silicon power MOSFET with similar on-resistance that does require a driver IC, the EPC2037 is much smaller and has many times superior switching performance, EPC reckons. In addition to wireless charging, circuit applications that benefit from the eGaN FET's performance include high-frequency DC-DC conversion, LiDAR/pulsed power, and class-D audio amplifiers.

To support easy 'in circuit' performance evaluation of the EPC2037, the EPC9051 is available



applications such as LiDAR.

The amplifier board features the 100V-rated EPC2037 eGaN FET. The amplifier is set to operate in differential mode and can be re-config-

ured to operate in single-ended mode. The key feature of the development board is that it does not require a gate driver for the eGaN FETs and is driven directly from logic gates. A separate logic supply regulator has also been provided on the board.

as a high-efficiency, differential-mode class-E amplifier development board that can operate up to 15MHz without the addition of a separate driver IC. The purpose is to simplify the evaluation process of class-E amplifier technology using eGaN FETs by allowing engineers to easily mount all the critical class-E components on a single board that can be easily connected into an existing system.

This board may also be used for applications where a low-side switch is utilized. Examples include, but are not limited to, push-pull converters, current-mode Class-D amplifiers, common-source bi-directional switch, and generic high-voltage, narrow-pulse-width

pricing is \$0.55 each (in 1000-unit quantities) for the EPC2037 power transistors and \$158.13 for the EPC9051 development board. Both products are available from Digi-Key.

<http://digikey.com/Suppliers/us/Efficient-Power-Conversion.page>

<http://epc-co.com/epc/Products/eGaNfets/EPC2037.aspx>

<http://epc-co.com/epc/Products/DemoBoards/EPC9051.aspx>

## EPC adds dual E-mode 120V, 60mΩ power transistor for wireless power transfer Class-E amplifiers

Efficient Power Conversion Corp has introduced the EPC2110 as the newest member of EPC's family of enhancement-mode gallium nitride integrated circuits.

The EPC2110 is a dual (common-source) eGaN FET configuration in a small 1.35mm x 1.35mm, 120V<sub>DS</sub>, 20A device with a maximum  $R_{DS(on)}$  of 60mΩ with 5V applied to the gate. The GaN IC delivers what is

claimed to be high performance due to its ultra-high switching frequency, extremely low  $R_{DS(on)}$ , exceptionally low  $Q_G$  and in a very small package.

Compared to a silicon power MOSFET with similar on-resistance, the EPC2110 is much smaller and has many times superior switching performance, EPC reckons. Circuit applications that benefit from the

eGaN IC's performance include ultra-high-frequency DC-DC conversion, synchronous rectification, class-D audio amplifiers and, most notably, wireless power transfer.

The EPC2110 is priced at \$1.06 in 1000-unit quantities, and is available through Digi-Key Corp.

<http://epc-co.com/epc/Products/eGaNfets/EPC2110.aspx>

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# IQE's GaN-on-SiC epiwafers used to achieve record power and frequency results for satcom and 5G applications

## Single 0.14 $\mu\text{m}$ -gate-length GaN MMIC process yields both 7.7W/mm at 35GHz and 12.5W/mm at 10GHz

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has been acknowledged for supplying commercially ready 100mm gallium nitride on silicon carbide (GaN-on-SiC) epiwafers that were used to produce record results for both high-gain and high-power-density transistor devices, enabling — for the first time — a flexible monolithic microwave integrated circuit (MMIC) design for efficient high-voltage/high-power broadband operation at frequencies ranging at 0–40GHz (Fitch et al, 'Implementation of High-Power-Density X-Band AlGaIn/GaN High Electron Mobility Transistors in a Millimeter-Wave Monolithic Microwave Integrated Circuit Process', IEEE Electron Device Letters, vol 36, no. 10, October 2015).

The high-electron-mobility transistor (HEMT) devices were produced using GaN-on-SiC wafers purchased from IQE by the US Air Force Research Laboratory (AFRL),

Sensors Directorate, Aerospace Components Division, Devices for Sensing Branch at Wright-Patterson Air Force Base in Dayton, OH.

High-frequency microwave capabilities of up to 40GHz (the Ka-band) are essential for satellite communications and will become increasingly important for next-generation (5G) wireless communications, notes IQE. However, until now, designers have faced compromises between frequency and power.

The solution outlined in the paper provides designers with the option of incorporating two different devices by implementing a 0.14 $\mu\text{m}$ -gate-length GaN MMIC process capable of high-efficiency Ka-band operation while simultaneously achieving high-power-density X-band operation using the same process flow.

The authors demonstrated power density of 7.7W/mm at 35GHz and drain bias of  $V_{DS} = 30\text{V}$  on a stan-

dard 4 x 65 $\mu\text{m}$  T-gated FET and then 12.5W/mm at 10GHz and  $V_{DS} = 60\text{V}$  on a 4 x 75 $\mu\text{m}$  T-gated FET by adding a field plate. These are said to be the highest reported power densities achieved simultaneously at X-band and Ka-band in a single wideband GaN MMIC process.

The epiwafers were produced at IQE's New Jersey facility using metal-organic chemical vapor deposition (MOCVD) on 4" semi-insulating SiC substrates.

"These results, achieved on our GaN-on-SiC epiwafers, demonstrate the ability of IQE to produce record-breaking, world-leading results on commercial platforms that enable today's leading-edge satellite communications and will be essential for enabling next-generation wireless technologies," comments Dr Wayne Johnson, vice president of IQE's Power Business Unit.

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

## IQE wins Advanced Manufacturing title at Made in Wales Awards

IQE plc of Cardiff, Wales, UK has won the Advanced Manufacturer title at the Insider Media Made in Wales Awards 2015 (organized by UK-based business publisher Insider Media Ltd).

Sponsored by Hunter Selection, the award was presented during a gala ceremony at Cardiff City Hall in recognition of IQE's close work with the Welsh Government and Cardiff University to achieve key milestones in developing an advanced, high-tech manufacturing capability with the vision of establishing the world's first compound semiconductor cluster in Wales.

"The company is uniquely positioned to lead the establishment of

a technology cluster to help drive the high-tech manufacturing capabilities for the development and commercialization of next generation semiconductors," reckons IQE's CEO Dr Drew Nelson.

In August, IQE announced the formation of the Compound Semiconductor Centre (CSC), a joint venture between IQE and Cardiff University. A formal launch is scheduled for November at events in Westminster and Cardiff. "By developing regional specialization, we plan to build the world's first semiconductor cluster, creating high-quality businesses and jobs," says Nelson.

The new centre provides a key milestone towards the creation of

a regional specialization in compound semiconductor technologies and will build on the work of Cardiff University's Institute of Compound Semiconductors (announced in May) to provide a dedicated facility for research into novel deployment of compound semiconductors.

IQE is currently leading a consortium of up to 40 businesses and institutions across Europe in an application under Horizon 2020 (the European Union's framework program for Research and Innovation for 2014–2020) to fund the establishment of up to 20 pilot production lines for compound semiconductor-based technologies.



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## Panasonic commercializes high-heat-resistant encapsulation material for SiC and GaN power devices

Panasonic Corp of Osaka, Japan has developed an encapsulation material for power devices with what it claims is the greatest heat-resistance performance (glass transition temperature) of 210°C and superior long-term reliability. The firm is shipping samples of CV8540 series products from October.

To address demands for smaller-sized and lighter-weight in-vehicle devices that consume less energy, industry is paying attention to power devices based on silicon carbide (SiC) or gallium nitride (GaN), says Panasonic. When used in a vehicle, however, power devices must have superior high-temperature resistance and high-current characteristics, and excellent long-term reliability.

Silicon devices currently in widespread use can sometimes reach temperatures of up to 125–150°C in operation. Because of their ability to deal with high currents, SiC or GaN devices can operate in such high-temperature environments even when temperatures soar over 200°C.

To make the most of this advantage, semiconductor encapsulation materials for power devices must also have greater heat resistance and long-term reliability. Conventional



**High-heat-resistant semiconductor encapsulation material.**

encapsulation materials are at a disadvantage in that they peel off from the leadframe and the device when subjected to high temperatures. Panasonic has now achieved what it claims is the greatest heat-resistance performance and improved the adhesive properties inside the material. The new encapsulation material's glass transition temperature of up to 210°C compares with 170–180°C for Panasonic's conventional CV4100 series products.

This has allowed Panasonic to develop and commercialize encap-

sulation material with superior long-term reliability. The firm says that, in environmental resistance tests (a 1000-cycle thermal cycle test from –40°C to 200°C; and a high-temperature shelf test, at 200°C for 3000 hours), neither cracks in the encapsulation material nor peeling from the leadframe and the power device element were observed. Superior long-term reliability contributes to improving the reliability of power devices, says Panasonic.

<http://panasonic.net>

## Element Six presenting diamond heat spreaders for thermal management of hotspots in GaN devices

At the IMAPS 48th International Symposium on Microelectronics in Orlando, FL, USA (26–29 October), Thomas Obeloer, business development manager at Luxembourg-registered synthetic diamond materials firm Element Six (a member of the De Beers Group of Companies), presented 'Optimizing Diamond Heat Spreaders for Thermal Management of Hotspots for GaN Devices' and discussed the application of a hybrid silicon micro-cooler with diamond heat spreaders to effec-

tively cool gallium nitride devices.

As part of the session 'Packaging the Internet of Things & Other Advanced Applications: High Power / High Temperature', Obeloer discussed the need for new thermal management solutions for GaN-based devices in order to preserve high reliability and to unlock GaN's intrinsic performance potential as devices become increasingly smaller with higher power densities.

Obeloer is presenting findings from an extensive experiment measuring the effectiveness in heat

dissipation leveraging several grades (i.e. thermal conductivities) of chemical vapor deposited (CVD) diamond heat spreaders paired with a silicon-based micro-cooler. Results prove that the maximum chip temperature can be reduced by more than 40%, says the company, and that 10kW/cm<sup>2</sup> hotspot heat flux can be dissipated while maintaining the maximum hotspot temperature at below 160°C.

[www.imaps.org/imaps2015](http://www.imaps.org/imaps2015)

[www.e6.com/GaN](http://www.e6.com/GaN)

## NI AWR Design Environment V12.01 update now available

NI (formerly AWR Corp) of El Segundo, CA, USA has announced the availability of a new update to version V12 of NI AWR Design Environment, which targets designers of monolithic microwave integrated circuits (MMICs), radio-frequency printed-circuit boards (RF PCBs), and modules.

Introduced in June, V12 offers

new amplifier-, antenna- and radar-specific features, as well as ease-of-use improvements, speed enhancements and additional third-party integration flows.

Continuing to build upon the new load-pull features of V12, the V12.01 update includes numerous additions to the load-pull capabilities, as well as multiple improvements

to system simulation within (VSS) Visual System Simulator communications system design software and to layout, tuning, yield analysis and optimization capabilities within NI AWR Design Environment, inclusive of Microwave Office circuit design software and AXIEM and Analyst 3D electromagnetic (EM) simulators.

[www.awrcorp.com/v12](http://www.awrcorp.com/v12)

## Accel-RF opens permanent East Coast US office

Accel-RF Instruments Corp of San Diego, CA, USA (which produces turn-key reliability and performance characterization test systems) has opened a permanent office on the East Coast, located in the Innovation Center in Jackson Technology Park, at 94 Jackson Road, Suite 106A, Devens, MA 01434.

The new location is focused on application support as well as

equipment maintenance service, and will allow the firm to better serve existing and future customers in the Eastern USA.

"This is a significant move for Accel-RF and something we felt compelled to do in order to maximize support to all of our East Coast customers," says president & CEO Roland Shaw. "We consider the East Coast as a major region of

compound semiconductor development and manufacturing expertise."

Jeff Cotton, a key contributor to product design in San Diego, will head the East Coast office. Along with personnel, Accel-RF will relocate equipment from its AARTS automated test equipment product line for support and system upgrade capacity.

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

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# Veeco's Q3 revenue up 51% year-on-year, but MOCVD orders slump due to LED oversupply for display backlighting and China slowdown

## Full-year revenue forecast cut by 20% due to weaker LED industry

For third-quarter 2015, epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue of \$140.7m, up 51% on \$93.3m a year ago although up only 7% on \$131.4m last quarter (which was the highest quarterly revenue since 2012).

On a geographic basis, China rose from 50% of total revenue last quarter to 58%. The remaining 42% was spread fairly evenly across the USA, EMEA (Europe, the Middle East & Africa) and Rest of the World (including Taiwan, Japan and Korea) at 13-15% each.

The Advanced Packaging, MEMS & RF segment contributed 10% of total revenue (relatively level on last quarter's 11%). The Scientific & Industrial segment comprised 10% of total revenue, down on 14% last quarter. The Data Storage segment remained about 13% of revenue.

The Lighting, Display & Power Electronics segment — primarily MOCVD systems — rose from 62% to 67% of total revenue. Veeco obtained final product acceptance on many EPIK MOCVD tools and recognized a majority of previously deferred EPIK system revenue in Q3. However, service revenue was hit by declining utilization rates for MOCVD systems, brought on by the broader slowdown in the LED market.

"According to [market research firm] IHS, demand for LCD TVs declined to their lowest levels since

the global recession, impacted by the ongoing economic slowdown in China and weaker currencies in multiple markets," notes

chairman & CEO John R Peeler.

"These conditions resulted in excess supply of LEDs for display backlighting and excess MOCVD capacity.

While demand for LED lighting units has remained healthy, due in part to lower bulb pricing, lighting demand was insufficient to absorb the steep decline in display units," he adds.

"Additionally, the decline in LED bulb prices has placed severe pricing pressures on chipmakers and has impacted their profitability. As a result, LED manufacturers are delaying their investment plans for both capacity and replacement tool purchases, and we've had a customer push out a delivery of a sizable order booked earlier this year."

Nevertheless, driven by favorable business volume and mix, non-GAAP gross margin has risen further, from 35.5% a year ago and 37.9% last quarter to 39.1% (near the top of the 37.5-39.5% guidance range).

Operating expenses have fallen from \$40m last quarter to \$36.4m

**Demand for LED lighting units has remained healthy but, due in part to lower bulb pricing, lighting demand was insufficient to absorb the steep decline in display units**

(much lower than the \$40-42m guidance) due to reduced incentives, commissions and variable charges associated with the current business conditions.

Operating income has almost doubled from \$9.75m last quarter to \$18.6m. So, after depreciation of \$3.2m, adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) was \$21.8m, up from \$12.8m last quarter and compared with a loss of \$1.8m a year ago, driven by operational leverage and favorable mix. Likewise, net income was \$13.6m (\$0.33 per share), up from \$8.4m (\$0.20 per diluted share) last quarter and compared with a loss of \$0.8m (\$0.02 per share) a year ago.

Operating cash flow generation has grown from \$8m last quarter to \$9.9m. During the quarter, cash balances rose by \$7m to \$403m.

"Veeco's third quarter results demonstrate solid operational execution with gross margin, adjusted EBITDA and earnings per share all above the mid-point of our guided ranges," comments Peeler.

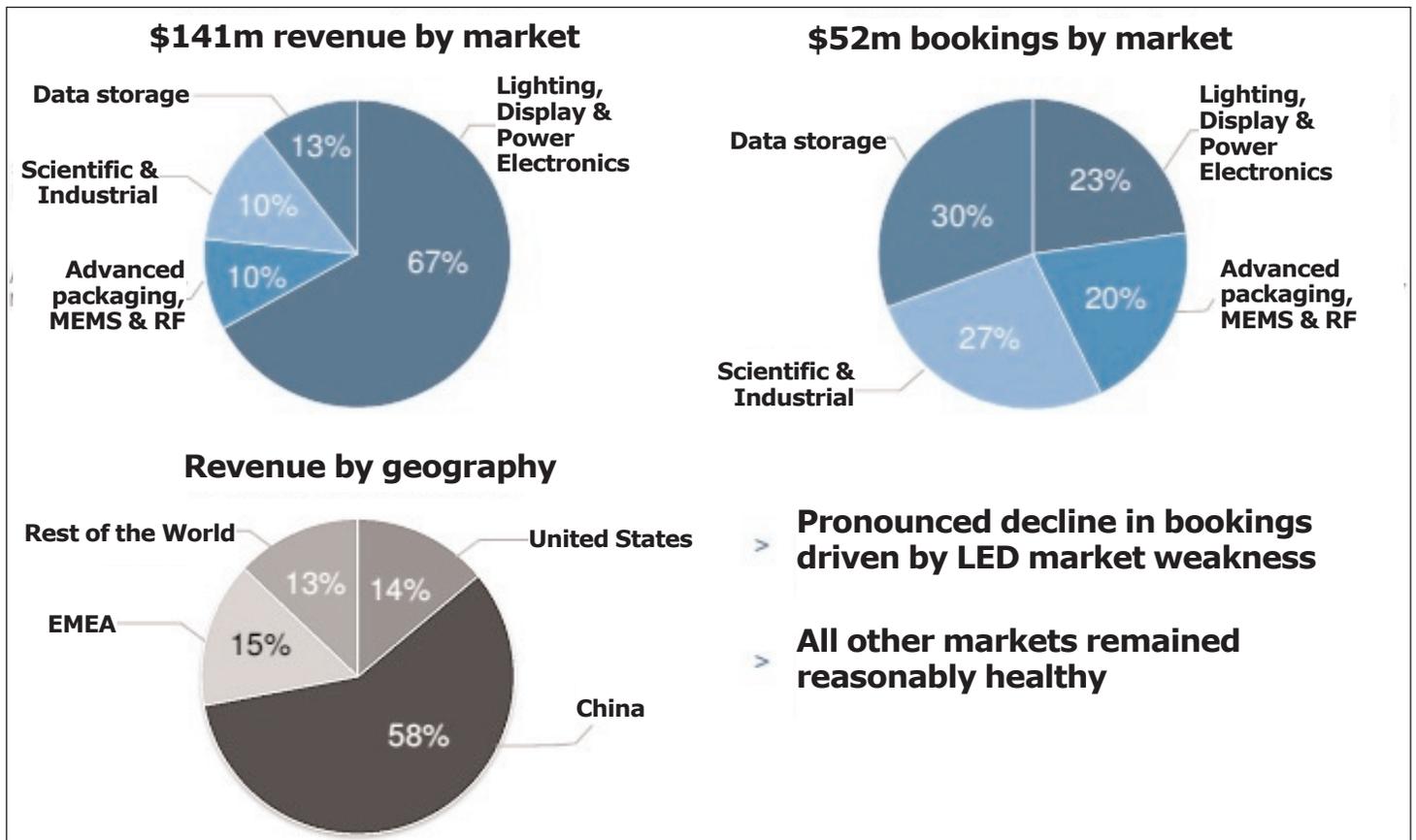
However, in the final weeks of the quarter business conditions deteriorated and severely reduced order bookings, mostly due to MOCVD orders being well below expectations. "We had been actively engaged with leading LED manufacturers to add new MOCVD capacity or replace portions of the installed base," notes chief financial officer & executive

## Share repurchase program authorized

Veeco's board of directors has authorized a program to repurchase (over the next two years) up to \$100m of the firm's outstanding common stock (about 12% of Veeco's outstanding shares),

funded using available cash balances and cash generated from operations. This "underscores our confidence in longer-term growth prospects and our commitment to enhance shareholder value," says

Peeler. "Our strong balance sheet provides us with the flexibility to execute share repurchases while continuing to invest in R&D and other opportunities to profitably grow our business."



VP-finance Sam Maheshwari. "Based on our discussions, we expected sizeable orders from at least three LED manufacturers to occur in second-half 2015," he adds. "However, as industry conditions continued to weaken [amid ongoing economic uncertainty in China and weak LED demand for TV display backlighting], these customers ultimately made the decision to delay their investment for the time being. This is reflected in our Lighting, Display and Power Electronics bookings, which declined by nearly \$75m sequentially and represented only 23% of total Q3 bookings [compared with 70% last quarter]."

Compared with 14% last quarter, Advanced Packaging, MEMS & RF bookings comprised 20% of total orders in Q3. Scientific & Industrial bookings rose from 10% of total orders last quarter to 27%, fairly evenly divided between MBE and ion beam deposition tools. Data Storage bookings rebounded from just 6% of total orders last quarter to 30% (although demand in this market is expected to fluctuate).

Total order bookings have plunged from \$124m last quarter to a much

less-than-expected \$52m (although they would have been relatively level quarter-over-quarter without the MOCVD postponements). During the quarter, total order backlog hence plunged from \$279m to \$187m.

The balance of the deferred EPIK MOCVD revenue is expected to be largely recognized in fourth-quarter 2015. However, Veeco expects Q4 revenue to fall to \$90–110m, impacted by the push-out of a number of MOCVD tools into 2016 by a China-based LED manufacturer while this customer faces challenges in securing letters of credit.

Gross margin should be 32–35%, due to the combined impact of significantly lower volume and an unfavorable mix. Veeco's ability to reach the targeted gross margin of 40% by Q4/2015 has been impacted by low MOCVD sales volume, in combination with low-margin EPIK tools booked last year as part of a large-quantity order. However, EPIK cost-reduction plans are on track and should be fully implemented by end-2015. "EPIK performance in the field remains strongly differentiated, and we have seen no deterioration in pricing environment, just

a significant drop-off in volume," notes Maheshwari. "We remain confident that our target gross margin of 40% is achievable as MOCVD volume picks up."

Operating expenses in Q4 are expected to be \$35–37m (including the reimbursement for certain development costs which were largely incurred in prior quarters). Operating income should be between –\$6m and +\$2m. After depreciation of \$3m, adjusted EBITDA should be between –\$3m and +\$5m. Earnings per share are expected to be between a loss of \$0.12 and a profit of \$0.07.

For full-year 2015, Veeco is lowering its revenue guidance by about 20% to \$460–480m, up 17–22% on 2014's \$393m (rather than greater than 35%, forecast previously).

"Given our limited visibility in the customer order timing, it is difficult to predict the duration of this [MOCVD] investment pause," notes Peeler. "However, demand for LED lighting remains healthy, which gives us confidence that investments will resume once industry conditions improve," he adds.

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

# Aixtron's revenue grows 35% in Q3

## Favorable product mix yields first positive EBITDA since Q4/2013

For third-quarter 2015, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €54.6m, up 35% on €40.4m last quarter and up 19.7% on €45.6m a year ago due to increased scheduled shipments.

Penetration of LED technology in the lighting market continues. Because of the continuing qualification processes for the AIX R6 showerhead metal-organic chemical vapor deposition (MOCVD) system (launched last November for the mass production of LEDs based on gallium nitride), demand for this system type remained subdued. Revenue growth was therefore

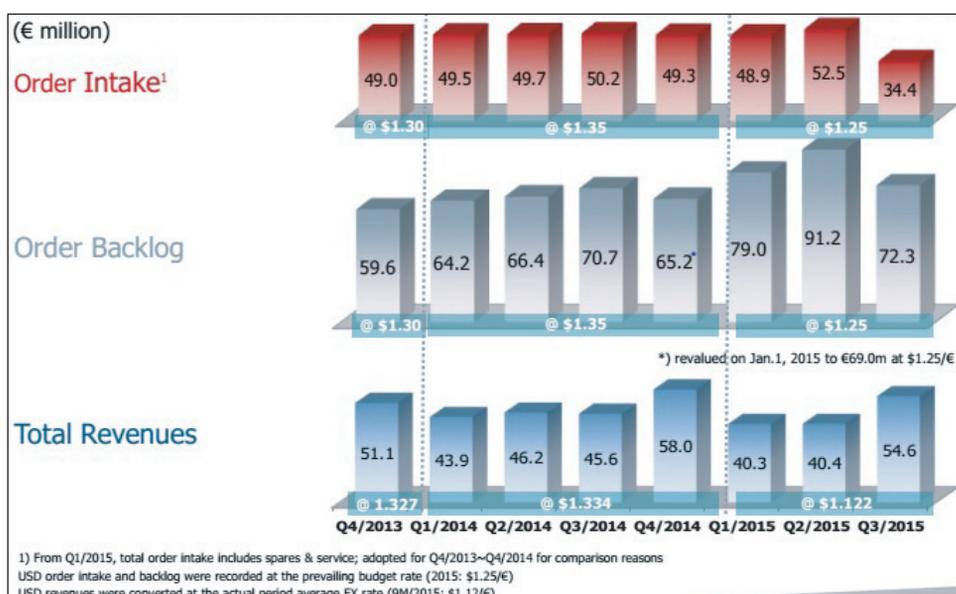
based on a wide range of different applications such as LEDs, laser, memory chips and power electronics.

Gross margin has rebounded from just 9% last quarter to 33%, due to a more favorable product mix and lower operational costs, including a payment from a contractual settlement.

Mainly due to better cost control and income from a contractual compensation recorded in other operating income, operating expenses have fallen further, from €24.4m a year ago and €21.5m last quarter to €16.3m.

Hence, for the first time since fourth-quarter 2013, earnings before interest, tax, depreciation and amortization (EBITDA) was positive, at €4.1m, compared with -€15.3m last quarter. Earnings before interest and taxes (EBIT) was also positive, at €1.5m, compared with an operating loss of -€17.9m last quarter.

Despite being an improvement from -€21.7m a year ago, free cash flow has fallen back from -€0.1m last quarter to -€10m. However, this has resulted mainly from the currency difference in the \$-based cash and cash equivalents. During the quarter, cash and cash equivalents (including bank deposits with a maturity of more



than three months) hence fell by €11.9m from €255.4m to €243.5m. Aixtron does not have any bank borrowings.

Total order intake (including spares and service) was €34.4m, down 34% on €52.5m last quarter, reflecting the lower overall market demand as well as the effects from the ongoing qualification processes for the AIX R6. Total equipment order backlog at the end of September was €72.3m, up 2% on €70.7m a year previously but down 21% on €91.2m at the end of June. However, this continues to exclude tools from the order of a major Chinese customer, for which deliveries have been postponed from 2015 to 2016 (depending on the progress of the ongoing milestone-based qualification process).

Due to the postponed shipments (in particular of the AIX R6 showerhead system), in mid-October Aixtron lowered its full-year 2015 revenue guidance from €220–250m to €190–200m (based on the \$/€ exchange rate of 1.12 at the end of September). "We work intensively with our customers to push forward and to successfully complete the qualification processes," says president & CEO Martin Goetzeler. Aixtron continues to expect to return to EBITDA break-even in

second-half 2015. Year-on-year, EBIT is expected to improve but to remain negative for full-year 2015.

"We continue to proceed in the strengthening of our product and technology portfolio," says Goetzeler. "In the area of OLEDs [organic light-emitting diodes], we have received a first order for our encapsulation technology OptaCap [gained through the acquisition of PlasmaSi Inc of Fremont, CA, USA, which provides low-temperature silicon nitride plasma-enhanced chemical vapor deposition (PECVD) systems for the encapsulation of organic thin-films]. The test runs of our Gen8 demonstrator for the production of large-area OLEDs are moving forward on schedule and therefore we anticipate results from customer demonstrations within the coming months," he adds.

"In addition, we were able to score in applications such as LED, laser, telecommunication and power electronics as well as in memory products," continues Goetzeler. "The margin improvement resulting from it supports our recently communicated profit expectations for the current financial year," he adds. "The third quarter also proves that markets in Europe and the US are still of great importance."

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

## LandMark orders another Aixtron MOCVD system

LandMark Optoelectronics Corp of Tainan City, Taiwan, which supplies GaAs and InP based epitaxial wafers for optical communications, industrial applications and special-purpose usage, has placed a repeat order for another Aixtron AIX 2800G4-TM metal-organic chemical vapor deposition (MOCVD) system (to be delivered in first-quarter 2016) for the production of laser diode devices.

Based on Aixtron's production-proven Planetary Reactor platform and particularly suitable for the production of high-performance laser diodes, the AIX 2800G4-TM system is complemented by a highly efficient Transfer Module (TM) that enables higher throughput and reduced cycle times. Also, the equipment design allows flexible configuration of wafers from 2" to 8"

to address customer's product evolution over time while minimizing cost per wafer.

"We will provide full support to LandMark to enable our customer to start up production with the new tool as quickly as possible," says Aixtron's executive VP & chief operating officer Dr Bernd Schulte.

[www.lmoc.com.tw/en/e-index.html](http://www.lmoc.com.tw/en/e-index.html)  
[www.aixtron.com](http://www.aixtron.com)

## Asahi Kasei buys Veeco MBE system for IR sensors

Tokyo-based electronics company Asahi Kasei Microdevices (AKM) has bought a Veeco GEN200 molecular beam epitaxy system and SUMO effusion cells to expand its production of infrared sensors.

"Veeco clearly demonstrated their expertise and their system's superior process performance capability," comments Dr Yoshihiko Shibata, general manager of Asahi Kasei

Microdevices' Fuji Manufacturing Center. "The GEN200 provides us with superior heater performance and the SUMO effusion cells offer exceptional uniformity and process stability that are required to meet our demanding sensor production requirements," he adds.

Veeco says that, based on customer feedback, the GEN200 MBE system delivers compelling cost of ownership

through long campaigns and excellent wafer quality in the production of GaAs- and InP-based wafers for infrared sensors and laser diodes. The system also features a modular architecture that allows a significantly smaller footprint than comparable MBE systems and allows for up to two growth modules for greater throughput, the firm adds.

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

Web: [laytec.de](http://laytec.de)

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Knowledge is key

# Bruker to acquire Jordan Valley Semiconductors

Bruker Corp of Billerica, MA, USA (a provider of scientific research instruments and analytical solutions for molecular and materials research as well as for industrial and applied analysis) has agreed to acquire the shares of x-ray-based in-line metrology and defect inspection tool maker Jordan Valley Semiconductors Ltd (JVS) of Migdal Haemek, Israel (which has subsidiaries in Durham, UK; Austin, TX, USA; Hsin-Chu, Taiwan; and Suwon, South Korea).

Bruker says that the acquisition uniquely positions it to offer solutions for nanotechnology research and semiconductor metrology. With trends toward increased connectivity and access to larger amounts of data, new nanometrology needs are driving growth opportunities at advanced semiconductor nodes with even smaller features and three-dimensional structures, the firm adds.

Bruker expects that the combination and synergy between its analytical x-ray technologies and automated atomic force microscopy (AFM) systems and Jordan Valley's in-line x-ray metrology products will position its Semiconductor Division to be a leading-edge metrology system provider for semiconductor applications at advanced nodes.

Jordan Valley has been providing x-ray metrology and defect-detection technology to the semiconductor industry for 30 years, with 75% of the world's top 25 semiconductor manufacturers relying on its metrology tools for front-end and back-end applications, including the development of next-generation thin films. The firm's fully automated, non-contact and non-destructive tools are designed for production control on patterned or blanket wafers.

"The rapid growth of mobile technology, cloud computing and big data processing generates new requirements and opportunities for faster and more precise metrology of smaller feature sizes and 3D structures at advanced semiconductor nodes," says Mark R. Munch Ph.D., presi-

**With trends toward increased connectivity and access to larger amounts of data, new nanometrology needs are driving growth opportunities at advanced semiconductor nodes with even smaller features and three-dimensional structures**

dent of the NANO Group, which includes Bruker's Semiconductor Division. "Jordan Valley has been a true pioneer in offering advanced and unique x-ray metrology solutions as feature sizes continue to shrink," he comments. "The combination of Jordan Valley's core metrology strengths with Bruker's complementary x-ray technologies will enable us to stay ahead of this rapid development and continue to support the semiconductor industry with unmatched next-generation x-ray solutions," Munch believes.

"For the past several decades, Jordan Valley has been committed to providing the best non-destructive x-ray metrology products, with the most responsive service and support to semiconductor manufacturers," says Jordan Valley Semiconductors' founder & CEO Isaac Mazor. "We look forward to the enhanced product innovation and global market reach that we will enjoy within the Bruker Semiconductor Division."

The transaction is expected to close in fourth-quarter 2015, and the acquired business is expected to add \$25-30m to Bruker's 2016 revenue, and about \$0.01-0.02 to Bruker's 2016 earnings per share.

[www.bruker.com](http://www.bruker.com)  
[www.jvsemi.com](http://www.jvsemi.com)

## Cambridge Nanotherm appoints Erwin Wolf as CEO

Cambridge Nanotherm of Haverhill, Suffolk, UK, producer of innovative nanoceramic thermal management technology, has appointed LED industry expert and entrepreneur Erwin Wolf as its new CEO.

Wolf has strong LED technology background along with considerable experience in leading business ventures and advanced technology teams in the semiconductor field.

"The LED industry, and in particular the domestic lighting market, is seeing rapid growth driven by innovations in the manufacturing process," comments Wolf. "As the

LED market continues to heat up — both practically and metaphorically — the need for thermal management grows with it," he adds.

"Cambridge Nanotherm's thermal management technology offers LED manufacturers a unique alternative to traditional materials that not only enables significant cost savings to be realized but also opens the door to new applications and device possibilities. As more LED manufacturers switch to using our superior, cost-effective thermal management solutions the challenges for Cambridge Nanotherm are changing.

I'm looking forward to working with the team to meet these challenges head on and take the company to the next level of its evolution."

"LEDs continue to make inroads into the domestic market and new applications multiply," notes chairman Howard Ford. "Erwin brings a vast amount of industry knowledge and experience with him, especially from his previous LED related assignments at Osram and at Azzurro Semiconductors AG [which made GaN epiwafers based on large-area silicon substrates]."

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

## LayTec launching Gen3 class of modular metrology tools

In-situ metrology system maker LayTec AG of Berlin, Germany says that, starting in first-quarter 2016, it will ship in-situ metrology tools (EpiTT, EpiCurve TT and Pyro 400) as part of the new and modular Gen3 class.

The third generation of in-situ metrology tools offers what are said to be significant technology advances and is more flexible in customization to the needs of specific epitaxy processes.

As an important example of these improvements, the firm cites its recent progress in metrology for metal-organic chemical vapor deposition (MOCVD) related to ultraviolet light-emitting diodes (UV LEDs). Since 2010, LayTec has been working together with the Joint Lab GaN Optoelectronics of Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) in Berlin, Germany and the group of professor M. Kneissl at

Technical University of Berlin. Within the consortium 'Advanced UV for Life' under the program 'Zwanzig20 — Partnerschaft für Innovation' of Germany's Bundesministerium für Bildung und Forschung (BMBF), the research target is next-generation technology for UV-B and UV-C III-nitride-based LEDs.

[www.ur-zwanzig20.de](http://www.ur-zwanzig20.de)

[www.laytec.de/solutions/advanced-rd](http://www.laytec.de/solutions/advanced-rd)

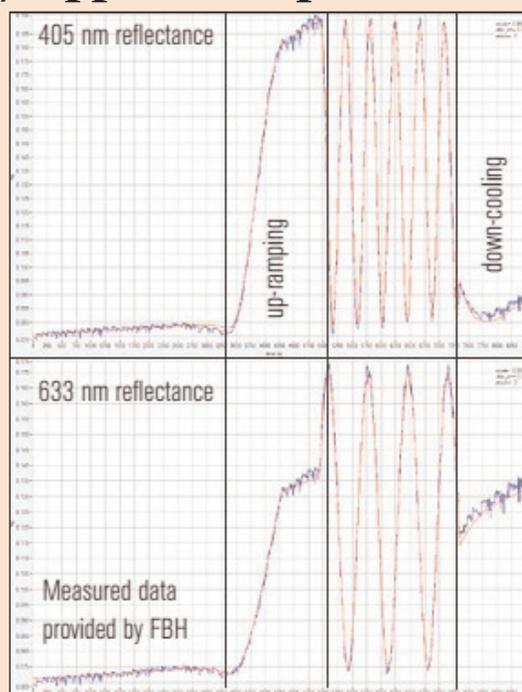
[www.fbh-berlin.com](http://www.fbh-berlin.com)

### FBH uses LayTec's EpiTT Gen3 metrology tool for high-temperature MOCVD growth of AlN/sapphire templates for UV LEDs

In the course of its cooperation with LayTec in the consortium 'Advanced UV for Life', the group of professor Markus Weyers at Berlin-based Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) has developed a high-temperature (HT) MOCVD process for growing low-defect-density aluminium nitride (AlN)/sapphire templates for UV LEDs.

Splitting UV LED growth into two separate steps in two different MOCVD systems completely avoids the possible memory-effect-related interference of aluminium gallium nitride (AlGaN) processes with the growth of high-quality AlN buffers.

This UV LED buffer growth (see Figure) is monitored by three-wavelength reflectance, improved for very thick AlN/AlGaN layer stacks, and by emissivity-corrected high-temperature sensing of LayTec's EpiTT Gen3 tool. The blue curve is the result of quantitative



**Two-step growth of AlN template structure for UV LEDs monitored by EpiTT Gen3 during AlN growth run in a modified HT Aixtron G3 Planetary reactor (950nm reflectance not shown).**

analysis of three-wavelength reflectance measured by EpiTT Gen3. The thickness of the AlN nucleation layer is determined from the fitting curves (red) to be  $43.2 \pm 0.2 \text{ nm}$ , and the AlN HT buffer layer thickness to be  $524.2 \pm 0.5 \text{ nm}$ . The consistency of the HT nk database that was employed is also obvious from the good agreement of the simulated curve segments in the temperature ramp-up and cool-down steps.

LayTec says that the key to the EpiTT Gen3 HT performance is not just the widened temperature sensing range but, most importantly, also the HT nk database (up to  $1500^\circ\text{C}$ ) for the AlN and AlGaN class of materials as well as improved performance for double-side polished sapphire wafers.

[www.laytec.de/EpiTT](http://www.laytec.de/EpiTT)  
[www.fbh-berlin.com](http://www.fbh-berlin.com)

## 405nm reflectance analysis at ICNS Metrology Workshop

At its Metrology Workshop during the 11th International Conference on Nitride Semiconductors (ICNS-11) in Beijing, China (30 August – 4 September), LayTec hosted more than 60 attendees.

Professor Dabing Li of the Chinese Academy of Sciences (CAS) reported on aluminium nitride (AlN) buffer

optimization for UV LED growth by means of 405nm reflectance (CrystEngComm 15 (2013) 6066). Dr Ding Li of FBH presented in-situ data of surface morphology during GaN growth on  $\text{Ga}_2\text{O}_3$ . Christoph Berger of Otto von Guericke University in Magdeburg, Germany gave a talk on the compensation of

Ge-doping memory effects in III-nitride processes, i.e. in highly doped GaN/GaN:Ge DBRs using 405nm reflectance. This technique is also of great importance for avoiding gallium carry-over (memory) effects in AlGaN/AlN structures in UV LEDs.

[www.laytec.de/UVLED](http://www.laytec.de/UVLED)

## Rubicon appoints former MEMC veteran as chief operating officer

Rubicon Technology Inc of Bensenville, IL, USA (which makes monocrystalline sapphire substrates and products for the LED, semiconductor and optical industries) has appointed Hany Tamim as chief operating officer, responsible for all global manufacturing operations.

Tamim will be based in Malaysia and report to CEO Bill Weissman. The COO role is a consolidation of two senior management positions

and will provide greater coordination of manufacturing operations at a lower cost, reckons the firm.

Tamim has experience in managing crystal growth and wafer manufacturing operations in both Malaysia and the USA, including 24 years with SunEdison (formerly MEMC), where he had leadership roles in global cost management, plant management and process engineering. He has Bachelor and

Master of Science degrees in Engineering from the University of North Carolina.

"His experience in managing crystal growth and wafer manufacturing operations in both the US and Malaysia are specifically relevant to the needs of our operations today as we implement changes in technology to improve our product cost," comments Weissman.

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

## Founder appointed chairman emeritus of Soitec group

Soitec says that following its board of directors' meeting on 11 September it has named André-Jacques Auberton-Hervé as chairman emeritus of Soitec group, which he founded together with



**Chairman emeritus**  
**André-Jacques**  
**Auberton-Hervé .**

Jean-Michel  
Lamure in 1992.

Auberton-Hervé has retired from his role as chairman of the board, but remains a director of Soitec.

The board of has appointed Paul Boudre as chairman.

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



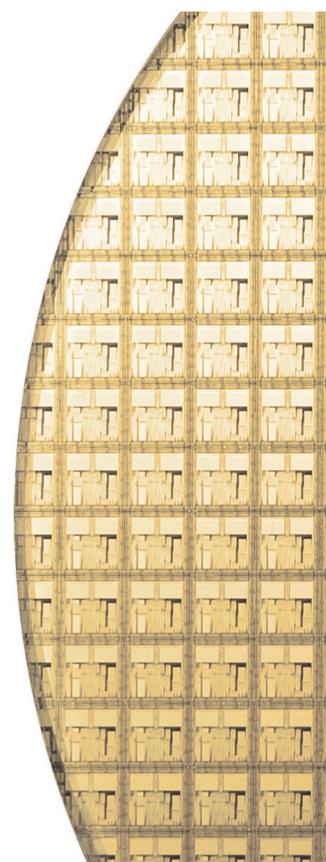
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# AquiSense unveils UV-C LED water disinfection system

AquiSense Technologies of Florence, KT, USA, which designs and makes UV-C LED systems, has unveiled the PearlAqua UV-C LED water disinfection system, which incorporates UV-C LEDs into a compact water treatment unit, without using chemicals or mercury-based UV lamps.

The LEDs also allow for instant, full-intensity power on start-up, unlimited cycling, and remote start/stop. A height of just 4 inches (103mm) aids integration of the PearlAqua into water treatment systems. Applications include life sciences, medical devices, transportation, and commercial water.

"This product marks a key milestone as the first production volume UV-C LED water disinfection system," claims founder & CEO Oliver Lawal. "It is the result of eight years development work, over \$5m investment, and hundreds of hours of user interactions."



**AquiSense's PearlAqua UV-C LED water disinfection system.**

AquiSense says that it uses advanced techniques for the evaluation of UV-C LEDs from leading device makers. Multiple UV-C LED devices are combined into a single, replaceable UVinaire lamp module

that is able to achieve the high levels of UV intensity required to provide maximum disinfection. "The fact that we're now able to produce a small-footprint, low-cost UV-C LED water treatment product in high volumes speaks to the strong progress that the UV-LED manufacturers have made over the past 18 months,"

comments Lawal. Pre-orders for PearlAqua are set to begin in September. First deliveries will commence in December. The unit is just the first in a new range of disinfection products to be launched by AquiSense.

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

# Aluminium Nitride Wafers

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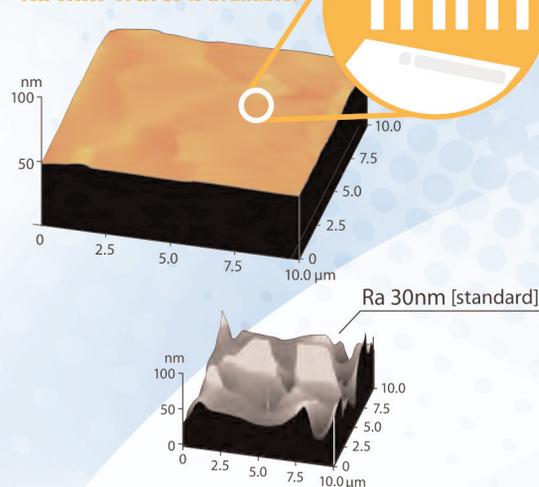
Bonding with semiconductor wafers

## Features :

High thermal conductivity  
Low coefficient of thermal expansion  
Excellent surface smoothness for bonding

Item	Unit	
Thermal conductivity	W/(m·k)	<b>170</b>
Coefficient of thermal expansion	10 <sup>-6</sup> /k	<b>4.8</b>
Surface roughness (Ra)	nm	<b>1</b>
Size	inch	<b>φ2 - φ6</b>

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 **MARUWA**

# Plessey gains £30m loan from Deutsche Bank for LED production expansion

UK-based Plessey is to carry out a major expansion of its LED manufacturing facility in Plymouth after securing a £30m (\$50m) loan from Deutsche Bank AG.

The £60m (\$100m) expansion will provide the base for new solid-state lighting technologies and products, increasing the firm's production capabilities by a factor of 30, more than tripling its workforce to about 535 and positioning Plessey to capture a significant share of the multi-billion dollar solid-state lighting market, it is reckoned.

Plessey says that its MaGIC (Manufactured on GaN-on-Si I/C) gallium nitride on silicon LED technology has the ability to cut the cost of LED lighting by using standard silicon manufacturing techniques instead of more traditional, costly, sapphire-based manufacturing.

According to a new report from MarketsandMarkets, the solid-state

lighting market will rise at a compounded annual growth rate (CAGR) of 7.31% from 2015 to \$22.2bn by 2020. Growth will be driven by high-brightness LEDs delivering higher energy efficiency in all lighting applications, with solid-state lighting forming a significant part of global efforts to reduce energy consumption and greenhouse-gas emissions.

"Deutsche Bank is providing us with a senior secured-term loan facility that meets our financial needs for the next 3–5 years," says Plessey's chief financial officer Iain Silvester. "The bank has come up with a progressive flexible facility that supports our expansion plans for our manufacturing capacity here in Plymouth," he adds.

Plessey plans to increase its annual manufacturing capacity from over 100 million square millimetres of gallium nitride material to more than 3 billion square millimetres.

The facility modifications, which are also supported by £6.7m from the Regional Growth Fund, will take place during 2015, with additional manufacturing tools and facilities coming on-stream through the end of this year through to 2017. During this time, Plessey expects about 400 new jobs to be created.

"We are entering a very exciting period for the company, with our new technology and products now gaining traction in one of the fastest-growing technology markets, solid-state lighting," says CEO Michael LeGoff. "The expansion is highly significant for the company but also for British high-tech manufacturing," he adds. "It aligns well with national strategies, such as the Growth Review, that support manufacturing and make the UK a global leading exporter of high-value goods."

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

## Chip-scale-packaged dotLEDs nominated for Elektra Award

Plessey's chip-scale-packaged dotLEDs have been shortlisted in the Design Team of The Year category of the Elektra Awards. Acknowledging product innovation and business success in the industry for more than a decade, the Elektra Awards celebrates the achievements of individuals and companies across the electronics industry. The awards showcase the best new products, technology innovation and company performances of the year.

The CSP-300's core LED chip is based on Plessey's proprietary gallium nitride on silicon (GaN-on-Si) manufacturing technology, which is fabricated on 6" silicon wafers. Plessey claims that this technology enables the lowest LED product cost combined with a superior thermal performance compared with competing technologies. Designed for wearable technology

applications such as smart watches, mobile backlighting and textiles, the dotLED has a footprint of only 0.55mm x 0.55mm and offers multiple whites, red, green and blue colours with various levels of light output.

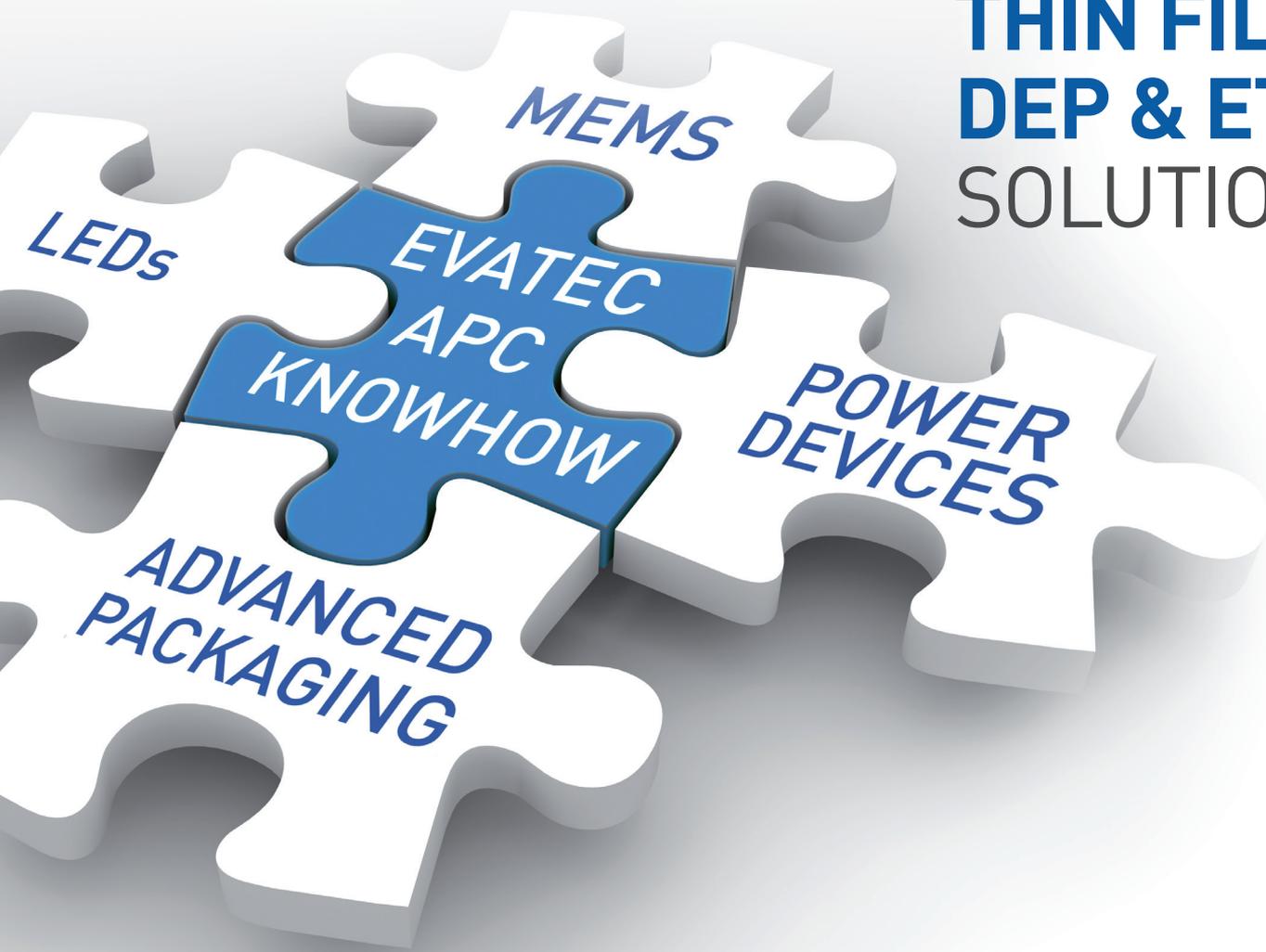
"Demand for wearable technology is increasing, and LED technology plays an increasingly major role in product realization in this sector," says Plessey's LED packaging specialist Zainul Fiteri. "The CSP-300 is designed to deliver the best, smallest-size, lowest-cost LED solution and therefore fulfil the needs of this emerging market," he adds. "The manufacturing process uses wafer-level packaging with through-silicon via (TSV) technology — a greatly simplified process compared to conventional LED packaging technologies with a shorter manufacturing cycle time, very high throughput and hence

reduced cost. The unique combination of the 6" silicon LED growth wafer process and the 8" silicon packaging wafer process results in significant economies of scale in manufacturing," Fiteri continues.

"dotLED is the smallest wearable LED in the market, with a true optical centre in a square form factor," Fiteri says. "This feature has critical impact in the end application, for example when it is desired to build a miniature array of devices in a display application. Competitive products with non-optimal centering and larger footprints do not allow the same small-form-factor arrays to be manufactured. With our design and manufacturing technology, and future evolution of circuit assembly techniques, future products could be as small as a 0.27mm square footprint with the same performance," he reckons.

[www.elektraawards.co.uk](http://www.elektraawards.co.uk)

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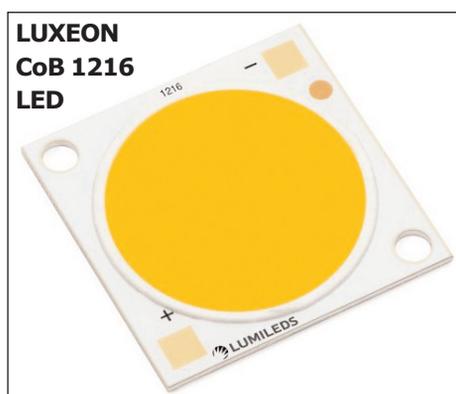
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# Lumileds boosts CoB LED flux by 40%, driving down fixture cost for streetlight & industrial high-bay luminaires

LED maker Lumileds of San Jose, CA, USA says that designers of high-lumen streetlights, high-bay fixtures and downlights are taking advantage of the latest addition to its portfolio of LUXEON CoB Core Range LEDs, the LUXEON CoB 1216. The arrays provide a 40% greater flux than Lumileds' existing CoBs in an identical mechanical footprint (achieving up to 15,000 lumens in an industry-standard package).

"We continue to push our chip-on-board technology to higher efficiency, which is important in all applications but particularly in outdoor fixtures," says Eric Senders, product line director for CoB LEDs. "With the new line of arrays, customers are achieving 150lm/W at nominal condition, which, combined with our lowest-in-the-industry thermal resistance, leads to the most



cost-efficient systems," he adds.

In addition to high lumen output and efficiency, the LUXEON CoB 1216 provides the beam uniformity and ease of design required for streetlights and high-bay fixtures, allowing replacement of 100–150W HID.

Featuring a 23mm light-emitting surface (LES) in a standard 28mm x 28mm package, the LUXEON CoB 1216 can take advan-

tage of the wide variety of optics and compatible holders in this size, allowing fixture manufacturers to speed time to market of their luminaires. "We are hearing very positive feedback from the several leading lighting companies who have already adopted the LUXEON CoB 1216," says Senders.

The LUXEON CoB 1216 is offered in what is claimed to be the industry's widest range of color temperatures (2200K to 5700K) and color rendering indexes (70, 80 and 90). Also, 100% of LUXEON CoB Core Range (Gen 2) arrays are hot tested at 85°C to ensure performance in real-world operating conditions and to minimize additional testing. A low thermal resistance substrate minimizes heat sink needs.

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

## Lumileds adds constant-voltage flexible LED strips to Matrix Platform family of integrated LED products

Lumileds has introduced the third member of its Matrix Platform family of integrated LED products.

The 24V constant-voltage LUXEON XF-3014 CV flexible LED strips distribute extremely uniform light across user-selectable lengths and require only a simple 24V constant-voltage driver, says Lumileds. The LED strips' flux uniformity and color uniformity aid applications such as edge-lit lights, downlights, cove lighting and accent lighting, the firm adds. The XF-3014 CV strips are claimed to be the industry's first LED strips to achieve 2% light output attenuation over a 10m strip. "Our unmatched flux uniformity eliminates the possibility of spottiness or color variation from strip to strip and over long lengths," says Andrew Cohen, product manager of the Matrix Platform family.

The LUXEON XF-3014 CV line of flexible LED strips provides 1000



lumens per meter and is offered as cuttable segments or with snap-in connectors. Specified at color temperatures of 2700K, 3000K and 4000K and a minimum color rendering index (CRI) of 80, the strips are offered in three configurations for design flexibility using:

- 6 LEDs per segment, cuttable every 96mm;
- 6 LEDs, in 96mm segments with connectors;
- 30 LED, in 480mm segments with connectors.

Each 96mm segment produces 112 lumens with luminous efficacy of 105lm/W at 24V (3000K).

Lumileds says that the Matrix

Platform speeds time to market by offering turnkey solutions using proven, reliable LUXEON LEDs integrated with components and connectors on flexible or rigid substrates. Due to its in-house capabilities and reliable assembly practices, the Matrix Platform is also said to simplify customer supply chains. The LUXEON XF-3014 CV line addresses the need for long lengths of LED flexible strips with uniform light output and simple 24V driver supportability that can be easily mounted with a pressure-sensitive adhesive.

[www.lumileds.com](http://www.lumileds.com)  
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# Cree's quarterly revenue rises 11%, driven by growth in commercial lighting

## RF revenue dips following delays in rollout of LTE networks in China

For fiscal first-quarter 2016 (ended 27 September 2015), Cree Inc of Durham, NC, USA has reported revenue of \$425.5m, down 1% on \$427.7m a year ago but up 11% on \$382.2m last quarter (and towards the high end of the targeted \$410–430m), led by strong demand for commercial lighting and a solid quarter for the firm's LED business.

Specifically, Lighting Product revenue was \$248m (58% of total revenue), up 8% on \$229m last quarter (led by continued growth in commercial lighting) and up 11% on \$223m a year ago. LED Product revenue was \$148.2m (35% of total revenue), down 15% on \$173.6m a year ago but up 21% on \$122.2m last quarter (allowing Cree to further reduce channel inventories). Revenue for Power & RF Products (now named Wolfsped) was \$29.3m (7% of total revenue), down 5% on \$30.8m last quarter and 6% on \$31m a year ago (due mainly to lower RF demand related to delays in the rollout of LTE networks in China). "Wolfsped, our recently rebranded Power & RF division, is working through some near-term softness in the RF side of the business due to macro headwinds," notes chairman, president & CEO Chuck Swoboda.

Although still down on 32.4% a year ago, non-GAAP gross margin has rebounded to 31.7% following a low of 21% last quarter (which was hit by charges from the restructuring of Cree's LED business — announced on 24 June — to reduce excess factory capacity and overheads by consolidating two fabs in Durham into one by the end of December). Specifically, although still below 39% a year ago, LED Product gross margin rebounded from just 7% last quarter to 35.5%, as Cree saw the initial benefits of lower cost due to the LED business restructuring, supplemented by patent license income. Lighting Product gross margin has

rebounded from 24.8% last quarter to 27.9% (up on 24.9% a year ago), due mainly to improved factory execution. However, Power & RF Product gross margin was 49%, down from 52.5% last quarter and 57.6% a year ago due to product mix.

Operating expenses were \$105m, less than \$108m last quarter (and less than expected due to lower-than-expected IP litigation spending). "We made progress towards our goal to deliver operating leverage," notes chief financial officer Mike McDevitt. Operating income was \$29.4m (driving operating margin up to 6.9% of revenue), above the middle of the targeted range.

Compared with a net loss of \$20.5m (\$0.19 per diluted share) last quarter (due to the LED business restructuring), Cree rebounded to a net profit of \$22.1m (\$0.21 per diluted share), although this was still down on \$29.6m (\$0.24 per diluted share) a year ago. However, this excludes \$15.9m of charges related to the LED factory capacity and overhead restructuring (following \$84m of charges in the June quarter).

Cash generated from operations has fallen from \$88m last quarter to \$46.8m. In addition to patent spending of \$4.3m, spending on property, plant & equipment (PP&E) has risen from \$48m to \$49.9m, raising total capital expenditure from \$53m to \$54.2m. Free cash outflow was hence -\$7.4m. However, Cree also spent \$70m to repurchase 2.7 million of its shares (following \$160m spent last quarter) plus \$13m to complete the acquisition in early July of power module provider Arkansas Power Electronics International Inc (APEI) of Fayetteville, AR, USA (aim-

**The LED restructuring is on track and the business results recovered nicely**

ing to accelerate the market for its Power & RF business' SiC power modules). Therefore, during the quarter, cash and investments fell by \$81.1m, from \$713m to \$632.1m. Cree ended the quarter with \$207m outstanding on its line of credit.

"Fiscal 2016 is off to a good start, with Q1 revenue and profits above the middle of our targeted range, driven by strong demand for commercial LED lighting and a solid quarter for our LED business," says Swoboda. "We are confident in our strategy and optimistic about the future, as the commercial lighting business is growing, the LED results recovered nicely in Q1 and Power & RF design momentum is strong," he adds. During the quarter, the US Air Force awarded a follow-on contract that will enable qualification of a power electronic module for the F-35 Joint Strike Fighter.

During the quarter, Cree expanded its LED downlight portfolio with the introduction of the KR8, its first 8" downlight, and the newest-generation LR6 downlight. It also launched the new Cree LED bulb (with improved performance, longer life and greater energy savings). In addition, Cree released its new XLamp XQ-E High Intensity LEDs (claimed to be the industry's first family of high-power color LEDs optimized for optical performance).

"Our innovation momentum remains strong across all three business segments," says Swoboda. "The commercial lighting business is growing and our transition to the new Cree Better Bulb is on plan," he adds. "The LED restructuring is on track and the business results recovered nicely in fiscal Q1."

For fiscal second-quarter 2016 (ending 27 December 2015), Cree targets revenue of \$425–445m, driven by further growth in commercial lighting. Gross margin should be level at 31.7%, rising in

each product areas but offset by lower non-recurring LED license-related revenue. Operating expenses are targeted to be \$106m (up \$1m due mainly to variable sales cost associated with higher lighting sales). Net income is targeted to be \$21–27m (\$0.21–0.26 per diluted share). The remaining \$3m of LED business restructuring charges should bring the total to \$102m.

Factory utilization is improving in LEDs, with 85% targeted by the end of December, when factory consolidation is completed. “Factory execution continues to be critical to achieving our targets,” comments Swoboda.

For full-year fiscal 2016, Cree targets revenue growth of about 10% from fiscal 2015’s \$1.63bn to \$1.8bn, with increased operating

margin of 8%. The firm also targets spending on property, plant & equipment (PP&E) to be lower than fiscal 2015, at \$150m (primarily in the first half of the year, to complete existing infrastructure projects and to provide incremental capacity for Lighting and Wolfspeed, as needed). The firm also continues to target free cash flow of about \$85m.

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

## Luminus launches high-efficacy 3V 3030 mid-power LEDs delivering 200lm/W, 97CRI & 2200K candle-warm options

Luminus Inc of Sunnyvale, CA, USA, which makes LEDs and solid-state light sources, has launched a family of 3V 3030 mid-power LEDs offering a wide range of options including luminous efficacy of 200lm/W, a color rendering index (CRI) of 95+, and a ‘candle-warm’ color temperature of 2200K.

Building on its range of chip-on-board (COB) arrays and mid-power products, Luminus’ new MP-3030-1100 series includes a total of 18 different CCT/CRI combinations to choose from, including cool-white 70 CRI products capable of delivering up to 200lm/W in outdoor applications and the AccuWhite 95 CRI minimum (97 typical) warm white for

luxury retail applications.

“Our customers have recognized the leading performance, breadth of product, and outstanding quality of light delivered by our COB arrays and big-chip LEDs in directional applications, and now they are thrilled to have the same characteristics in a mid-power product to enable a complete line of non-directional luminaires and bulbs which satisfy even the most demanding specifiers and end-users,” says VP of marketing Mark Pugh.

Another feature of the MP-3030-1100 family is ‘hot color targeting’, so that the LEDs are engineered to produce light with chromaticity tightly centered in the ANSI bin

under normal operating conditions of 85°C. Luminus claims that, in contrast, competitors’ LEDs — which are usually color targeted at 25°C — tend to drift away from the ANSI bin in the field, where operating temperatures are much higher. The firm’s 3030 LEDs are tested at 150mA nominal forward current and can be driven as hard as 240mA to provide optimal lumens per dollar. For users who want to maximize system efficacy, the 5700K, 70CRI product delivers 200lm/W at 65mA.

Luminus exhibited several new illumination light sources at the Hong Kong International Lighting Fair (27–30 October).

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

## Soraa promotes VP of North America sales & marketing to senior VP, global sales & marketing

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology built on ‘GaN on GaN’ (gallium nitride on gallium nitride) substrates, says that a surge in global demand for its full-visible-spectrum GaN-on-GaN LED lamps and Optical Light Engines has led it to promote George Stringer (most recently VP of North America sales & marketing) to senior VP of global sales & marketing, reporting directly to CEO Jeffery Parker. Stringer will lead the global sales organization, which has offices in USA, London and Tokyo.

“George is a highly recognized leader throughout the lighting industry with a history of success in building top sales talent and innovating sales processes,” comments Parker.

Stringer joined Soraa in 2013 and has led its sales expansion in North America. The firm says that his technical expertise in lighting and focus on delivering projects has helped it to increase sales, particularly in retail, hospitality and gallery/museum spaces. In his new role, Stringer will work closely with leading lighting designers, architects and building owners and operators

on projects globally.

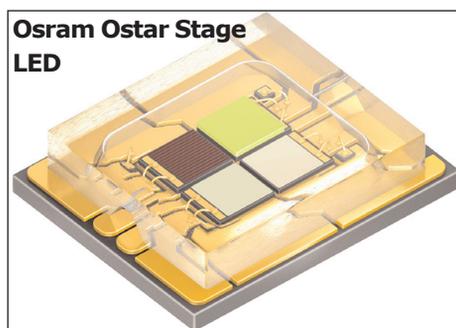
Prior to joining Soraa, Stringer worked for 16 years in senior-level sales and sales management roles at Acuity Brands Lighting, latterly as VP & general manager for Corporate Accounts, Renovation and Government, where he revitalized the National Account organization (introducing a new strategic vision and turning it into a high-performance sales channel). Stringer has expertise in all sales channels: distribution, agent specification, corporate accounts and consumer.

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

# Osram's new Ostar Stage Multichip LEDs doubles brightness from same surface area for stage spotlights

Osram Opto Semiconductors GmbH of Regensburg, Germany says that the new LE RTDUW S2WN version of its new Ostar Stage LED features four high-power chips with the latest thin-film and UX:3 technologies in red, green, blue and white. Providing twice the brightness with no increase in package size, the LED is suitable for use in stage spotlights, as well as mood and architectural lighting (in the latter case, they are the preferred light source for effect and accent lighting).

Due to the improved chip technologies, the new high-power LED's four chips (covering 1mm<sup>2</sup> each) can be operated for the first time at up to 2.5A(DC). This yields twice the output of 30W (electric) from the same chip and package area compared with the existing version,



adding another output class to the Osram Ostar Stage product family.

The Ostar Stage family now covers outputs between 15W and 60W (with the 60W coming from the previously released LE RTDUW S2WP version). "The higher current that is necessary for a higher output requires the thermal management of the Osram Ostar Stage to be adapted so that the heat generated in the chip can be removed as

effectively as possible," says product marketing manager Andrew Lin. Thermal resistance ( $R_{th}$ ) is 0.9K/W. "At the same time, many features such as the package size [4.68mm x 5.75mm x 1.26mm] and beam characteristics match those from previous versions," continues Lin. "That way, customers can stick to their existing optics and the overall design of their lighting solutions."

The new Ostar Stage LED is said to give users more flexibility for their stage spotlight product portfolio. Spotlights with the same number of LEDs will be more powerful, while spotlights with fewer light emitting LEDs will have the same brightness.

The new high-power LEDs will be available in high volume from first-quarter 2016.

[www.osram-os.com](http://www.osram-os.com)

## Osram Sylvania opens its first US-based LED module production line

Osram Sylvania Inc (part of Osram Americas in Danvers, MA, USA) has expanded its manufacturing capabilities in Hillsboro, NH (where the firm's automotive lighting division has its principal North American operations) by adding the plant's first surface-mount technology (SMT) production line for LED modules.

As what is said to be the leading firm globally in automotive lighting for original equipment manufacturers (OEMs) and the automotive after-market, Osram is pushing the transition to LED systems by investing in R&D and production capacities, infrastructure and expertise to support the technology migration. Millions of dollars were invested in the plant for the new ISO class 8 Gray Room. LED modules produced from the new line are already on the road in the 2016 Ford Explorer LED headlamp, with other programs in development for the future.

"Osram invested in industry-leading electronics production equipment in all three global regions to serve

our automotive customer base," says David Hulick, global OEM SSL marketing director, Osram Sylvania, during the firm's automotive lighting showcase in the Detroit area, where it displayed its lighting solutions for OEMs and set makers. "Innovative designs and state-of-the-art surface-mount technology lines, such as the new one installed in New Hampshire with tight tolerance LED placement capabilities, make it possible for Osram to deliver the precision, quality and supply that our global customers demand," he adds. "With the implementation of this new production capability in the NAFTA [North American Free Trade Agreement] region, we can better service our local customer base by providing the best local LED lighting production."

Highlights of the automotive lighting showcase were the first LED forward lighting headlamp in a pickup truck demonstrated on the 2016 Ford F-150, the LED headlamp with the new Hillsboro Osram LED modules in the 2016 Ford Explorer, and

adaptive matrix LED headlights in an Audi A7.

"Osram Automotive Lighting provides OEM customers with a portfolio of top-quality interior and exterior lighting solutions, ranging from individual LEDs to standardized LED systems as well as HID systems, auxiliary light sources and advanced halogen products," says Julian Dench, senior VP & general manager, SP Americas Region, Osram Sylvania. "This production facility will allow us to immediately respond to all of our customers' demands as a full-service automotive lighting leader."

Coupled with sister facilities in Europe and Asia, the new North American investment advances Osram's role in automotive electronics through a global quality-controlled (TS16949) automotive electronics manufacturing footprint. According to recent market reports, LED lighting adoption in the automotive category will rise sharply by the end of the decade.

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

## Osram adds filament LEDs to product portfolio

Osram Opto Semiconductors GmbH has launched the Soleriq L 38, the first filament LED in the Soleriq product family.

With a long and thin shape (a length of 30mm and a diameter of 1.8mm), the LEDs provide the basis for filament-style lamps, and they match incandescent lamps in terms of appearance and emission characteristics. Soleriq LEDs deliver a uniform appearance in terms of color and can serve as a high-quality light source suitable for aesthetic lighting applications in homes, hotels and restaurants.

Similar to a conventional filament, the shape of the Soleriq LED — in addition to its 360° emission angle and light production quality — make it suitable for use in LED lamps of all wattages as it mimics the appearance of classic light bulbs. Soleriq L 38 LEDs are offered in dif-

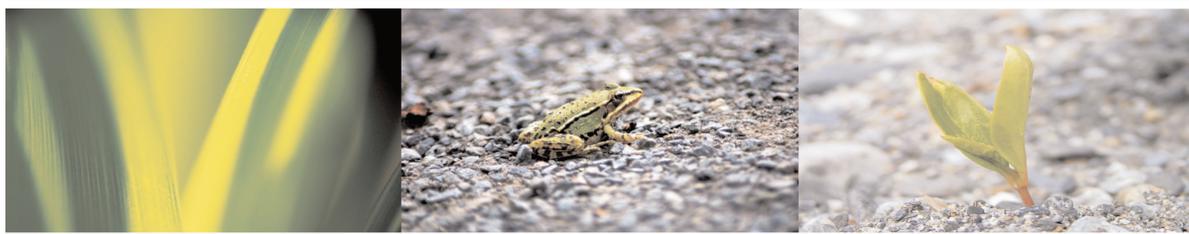
ferent MacAdam groups based on color temperature, and they are binned at a temperature of 85°C, which closely approximates to the temperature in the application.

"Customers will benefit from these properties, particularly if they want to install multiple lamps or luminaires fitted with Soleriq L 38 in a room," says Martin Wittmann, marketing & business development manager for General Lighting.

"Incorporating the LEDs in classic lamp production lines is simple," he adds. "With minor modifications to the manufacturing process, these LEDs can be installed in the lamp in the same way as traditional filaments." Additionally, sorting by forward voltage enables multiple LED filaments to be connected in parallel, resulting in reliable operation with no overloading of individual filaments, the firm adds.

The Soleriq L 38 offers high brightness, similar to all Soleriq products, and is available in three versions, with a luminous flux of 90, 130 or 140lm (and a forward voltage of 56–64V, 82–90V or 88–96V, respectively). These values enable all previous lamp wattages up to 60W to be replaced with equivalent LED filament solutions. The driver voltage needed for the LED filament lamps can be adjusted. All versions have a high luminous efficacy of 150lm/W and provide warm white light (with a color temperature of 2500–4000K). Due to a good color rendering index of over 80, the L 38 is suitable for indoor lighting, particularly in the home. The main applications include products with a traditional look and also modern interiors, such as classic clear glass bulbs with LED filaments.

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# Trumpf opens Berlin high-power laser diode engineering subsidiary

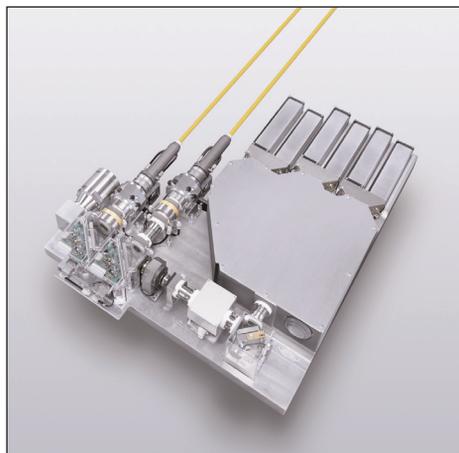
## Facility to build on collaboration with Ferdinand-Braun-Institut

Laser manufacturer Trumpf has opened a new subsidiary in Berlin for the engineering of laser diodes. In close proximity to, and in close cooperation with, the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) and other facilities and experts, the firm aims to continue expanding its technology in the high-performance diode laser sector (for use both as a pump source and as a direct diode laser). The close cooperation between industry and research is intended to make Trumpf's laser systems more energy-efficient.

"The Berlin subsidiary, with its initial staff of ten people and the joint ventures emanating from it, is of crucial importance for our development work on this key future topic," says Dr Berthold Schmidt, head of the central department for R&D at Trumpf. "We are attempting to look ten years ahead here, and to lay the foundations for future applications," he adds.

"We are looking forward to cooperate directly with Trumpf in the active Berlin research landscape," comments FBH director professor Günther Tränkle. "The joint venture underlines the capability of our FBH teams, as well as the desire, even of major players, to maintain and further extend their market lead with our assistance."

Trumpf and the FBH have already worked together on high-power diode lasers for several years. Trumpf also funds several PhD studentships at FBH. "Over the past years our research activities have resulted in numerous patents, enabling further improvements to diode lasers," notes Tränkle. "The demand is there and will continue to grow, because the market for laser systems that can process and cut metals is vast." For some materials, such as the tempered steel used in the manufacture of



**Trumpf's TruDiode 6006 lasers.**

monocoque safety cells in cars, the laser is virtually unrivaled, and has long since become an indispensable tool in production, says Trumpf.

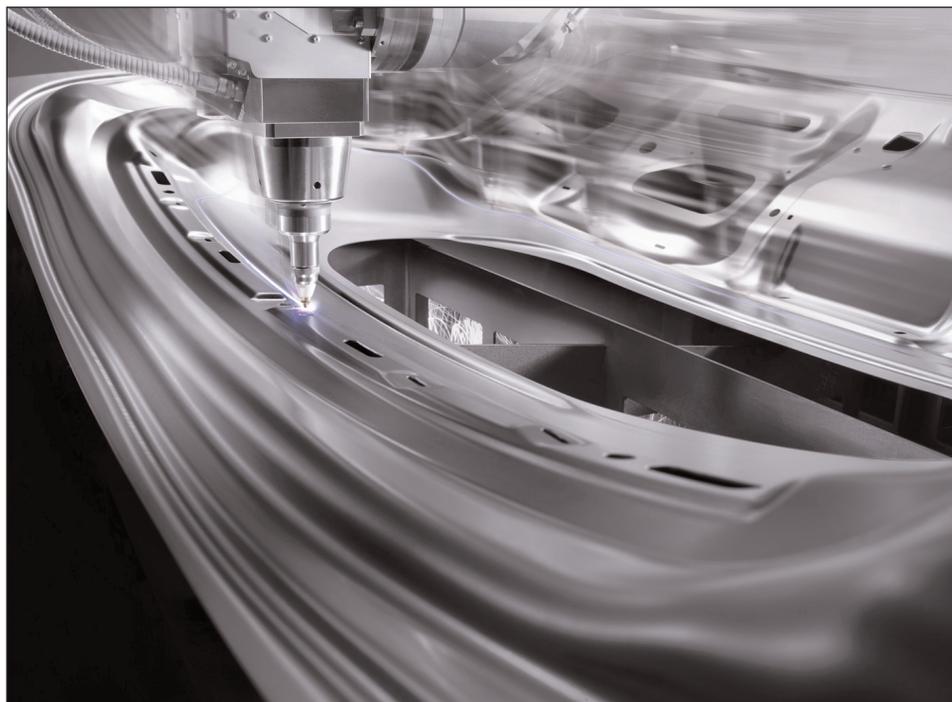
"For cutting thick sheet metal, a very powerful laser beam is required," notes Dr Stephan Strohmaier, who runs Trumpf's Berlin subsidiary. "Our goal is to efficiently combine ever more laser power inside an ever more brilliant beam," he adds. In terms of power density and power-to-light conversion rate, diode lasers from FBH

and Trumpf are currently among the most powerful in the world, it is claimed, and new records are frequently being set in the laboratories. The Berlin Trumpf subsidiary — which not only has capabilities in semiconductor laser physics, mounting technology, design and simulation but also has its own cleanroom facilities — will drive development further.

Trumpf notes that, not only do diode-pumped solid-state lasers and direct-diode lasers have particularly high efficiencies (30–40% or more), they also save on water and energy, and their compact design makes them material-friendly as well as comparatively cheap.

With direct-diode lasers, the laser radiation of several diodes is combined by using optic elements to create a beam of increasingly better focusability. This combination beam (just one tenth of a millimeter in diameter) can then be used to cut metals such as steel in the automotive and shipbuilding industries.

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



## Purdue launching Quantum Center during workshop

During the International Workshop on Quantum Control of Light and Matter (13–14 October), Purdue University launched the Purdue Quantum Center, dedicated to quantum science and technology that could bring advances rivaling those from integrated circuits and lasers, it is reckoned.

Speakers discussed topics in four sessions: Quantum Information and Computing, Quantum Nanophotonics and Metamaterials, Quantum Atomic and Molecular Optics, and Atom-like Solid State Systems.

"Quantum science and technology are likely to bring advances at least as great as those spawned by the integrated circuit and lasers," said Vladimir M. Shalaev (scientific director of nanophotonics at Purdue's Birck Nanotechnology Center and a distinguished professor of electrical and computer engineering), who is co-director of the center along with Chris Greene (Purdue's Albert Overhauser Distinguished Professor of Physics) and Andrew Weiner (the Scifres Family Distinguished Professor of Electrical and Computer Engineering).

Potential applications include advanced quantum computers and quantum Internet technology; compact and ultra-precise sensors for purposes including medical diagnostics and homeland security; and miniature chip-based devices for positioning and navigation instruments.

Researchers from the College of Science will focus on fundamental research, and the College of Engineering is focused on creating devices based on quantum technology.

The center is an extension of a team formed at Purdue in 2013 to work on quantum photonics. The colleges of Science and Engineering have since hired seven new faculty members in the research area.

In quantum photonics, technologies could make possible devices that can harness photons, dramatically increasing the performance of computers, sensors and other devices.

Quantum technology could be used to perfect spintronics. Conventional computers use the presence and absence of an electric charge to represent ones and zeroes in a binary code needed to carry out computations. However, spintronics uses the spin state of electrons to represent ones and zeros, and could yield circuits that

resemble biological neurons and synapses to perform tasks such as facial recognition. "One big challenge for spintronics right now is speed," Shalaev says. "It's too slow. However, we may be able to solve this problem by combining quantum nanophotonics with spintronics to speed it up dramatically."

[www.conf.purdue.edu](http://www.conf.purdue.edu)

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# Panasonic develops first 4.5W blue-violet laser

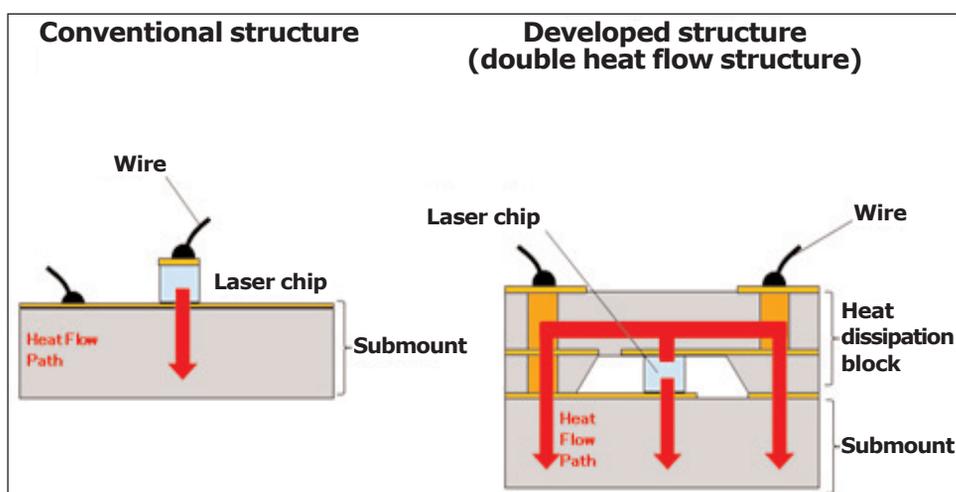
## Power output boosted by 1.5x, energy conversion efficiency by 1.2x

Panasonic Corp of Osaka, Japan has developed a blue-violet semiconductor laser with light output power of 4.5W (continuous wave). Even at 60°C (the maximum operating temperature for lasers in general), this is 1.5 times higher than the 3W of Panasonic's existing products with a conventional structure, says the firm. Also, energy conversion efficiency is 33% (1.2 times higher than the existing product, at 60°C, for light output of 3W), it adds.

Panasonic says that this improvement has been made possible by its unique double heat flow packaging technology, which improves heat dissipation. This new laser can help laser application systems — such as vehicle and industrial lighting as well as laser machining equipment — to be made smaller and consume less power, reckons the firm.

In general, the output power of semiconductor lasers decreases as the laser chip temperature rises. In addition, because the temperature is the determining factor for laser reliability, the actual light output that can be used in practical applications is limited by the laser chip temperature. Conventional blue-violet lasers dissipate heat from only one side of the laser chip, causing the laser chip temperature to increase and limiting the output to about 3W. Laser systems requiring an output of tens of watts would require a large number of lasers, causing more heat to be generated and requiring larger heat-sinks. To solve this challenge, individual lasers require higher efficiency and larger output, notes Panasonic.

The new double heat flow packaging technology can suppress the increase in the laser chip temperature that accompanies laser beam output. Consequently, the heat-induced drop in laser light output can also be prevented, enabling high-output and high-efficiency operation. As a result, in laser



systems using multiple lasers, the number of lasers can be reduced to two-thirds of those using conventional lasers. Moreover, because the heat-sinks can be smaller, the system itself can be made smaller and lighter, says Panasonic.

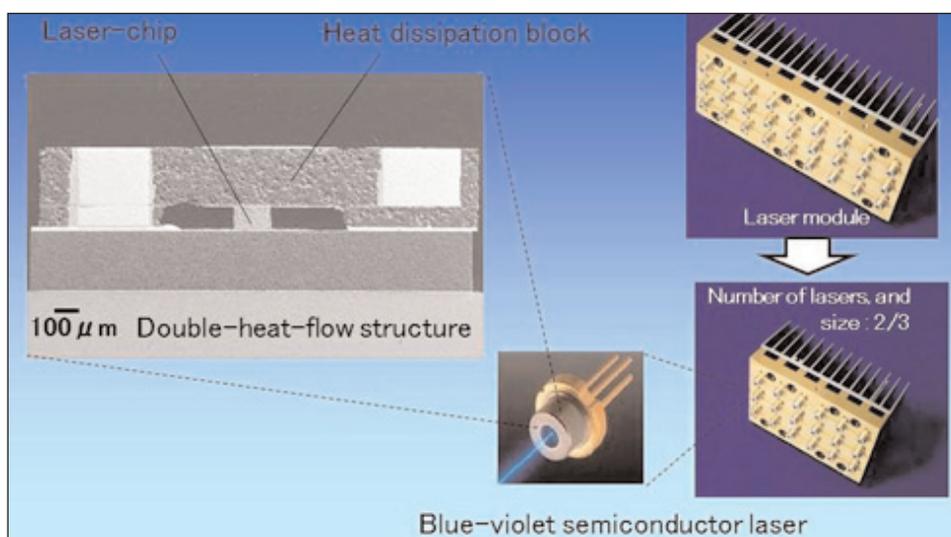
Panasonic says that the new device has been made possible through the following technologies:

- a heat dissipation structure realized by forming heat flow paths on both sides of the laser chip, increasing heat conduction from the laser chip to 1.6 times that of the existing product (thermal resistance of 6.6K/W for the new product, compared with 10.5K/W for the existing product);
- a low-strain heat dissipation block structure using aluminium nitride (which has the almost same coeffi-

cient of thermal expansion as the laser chip) — reduced strain in the chip yields stable output, increasing reliability.

Panasonic presented the research results on 28 September at the 47th annual International Conference on Solid State Devices and Materials (SSDM2015) in Sapporo, Japan. The work is partially supported by Japan's New Energy and Industrial Technology Development Organization (NEDO), under the Strategic Innovation Program for Energy Conservation Technologies. Panasonic holds 23 patents in Japan and 31 patents overseas (including pending applications) on the new high-output blue-violet semiconductor laser technology.

<http://panasonic.net>



**Double heat flow packaging technology.**

# POET to deliver integrated VCSEL prototypes in second-quarter 2016

## Ahead of schedule in consolidating Toronto–Connecticut–San Jose footprint to Silicon Valley by first-quarter 2016

POET Technologies Inc of Toronto, Canada — which, through subsidiary OPEL Defense Integrated Systems (ODIS Inc) of Storrs, CT, USA, has developed the proprietary planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — has strengthened its balance sheet and accelerated its lab-to-fab commercialization initiative in expectation of delivering its first prototypes in 2016.

“We start the new quarter with a significantly strengthened balance sheet — with \$20.5m in cash, with only small operational liabilities,” says executive co-chairman Peter Copetti. “We expect these funds to provide about eight quarters of development runway, beyond the point of demonstrating working prototypes within the next year,” adds executive co-chairman Ajit Manocha.

### Module-on-a-chip

The firm says it is poised to roll out a monolithic optoelectronics process platform that enables improvements in energy efficiency, component cost and size in the production of smart optical components, driving applications ranging from data centers to consumer products.

“The company’s patented module-on-a-chip process, which integrates digital, high-speed analog and optical devices on the same chip, is designed to be the next industry standard for smart optical components fabrication,” says Manocha. “By adding electronics functionality to optics — lasers, detectors, IR sensors — POET powers ‘smart’ optoelectronic devices that demonstrate step-function improvements in low-power performance, cost and size. Specifically applied to short-reach VCSEL (vertical-cavity surface-emitting laser)-based

transceivers for example, POET could enable up to 10x improvements in power consumption, component cost, and form factor,” says CEO Dr Suresh Venkatesan. “Put simply, that means we make what’s on a wafer up to 10 times more energy efficient, 10 times cheaper and more than 10 times smaller,” he adds. “We believe we are the only company that could achieve this level of disruption.”

### Performance of light at the cost of copper

The firm claims that the POET technology platform enables the power of optical communications at potentially similar price points to copper.

“Advances in silicon technology enable hugely efficient computational efficiencies,” says Venkatesan. “A single computation, for example, can be completed at fractions of pico-joules of energy. However, transmitting or communicating this piece of information over traditional copper interconnects can consume up to 100 times that energy,” he adds. “While optics can dramatically lower power consumption, we haven’t seen any optical solution that has yet been cost-competitive with copper interconnects. The POET platform, when implemented, could change that — thus creating a discontinuity in traditional learning curves,” he believes.

**We start the new quarter with a significantly strengthened balance sheet... We expect these funds to provide about eight quarters of development runway, beyond the point of demonstrating working prototypes**

### Market focus, proven business model, and facilities transition ahead of plan

The firm says that its initial market focus is short-reach and very-short-reach data communications, a massive and particularly high-growth sector whose most acute pain points often revolve around power management within data centers. The POET platform may subsequently be applicable to smart optical products, with applications ranging from high-reliability defense, aerospace and energy applications to more common consumer devices.

Venkatesan says that the firm’s business model is expected to include a long-proven mixture of product sales and licensing; organic growth and acquisition; and direct and indirect sales. POET also expects to go to market primarily with partners — both in sales and manufacturing. Typifying the latter is the firm’s recent VCSEL manufacturing services agreement with a commercial foundry.

“Our partnerships bring scalable manufacturing and custom VCSEL foundry capabilities that we need to accelerate our lab-to-fab migration,” says Venkatesan. “We are on-plan to begin transferring our proprietary technology in this year’s Q4... as well as to demonstrate integrated VCSEL prototypes in the second quarter of 2016,” he adds.

The firm also reports that it is ahead of plan in consolidating its Toronto–Connecticut–San Jose footprint and bringing the bulk of its operations to Silicon Valley in fourth-quarter 2015. The consolidation should be completed in first-quarter 2016. The move is expected to result in insignificant one-time charges.

[www.poet-technologies.com](http://www.poet-technologies.com)

## III-V quantum dots and dashes on silicon target efficient 16 x 25Gb/s WDM photonic integrated circuits

### EU's SEQUOIA project demonstrates chirp-managed lasers directly modulated at 25Gb/s and comb laser integrated with cascaded ring resonator modulators

The European Union's Seventh Framework Program (EU FP7) three-year-long project SEQUOIA (energy efficient Silicon Emitter using heterogeneous integration of III-V QUantum dOt and quantum dash materIAls) has reported what it says are significant advances in silicon-based photonic integrated circuits (PICs) since its start in October 2013.

The project has made two innovations: the use of novel III-V materials, namely quantum dot (Qdot)- and quantum dash (Qdash)-based materials, and the exploitation of novel photonic device concepts through hybrid III-V/silicon integration.

During the first period the quality of Qdot/Qdash materials was improved significantly, and the University of Kassel has recently demonstrated Qdot lasers with a record bit rate of 34Gb/s in direct modulation. In parallel, Qdot wafers have been successfully

bonded onto silicon wafers.

Two types of PIC final demonstrators have been designed: chirp-managed lasers (CMLs) directly modulated at 25Gb/s and a comb laser integrated with cascaded ring resonator modulators. Providing a total capacity of 400Gb/s through the use of 16 wavelength-division multiplex (WDM) channels, these PICs are said to offer better performance at reduced cost and enhanced functionality through the use of new materials and novel integration processes.

With funding of €5m (including €3m from the European Commission), the five-partner, three-country consortium is led by III-V Lab of Paris, France (the joint Alcatel-Lucent, Thales and CEA-Leti industrial research laboratory), which has expertise in indium phosphide (InP) photonics and hybrid integration of III-Vs on silicon. Two German partners, Dortmund-based Innolume GmbH and the University of Kassel,

have a track record in materials and III-V optoelectronics. Nanotechnology R&D center CEA-Leti of Grenoble, France is a leading laboratory in silicon photonics, and has competence in both the design and fabrication of silicon PICs. The Technical University of Denmark's DTU Fotonik research institute has a track record in optical communication systems demonstrations. Foton Laboratory at France's University of Rennes 1 has competence in high-capacity optical transmission systems. The teams at both DTU and University of Rennes 1 have demonstrated what is reckoned to be record CML performance.

[www.uni-kassel.de/projekte/sequoia/project-infos.html](http://www.uni-kassel.de/projekte/sequoia/project-infos.html)

[www.3-5lab.fr](http://www.3-5lab.fr)

[www.leti.fr](http://www.leti.fr)

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

[www.fotonik.dtu.dk](http://www.fotonik.dtu.dk)

[www.insa-rennes.fr/en/](http://www.insa-rennes.fr/en/)

[foton-insa.html](http://foton-insa.html)

## MACOM launches first surface-mount modulator driver for 46 Gbaud applications

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 launched the wideband MAOM-003427, a quad-channel linear modulator driver with 46 Gbaud capability to support next-generation 200G and 400G applications. This latest addition to MACOM's portfolio of drivers for optical infrastructure enables system designers to address higher-baud-rate applications with lower-cost surface-mount technology. "I am very proud to announce

another first for MACOM in the optical industry"

MACOM introduction what were claimed to be the industry's first quad-channel surface-mount drivers in 2013. To date, surface-mount packaging has been used extensively in 100G and 200G systems operating at 32 Gbaud while higher-baud-rate systems have required more expensive 'gold box'-style packages. The MAOM-003427 instead offers equivalent performance in a surface-mount package, enabling lower-cost and smaller-form-factor solutions.

The MAOM-003427 has wide

bandwidth, low power dissipation and linearity that supports the implementation of higher-order modulation schemes at baud rates up to 46 Gbaud. The driver is pin-compatible with MACOM's existing 32Gbaud surface-mount solutions (MAOM-003405 and -003407), offering designers an easy upgrade path.

The MAOM-003427 modulator driver is sampling to customers now. MACOM was also present at the European Conference on Optical Communication (ECOC 2015) in Valencia, Spain (28-30 September).

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



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# GigOptix's revenue rises for sixth consecutive quarter to record \$10.4m

## Record profit driven by growth in High-Speed Communications

For third-quarter 2015, GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks) has reported a sixth consecutive quarterly revenue increase, to a record \$10.4m, up 6% on last quarter's \$9.8m and 23% on \$8.5m a year ago (and above

the expected \$10.3m). Product revenue in particular was up 7% on last quarter and 29% on a year ago.

The High-Speed Communications business (Datacom and Telecom optical communications products plus wireless RF point-to-point products) has grown further to \$7.6m (73% of total revenue), up 15% on \$6.6m (67% of total revenue) last quarter and up 41% on \$5.4m (64% of total revenue) a year ago. This continued growth was led mainly by another strong quarter in 40 and 100Gb/s drivers and amplifiers for datacom transceivers and active optical cables (AOCs) that populate the newly installed cloud mega data-centers.

Revenue from the Industrial ASIC (application-specific integrated circuit) product line has fallen from \$3.3m (33% of total revenue) last quarter to \$2.8m (27% of total revenue) as the firm continues to shift focus from its legacy customized ASIC products to high-speed optical

and new-generation RF ASICs while acquiring new customers in various new market segments.

On a non-GAAP basis, gross margin was 66%, level with last quarter's record and up on 61% a year ago.

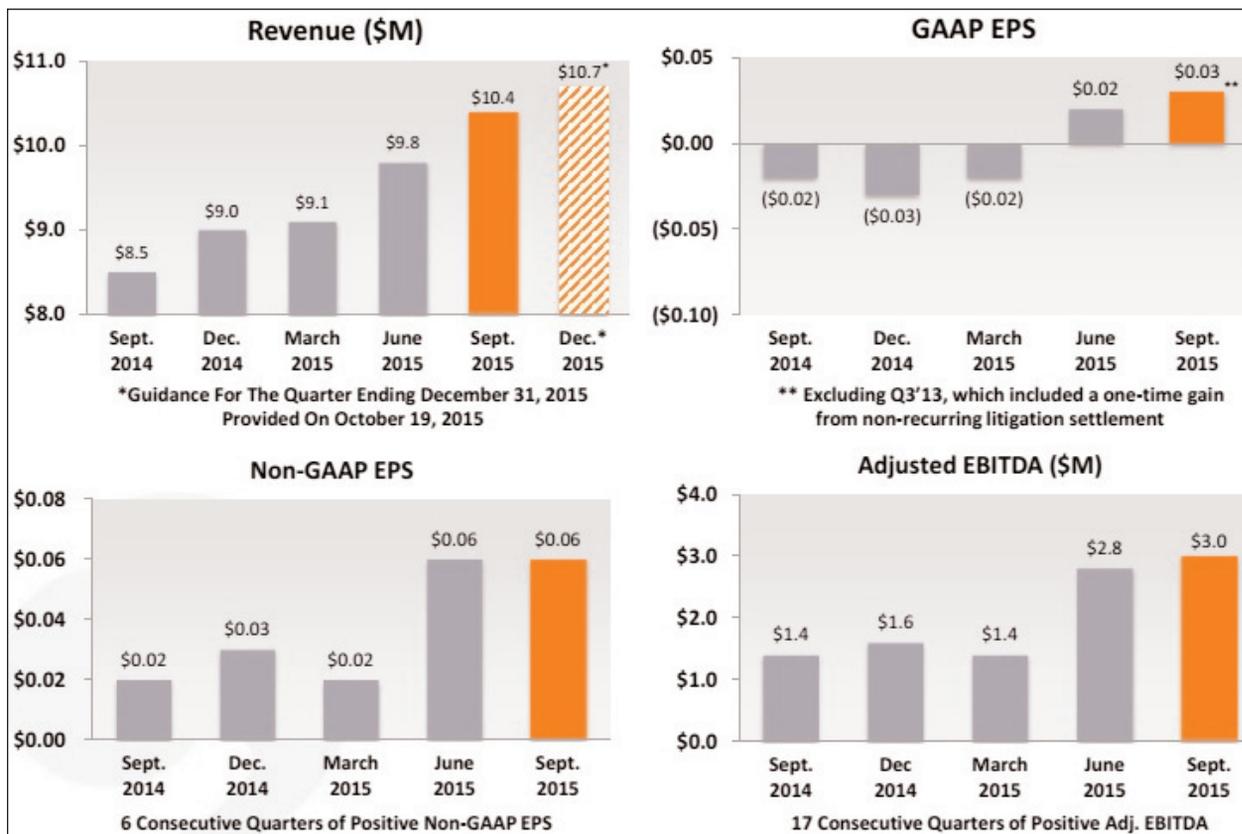
Operating expenses were \$4.5m, up slightly from \$4.4m last quarter and flat on a year ago. "We continue to manage our expenses tightly while continuing to invest in innovations," says chief financial officer Darren Ma.

A sixth consecutive quarter of net income yielded a record \$2.3m (\$0.06 per diluted share), up from \$2.1m (\$0.06 per diluted share) last quarter and \$0.7m (\$0.02 per diluted share) a year ago. A 17th consecutive quarter of positive adjusted EBITDA likewise yielded a record \$3m, up from \$2.8m last quarter and \$1.4m a year ago.

Capital expenditure (CapEx) was about \$0.2m. Free cash flow was \$0.5m. However, during the quarter, cash and cash equivalents almost doubled from \$18.4m to \$35m, due

to about \$16.5m in net proceeds from August's public offering of common stock. However, this does not include \$5.2m paid for the acquisition of South Korea-based Terasquare Co Ltd — establishing the subsidiary GigOptix-Terasquare-Korea (GTK) Co Ltd (to become GigOptix's center for ASIC product design and development) — which will be accounted for in fourth-quarter 2015. "The sole purpose of enhancing the balance sheet was to support further strategic moves and acquisitions to enhance the continuous fast growth of the company," notes chairman & CEO Dr Avi Katz.

"We produced another quarter of record financial results, further demonstrating that our business strategy to expand into high-growth markets, both organically and through strategic acquisitions, accompanied by tight cost controls, is generating exceptional performance," says Katz. "Our all-time record results and enhanced prof-



itability this quarter were driven by significant growth in our High-Speed Communications business. We continue to be the dominant supplier of RF devices for current 40Gbps and future 100Gbps active optical cables and transceivers for the fast-growing data-center market. We have also enhanced our customer base for datacom and telecom-metro 100Gbps links," he adds. "With the addition of Terasquare, we are now strongly positioned to further increase our cloud-based links market-share by having a complete and superior IC portfolio of industry-leading 100Gbps datacom solutions for Ethernet, Fiber Channel, and Infini-Band data-center connectivity... the transaction will result in a meaningful increase of the High Speed Communications revenue in fiscal 2016 and beyond," Katz believes.

"Earlier this month [October] we announced another milestone in the development of our Industrial ASIC product line with a substantial \$6.1m contract with one of the world's largest suppliers of advanced aerospace for commercial and

defense products," notes Katz. Revenue from this agreement will begin in fourth-quarter 2015 and be spread over the next two years. "When combined with the \$7.9m order we announced in May of this year from another major supplier in the same industry, we have the foundation in place to deliver continued strong financial performance in 2016," he adds.

For fourth-quarter 2015, GigOptix expects record revenue of \$10.7m (up 18% year-on-year), with gross margin remaining in the mid-60s. Operating expenses should rise by about \$0.4m, driven primarily by the Terasquare acquisition and its consolidation into GigOptix.

Adding to record year-to-date revenue of \$29.3m (up 23% year-on-year on \$23.9m in 2014), full-year revenue should hence be a record \$40m in 2015, up 21% on 2014 (and up from the previous guidance of \$39m given in July and \$37.5m given in February). After generating record net income of \$5.1m (\$0.14 per diluted share) in the first three quarters of 2015 versus \$0.34m (\$0.01 per diluted

share) a year ago, the firm also expects greater annual profitability. "Based on the fourth quarter fiscal 2015 revenue guidance, fiscal 2015 will result in the highest-revenue and most profitable year in the company's history," notes Katz.

"In Q4 we expect our level of CapEx investments to increase due to further investment to support our fast-growing segments driving revenue growth in 2016," notes Ma. "We currently expect 40Gb/s product to continue to be the dominating device in the data-center connectivity through 2016," says Katz. "The next generation of 100Gb/s product will continue to be qualified through the rest of this year and 2016, and we expect production volume sales of this product family to start in the second half of 2016 and to overtake the 40Gb/s device volume shipment sometime in late 2017," he adds. "The deployment of this current generation of NRZ modulated devices, both in 40Gb/s and in 100Gb/s, will last at least three more years before any other modulation schemes such as PAM-4 will replace it."

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

## GSI's board rejects latest acquisition proposal from GigOptix

GSI Technology Inc of Sunnyvale, CA, USA — a provider of static random access memory (SRAM) products primarily incorporated in networking and telecoms equipment — says that its board of directors (in consultation with its financial and legal advisors) has unanimously determined to reject the unsolicited, non-binding and conditional proposal made on 4 June by GigOptix to acquire GSI for \$6.50 per share, consisting of a combination of GigOptix common stock and cash (including GSI's cash paid as a special dividend).

The proposal represented a 26% premium above the closing price of GSI's stock of \$5.14 on 2 June (amounting to about 3.5 times revenue and 4.0 times GSI's enterprise value), according to GigOptix at the time.

"Representatives of our management and several members of our board of directors, along with our financial and legal advisors, held meetings with you and your advisors to provide you and your team with an opportunity to clarify your proposal, provide additional information regarding the financing commitment referred to in your letter and demonstrate why you believed that the proposed transaction was in the best interests of our stockholders," said GSI's lead director Arthur O. Whipple in a letter to GigOptix's chairman, CEO & president Avi Katz. "We entered into a mutual nondisclosure agreement, although you did not request, and we did not provide GigOptix with, any non-public information regarding GSI Technology. At our most recent meeting on 31 August 2015,

you substantially revised your proposal by, among other things, reducing the per share consideration to \$5.04 per share," he added.

"After carefully and thoroughly reviewing your revised proposal, in consultation with its financial advisors Robert W. Baird & Co Incorporated and its legal advisors DLA Piper LLP (US), our board has unanimously concluded that further pursuit of your unsolicited proposal would not be in the best interests of our stockholders," continued Whipple. "The board believes that GSI Technology's prospects as a strong independent company are excellent and that our goal of continuing to build long-term stockholder value will be best served by remaining focused on the execution of our business plan."

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

# GigOptix completes acquisition of Terasquare

GigOptix Inc of San Jose, CA, USA (a fabless supplier of high-speed semiconductor and optical communications components for long-haul and metro telecoms, cloud and data-center connectivity datacoms, point-to-point backhaul wireless applications, and interactive interfaces for consumer electronics links via fiber-optic and wireless networks) has completed its acquisition of Terasquare Co Ltd of Seoul, South Korea, establishing GigOptix-Terasquare-Korea (GTK) Co Ltd.

Terasquare is a fabless supplier of low-power-consumption, CMOS SerDes (serializer/deserializer) high-speed communication inter-

face semiconductors for 100Gbps Ethernet, Fiber Channel, and EDR Infiniband applications.

The combined product portfolio positions GigOptix as a supplier of 100Gbps+ datacom solutions for Ethernet, Fiber Channel, and Infiniband data-center connectivity. Terasquare's proven clock data recovery (CDR) technology is being integrated into GigOptix's current High Speed Communications portfolio.

With what is claimed to be an already dominant market share in the current generation of 40Gbps active optical cables (AOCs) and transceivers for data-center connectivity, in the next few months

GigOptix will introduce a complete 100Gbps chip-set solution, positioning it for further growth as the industry transitions from 40Gbps to 100Gbps+ speeds.

GigOptix demonstrated its third-generation 100Gbps short-reach chipset with its new 28Gbps quad CMOS CDR at the European Conference on Optical Communication (ECOC 2015) in Valencia, Spain (28-30 September), where error-free, three separated channels for 100m, 150m and 300m were demonstrated.

Initial revenue from these next-generation products is expected in fiscal first-half 2016.

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

## GigOptix gives live 100GbE demonstration of new quad-channel CMOS CDR with drivers and transimpedance amplifiers at ECOC

At the European Conference on Optical Communication (ECOC 2015) in Valencia, Spain (28-30 September), GigOptix showcased a live show-floor demonstration utilizing its third-generation 100Gbps short-reach chipset with its new 28Gbps quad-channel CMOS CDR (clock & data recovery) product.

The HXC42400 quad CMOS CDR is a new addition to GigOptix's datacom portfolio, resulting from the acquisition of Terasquare, and complements the HXT8204 28Gbps quad-channel vertical-cavity surface-emitting laser (VCSEL) driver array and HXR8204 28Gbps trans-impedance (TIA) receiver array (both launched in March) to enable next-generation short-reach SR4 (100m) and extended-reach SR4 (eSR4 - 300m) module and active optical cable (AOC) applications.

The datacom demo showcased:

- the HXC42400: a 28Gbps 4-channel CMOS CDR/re-timer designed for low-power 100GbE (QSFP28) modules, 100GbE AOC, and supporting OTN OTU4, 32G Fibre Channel, and EDR

Infiniband.

- the HXT8204: a 28Gbps 4-channel VCSEL driver designed for compact, low-power 100GbE SR4 optical transmitter pluggable modules and AOCs.

- the HXR8204: a 28Gbps 4-channel TIA with integrated limiting amplifier receiver array designed for high-capacity datacom 100GbE SR4 pluggable modules and AOCs.

The HXC42400, HXT8204 and HXR8204 are suitable for optical module, active optical cable, and optical engine applications with their partitioning of the CDR power dissipation from the temperature-sensitive, high-performance VCSEL, VCSEL driver, photo-detector, and TIA circuit elements for 100m and extended-reach applications module or AOC applications. The HXC42400 quad CDR solution is applicable to 100GbE (QSFP28) module, OTN OTU4, 32Gbps Fibre Channel, and EDR Infiniband applications.

In addition, a live demonstration by BrPhotonics showcased:

- a 100Gbps Integrated TOSA Reference Platform for CFP2 transceivers: a 100Gbps DP-QPSK

TOSA reference platform with 100Gbps DP-QPSK polymer modulator chip, example coherent receiver, and biasing circuitry.

In partnership with GigOptix and CPqD (an independent Brazil-based research center focused on information & communication technologies with activities in system- and device-level optical communications), the Brazilian joint venture BrPhotonics is demonstrating a coherent optical link design for 100Gbps long-haul communications with a complete CFP2 TOSA and separate receive path circuitry. The integrated CFP2 TOSA and Reference Platform utilize a linear quad MZM driver, a BrPhotonics 100Gbps DP-QPSK Thin Film Polymer on Silicon (TFPS) modulator, and an independent tunable laser. Discrete coherent receiver devices are located on the reference PCB as well as the GigOptix bias boards. The demonstration setup provides eye-diagram display on a real-time sampling scope, and X and Y polarization observation via optical constellation analyzer.

[www.ecoc2015.org](http://www.ecoc2015.org)

# GigOptix gives live 100GbE interoperability demonstration of 100G short-reach chipset and 28G quad CMOS CDR with II-VI's VCSELs

At the European Conference on Optical Communication (ECOC 2015) in Valencia, Spain (28–30 September), GigOptix Inc of San Jose, CA, USA (a fabless supplier of high-speed semiconductor and optical communications components for long-haul and metro telecoms, cloud and data-center connectivity datacoms, point-to-point backhaul wireless applications, and interactive interfaces for consumer electronics links via fiber-optic and wireless networks) showcased a live demonstration utilizing its third-generation 100Gbps short-reach chipset with its new 28Gbps quad CMOS CDR (clock & data recovery) product and the vertical-cavity surface-emitting laser (VCSEL) solutions of II-VI Inc of Saxonburg, PA, USA.

The HXC42400 quad CMOS CDR is a new addition to GigOptix's datacom portfolio, resulting from the acquisition in September of Terasquare, and complements the HXT8204 28Gbps quad-channel VCSEL driver array and HXR8204 28Gbps trans-impedance (TIA) receiver array (both launched in March) to provide a complete 'one-stop shop' chip-set solution offering to enable next-generation short-reach SR4 (100m) and extended-reach SR4 (eSR4 – 300m) module and active optical cable (AOC) applications. "Our complete solution now offers leading optical link reach with robust performance and unique on-chip testability features."

Due to its unique architecture, GigOptix's new quad-channel HXC42400 25–28Gbps CMOS CDR enables what is said to be industry-leading low power dissipation and the industry's first solution with programmable receiver and transmitter bandwidth in a single device to optimize input jitter tolerance (IJT) and output jitter for superior link performance. To maintain and

optimize signal integrity (SI) under adverse insertion loss (IL) situations, the HXC42400 includes up to 16dB of programmable continuous time linear equalization (CTLE) and a 1-tap decision feedback equalizer (DFE) with a 3-tap programmable de-emphasis block provides up to 12dB gain for the pre- and post-taps. It features reference-less operation and many on-chip testability features including Eye-Monitor (iMON), PRBS generator/checker, an arbitrary pattern generator, and a unique jitter tolerance (JTOL) test capability.

The HXT8204 four-channel VCSEL driver supports modulation and average VCSEL currents up to 10mA with a dedicated burn-in capability up to 15mA average current. The 1MHz I2C interface enables full control of all driver functions including input equalization, output peaking and peaking duration, signal detect and squelch, channel polarity inversion, diagnostics such as average current and temperature monitoring as well as user-maskable interrupts and VCSEL voltage supervisory functions.

The HXR8204 four-channel receiver with integrated TIA provides 60uAPP input sensitivity at 28Gbps with  $10^{-12}$  bit error rate (BER), AGC and ATC, and a limiting post-amplifier stage. Linear, per-channel RSSI outputs are provided to enable active alignment during manufacturing

to provide optimum performance and manufacturability. The 1MHz I2C interface enables full control of additional functionality such as signal detect and squelch, pre-emphasis, maskable interrupt generation, internal temperature monitor selection, channel polarity inversion, and output voltage swing with enable.

"GigOptix is very appreciative of our long-standing relationship with II-VI and pleased to introduce our latest product offering while showcasing and expanding the interoperability of our two companies' solutions," says GigOptix's Datacom marketing director Tom Kapucija. "Our complete solution now offers leading optical link reach with robust performance and unique on-chip testability features," he adds.

"As a chip vendor open to the Datacom market, II-VI Laser Enterprise appreciates the flexibility and completeness of the GigOptix offer on the ICs market," says Michele Agresti, Datacom VCSELs product line manager at II-VI Laser Enterprise. "We are now looking forward to reinforcing and consolidating our cooperation, leveraging the success of our new 25Gb/s 850nm VCSEL and new GigOptix 25–28Gb/s driver/TIA chipset," he adds.

The HXC42400, HXT8204 and HXR8204 are suitable for optical module, active optical cable, and optical engine applications with their partitioning of the CDR power dissipation from the temperature-sensitive, high-performance VCSEL, VCSEL driver, photo-detector, and TIA circuit elements for 100m and extended-reach applications. The solution is applicable to 100G Ethernet (QSFP28, CFP2, CFP4), OUT-4, 32Gbps Fibre Channel, and EDR Infiniband.

[www.ecoc2015.org](http://www.ecoc2015.org)  
[www.gigoptix.com](http://www.gigoptix.com)

**The HXC42400 quad CMOS CDR is a new addition to GigOptix's datacom portfolio, resulting from the acquisition of Terasquare, and complements the HXT8204 28G quad-channel VCSEL driver array and HXR8204 28G TIA receiver array**

## Silicon photonics firm Luxtera hires vice presidents of worldwide sales and finance

Fabless silicon CMOS photonics firm Luxtera of Carlsbad, CA, USA has hired Brad Byk as VP of worldwide sales and Kelly Perez as VP of finance. Luxtera says that it will leverage their experience and knowledge as it accelerates its global commercial expansion.

"Luxtera has tremendous potential to be the next large scale public semiconductor company, and I look forward to help realize that potential. The market opportunity in front of us is unparalleled in my experience."

"Luxtera has transitioned into an extreme growth phase, as we're delivering products to hyper-scale data-center operators and system OEMs that rely upon Luxtera's silicon photonics technology," says president & CEO Greg Young.

"We've now built an executive leadership team capable of driving Luxtera to become a multi-billion-dollar company," he reckons.

Byk comes to Luxtera with over 25 years of experience in industry leading communications semiconductor companies and an impressive track record of scaling sales organizations while creating and executing high growth plans and delivering solid results.

Prior to joining Luxtera, Byk served as senior VP of worldwide sales for Skyworks Solutions Inc, where he led the firm to new markets and significant sales growth (\$1.1bn to \$2.4bn over four years). Previously, Byk served 13 years at Broadcom, most recently as senior VP of sales for the Americas and Strategic Accounts with responsibility for over \$3bn in annual revenue. Prior to this, he held sales and management positions at Advanced Micro Devices, FEI Microwave and TRW. Byk received a bachelor's degree in business administration from Long Beach State University and a master's degree in systems management from the University of Southern California.

"Luxtera has tremendous potential to be the next large-scale public semiconductor company," believes Byk. "The market opportunity in front of us is unparalleled in my experience."

Perez has over 20 years of experience in semiconductor and biotechnology companies, including expertise in global financial operations and controls, strategic planning and analysis, supply chain

finance, IT systems and applications. Perez will oversee Luxtera's global finance function, information technology and human resources.

Perez spent eight years at Sequenom Inc, where she was most recently VP corporate development & administration as well as serving other functions such as VP finance & treasurer. There, she was involved in raising more than \$400m in equity, debt and strategic transactions including Private Investment in Public Equity (PIPE), accelerated book build offerings, a convertible notes offering, a sale of a business unit, and strategic partnerships. She was also responsible for the financial and strategic planning and analysis, treasury, corporate risk management, human resources and project and portfolio management functions. Perez's background in semiconductors includes 11 years in companies including Nvidia Corp, Applied Micro Circuits Corp, QuickLogic Corp and Altera Corp. In her seven years at Nvidia, she grew the finance organization to support the company as it went from a \$300m to a \$2bn annual revenue run-rate.

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

## Source Photonics demonstrates CWDM QSFP28 single-mode transceiver

At the European Conference on Optical Communication (ECOC 2015) in Valencia, Spain (28-30 September), optical communication product maker Source Photonics Inc of West Hills, CA, USA demonstrated its CWDM QSFP28 single-mode transceiver operating in a 10km link.

The 3.5W QSFP28 transceiver is compliant to both the CWDM4 and CLR4 specifications and follows the production release and general availability of the first-to-market Source Photonics QSFP28 LR4 and LR4 Lite launched in March. Featur-

ing proprietary low-power electro-absorption modulated laser (EML)-based technology, the QSFP28 operates to 10km, allowing a link budget of 6.3dB while not requiring forward error correction (FEC). The longer reach and higher-link-budget capability will enable the transceiver to be used in otherwise dispersion-limited environments and to provide additional flexibility to deploy longer fiber routing inside the data-center on the CWDM grid, says the firm.

Source Photonics has designed the new CWDM4/CLR4 QSFP28

product on the same product and manufacturing platform as the LR4 and LR4 Lite versions, enabling rapid manufacturing ramp and leveraging existing manufacturing assets. With availability of the QSFP28 CWDM4/CLR4, LR4, LR4 Lite and CFP4 LR4/OTU4, Source Photonics says that it now can offer a complete suite of single-mode 100G solutions for inside data-center, data-center interconnect, routing, and client-side transport applications.

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

# Oclaro demos interoperability between 100G QSFP28 CLR4/CWDM4 and LR4 and ER4-Lite CFP, CFP2 and CFP4 transceivers, plus 400G lithium niobate modulator

At the European Conference on Optical Communication (ECOC 2015) in Valencia, Spain (28–30 September), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) gave 100G and 400G product demonstrations showcasing how its vertically integrated product lines deliver the higher speeds, lower power dissipation and smaller form factors that network and data-center operators need to provide more bandwidth without significantly expanding footprint, cost and power consumption.

“Our ECOC demonstrations highlight Oclaro’s continued ability to provide leading-edge optical components that help increase network bandwidth and enable next-generation applications such as streaming video and cloud computing,” says chief commercial officer Adam Carter. “Oclaro has been the leading transceiver supplier for 100G single-mode applications based on its

indium phosphide [InP] laser and modulator technology, and we are expanding on that leadership now that data centers are getting ready for 100G deployments,” he claims.

## 100G CWDM4 QSFP28 and 100G CFPx full line-up demo

Regarding 100G client-side technology, Oclaro showcased a live interoperability demonstration between its LR4 and ER4-Lite line-up of CFP, CFP2 and CFP4 transceivers and its new 100G QSFP28 CWDM4/CLR4 transceiver based on its directly modulated laser (DML) and electro-absorption modulated laser (EML) technology.

## Line-side product demonstrations

Oclaro also showcased several products from its vertically integrated DWDM product portfolio, including:

- a new 400G lithium niobate modulator for next-generation DWDM networks;
- analog coherent CFP2-ACO transceiver for metro and data-center interconnect applications at 100G

and 200G; and

- micro-ITLA and dual micro-ITLA lasers with grid-less wavelength tuning for coherent applications from 100G to 400G.

## Additional participation by Oclaro at ECOC

Oclaro contributed to the following papers presented at ECOC:

- ‘Facet-free Surface-emitting 1.3μm DFB Laser’ (contributors include Oclaro’s Tsukuru Ohtoshi, Kouji Nakahara, Akira Nakanishi, Kazuhiko Naoe and Shigehisa Tanaka); and
- ‘Uncooled (25–50°C) Operation of Self-Seeded RSOA for Low-Cost Colorless WDM-PON Transmitter’ (contributors include Oclaro’s Shunya Yamauchi and Masaru Mukaikubo).

Also, Oclaro’s director of strategic marketing Robert Blum spoke on the Market Focus panel ‘Photonic Integration in Indium Phosphide for Metro and Data Center Interconnects’.

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

## Oclaro reports better-than-expected preliminary quarterly results

### Strong growth in 100G products boosted by higher-than-expected revenue for 10G and 40G

In preliminary results for fiscal first-quarter 2016 (ended 26 September 2015), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) says that, compared with its guidance provided on 4 August, it now expects revenue of about \$87.5m, at the high end of the forecast range of \$82-88m (and up 6.5% on \$82.2m last quarter, although still down on \$89.2m a year ago).

“The preliminary results that we are reporting today reflect strong growth in our 100G product port-

folio,” says CEO Greg Dougherty. “In addition, we saw higher-than-expected revenues for our 10G and 40G products, coupled with a much more favorable product mix, resulting in gross margin exceeding our prior guidance,” he adds.

Gross margin (on a non-GAAP basis) should be 26–27%, above the high end of the forecasted 18–22% (and up from 19.9% last quarter and 16.5% a year ago).

Adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) should be \$4–4.5m, much better than the

forecasted range of between negative \$3m and breakeven (and compared with –\$1.2m last quarter and –\$8.9m a year ago).

During the quarter, cash, cash equivalents, restricted cash and short-term investments fell from \$115.1m to \$107.7m.

The preliminary, unaudited results are based on management’s initial review of operations for the quarter and remain subject to completion of the firm’s standard quarterly accounting close process. Oclaro will announce full results on 3 November.

## SWDM Alliance formed to support duplex multimode fiber for 40 & 100G enterprise & data-center applications

Nine companies have formed the SWDM Alliance to drive cost-effective utilization of duplex multimode fiber (MMF) infrastructure in cloud and enterprise data centers. The interest group will promote shortwave wavelength division multiplexing technology, allowing data-center operators to continue to extract value from their existing duplex MMF deployments and extend the usable lifetime of newly deployed MMF.

Optical shortwave technology is enabled by vertical-cavity surface-emitting lasers (VCSELs), which are the most cost-effective lasers used in data-center interconnections. VCSELs have been widely deployed at data rates up to 10Gbps, driving large-scale installations of duplex MMF in enterprise and cloud data-centers. A common technique to increase the data rate beyond 10Gbps is the use of four parallel VCSELs, each running at 10 or 25Gbps, transmitted over ribbons of parallel fiber. This technique requires eight

fibers instead of two: four to transmit and four to receive. Installing such parallel fiber can represent an expensive overhaul to the fiber plant in the data center due to the need for increased fiber capacity in the trunk and also new patch cables to the optical modules.

By contrast, SWDM technology allows users to leverage their installed duplex MMF at 40 or 100Gbps, using four VCSELs operating at different wavelengths multiplexed onto a single strand of MMF, hence requiring only one transmit fiber and one receive fiber. This provides the ability to migrate from 10 to 40 or 100Gbps, while minimizing overall power dissipation and maximizing transmission distance.

Founded by CommScope, Corning, Dell, Finisar, H3C, Huawei, Juniper Networks, Lumentum and OFS, the SWDM Alliance is dedicated to promoting the adoption of SWDM technology in order to provide cost-effective data-center technology

solutions. The alliance is neither a standards organization nor a multi-source agreement. The group does not address market segmentation, pricing or competitive issues.

"Data-center operators have already invested in duplex MMF infrastructure for their 10Gbps deployments," says Vladimir Kozlov, CEO of Lightcounting Market Research. "Using SWDM technology to maximize the utility of those duplex deployments is an example of how equipment providers can offer innovative, cost-effective upgrades to the higher data rates that are now required," he adds.

"Multimode fiber and VCSEL technology have been the workhorse of the modern data center," adds Finisar's senior director of marketing Steffen Koehler. "SWDM builds on this history of cost-effective, high-bandwidth interconnect technology to continue the evolution of these data centers."

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

## Finisar demonstrates first 100G QSFP28 SWDM4 module for duplex multimode fiber

Fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA has announced the first 100G QSFP28 SWDM4 module, operating over standard, duplex multimode fiber.

Shortwave wavelength division multiplexing (SWDM) technology enables data-center operators to upgrade from 10G to 40G and 100G using their existing duplex multimode fiber (MMF) infrastructure. Finisar says the new module brings a cost-effective upgrade path to real-world data centers. The SWDM4 module was demonstrated at the European Conference on Optical Communication (ECOC 2015) in Valencia, Spain (28–30 September).

Suitable for cost-sensitive enterprise data centers as well as for cloud

data centers, the new 100G SWDM module enables operators to upgrade data rates without requiring capital investment for additional fiber.

The module is based on Finisar's history of reliable shortwave vertical-cavity surface-emitting laser (VCSEL) technology. VCSELs offer the lowest cost, highest density and lowest power dissipation in the optical industry.

The 100G SWDM module follows the demonstration of a 40G SWDM4 QSFP+ module at the Optical Fiber Communications (OFC 2015) conference in Los Angeles in March. With the new module, Finisar now has a complete suite of 40G and 100G pluggable transceiver products capable of operating on links built with the traditional

duplex MMF already installed in existing data centers.

Finisar's demonstration showcased a 100G SWDM4 link established between a pair of QSFP28 modules operating over standard duplex MMF. Select customers are already evaluating samples of the 100G QSFP28 SWDM4 module.

### Shortwave wavelength division multiplexing (SWDM)

Cloud and enterprise data-center operators use multimode fiber for most of their deployments. While single-mode fiber offers transmission advantages, the high-precision optics required to build single-mode modules have made them a more expensive option. This has led to widespread adoption of duplex MMF in large-scale deploy- ➤

► ments where 10G Ethernet links were the primary data rate. Upgrading to 40 and 100 GE using MMF has traditionally required the use of parallel ribbons of fiber. Such an upgrade entails significant investment in the data center, including increased fiber in the trunk and new patch cables to optical modules.

By contrast, SWDM allows continued use of existing duplex MMF infrastructure and extends its usable lifetime. SWDM multiplexes different wavelengths onto duplex MMF utilizing WDM VCSEL technol-

ogy. VCSELs have been proven in high-speed optical communications and are widely deployed in 10 GE interconnection applications. By simultaneously transmitting four VCSELs, each operating at a slightly different wavelength, a single SWDM transceiver can reliably transfer 40 GE (4x10G) or 100 GE (4x25G).

"As the first to demonstrate and market SWDM modules, Finisar is committed to driving widespread adoption of this technology," says director of marketing Steffen Koehler. "With the 100G SWDM4

module, Finisar helps to ensure that duplex MMF continues to be the most cost-effective interconnect for all but the very largest data centers."

At ECOC, Finisar is also displaying equipment from its wide portfolio of products, including its latest transceivers, optical engines, active optical cables (AOCs), optical components, optical instrumentation, reconfigurable optical add/drop multiplexer (ROADM) & wavelength management, optical amplifiers, and RF-over-fiber.

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

## Finisar demos 400G Ethernet technology and previews CFP8 module supporting single- and multi-mode fiber

At the European Conference on Optical Communication (ECOC 2015) in Valencia, Spain (28–30 September), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA demonstrated several technologies for high-speed optical networking applications.

Demonstrations included a preview of the new 400GE CFP8 module, next-generation 25GE LR SFP28 transceivers enabling 10km links over single-mode fiber, QSFP28 SR4 and SFP28 SR transceivers without forward error correction (FEC) for low-latency applications, and new WaveAnalyzer software with enhanced capabilities.

### 400G Ethernet technology

The 400G Ethernet technology display showcased the current breadth of the ecosystem, including Finisar 100GE and 400GE modules, Xilinx field-programmable gate arrays (FPGAs) and test equipment from Viavi Solutions and Spirent. The live demonstration featured an error-free 400G SR16 optical link using four Finisar 100GE CFP4 SR4 modules driven by a 400GE Xilinx FPGA.

A 400GE CFP8 module was also displayed. CFP8 is a new, first-generation optical transceiver form factor for 400G Ethernet applications.

Already being defined by the CFP MSA (multi-source agreement), CFP8 enables 6.4Tb/s on a 1RU host system card. With physical dimensions similar to a CFP2 module, it is currently the only form factor that supports both multimode and single-mode applications at this link speed, as well as both CDAUI-16 (16x25G) and CDAUI-8 (8x50G) electrical I/O. CFP8 modules can additionally support high-density 4x100GE fan-out applications with double the 100G port density of QSFP28, while providing the flexibility to also support 400GE as service providers upgrade their networks.

### Long-wave 10km 25GE SFP28 transceivers

Finisar also demonstrated its 25GE LR SFP28 transceivers enabling a 10km link over single-mode fiber at full data rate (25.78Gb/s). 25GE is the natural progression of Ethernet, enabling a seamless upgrade path for 10GE LR links in enterprise, data-center, wireless and access applications. They will also interoperate in a fan-out configuration with a 100G PSM4 module. To satisfy customer requests, Finisar plans to move to volume production ahead of the formal definition of the 25GE standard. 25GE SFP28 transceivers are currently sampling.

### Low-latency QSFP28 and SFP28 transceivers for links without FEC

For low-latency applications, Finisar demonstrated new versions of its 100GE QSFP28 SR4 and 25GE SFP28 SR transceivers interoperating without forward error correction. The transceivers support links up to 30m on OM3 and 40m on OM4 fiber. Ordinarily, FEC is required by the IEEE standard to ensure that 25GE SR4 optical links are closed and error-free. However, FEC increases latency, and there are many applications where turning off FEC is required to decrease latency or reduce power consumption on the host board. The superior optical performance of the new transceivers eliminates the need for FEC. Based on its in-house vertical-cavity surface-emitting laser (VCSEL) technology and vertical integration capability, Finisar is able to meet the non-FEC, low-latency requirements in multiple form factors.

### WaveAnalyzer and WaveManager software upgrades

Finisar has launched upgraded software for the WaveAnalyzer 1500S High Resolution Optical Spectrum Analyzer, including an app for remotely accessing WaveAnalyzer software from Android devices. Also available is WaveManager version 2.7.

[www.ecoc2015.org](http://www.ecoc2015.org)

# NeoPhotonics launches products to support 400G coherent transport for long-haul, metro and data-center interconnect networks

## High-speed InP waveguide photodetector-based coherent receivers and dual-output ultra-narrow-linewidth lasers pave way for 400G systems

At the European Conference on Optical Communications (ECOC 2015) in Valencia, Spain (28–30 September), 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) announced a suite of products and technologies designed to support 400G-and-beyond optical transport across multiple network segments, including long-haul, metro and data-center interconnects (DCI).

The suite includes high-speed indium phosphide (InP)-based waveguide photodetectors for coherent receivers with higher-baud-rate transmission, ultra-narrow linewidth lasers for higher-order constellations such as 16QAM and 64QAM, dual-output lasers for dual-carrier architectures, and small-form-factor coherent components for high-density line-cards and pluggable coherent optics. "Moving from 100G to 400G coherent transport systems requires increased performance coupled with smaller size and lower power, which clearly demonstrates the power of our hybrid photonic integration"

NeoPhotonics' 400G product and technology suite addresses each of the approaches for increasing transport bandwidth. Conceptually, the most straight forward path to increasing the bandwidth is to increase the symbol rate by increasing the raw speed of the optical system, says the firm. NeoPhotonics' InP-based high-speed waveguide photo-detectors can be incorporated in both monolithic and hybrid integrated coherent receivers (ICRs) and are capable of supporting symbol rates of 64 Gbaud, which is twice the

standard 32 Gbaud in existing 100G systems.

Higher-baud-rate transmission is best suited to long-haul applications where higher data rates can be achieved without compromising system reach. The ICRs are configured in compact small-form-factor packages and, when coupled with NeoPhotonics' Dual micro-integrable tunable laser assembly (micro-ITLA), efficiently support dual-carrier 400G implementations. The Dual micro-ITLA provides two independent, ultra-narrow-linewidth, separately tunable lasers in a form factor that is 25% smaller than separate micro-ITLAs and is well suited to dense line-cards with either 400G or multiple 100G ports, reckons the firm.

A second approach to increasing transport bandwidth is to use higher-order modulation techniques to increase the number of bits per symbol. Thus, using 16QAM doubles the number of bits transported compared to standard QPSK implementations (even though the underlying baud rate is unchanged) and 64QAM quadruples the data rate. Higher-order modulation is often used for metro and DCI, since the same optical components can support double or quadruple the data rate, although over a shorter reach. However, such higher-order modulation schemes are more sensitive to both amplitude and phase noise, since the separation between states is necessarily reduced, and therefore require the most stable, ultra-narrow linewidth laser sources. Inherent to their design, external-cavity lasers have the narrowest linewidth in the industry, and NeoPhotonics' micro-ITLA exhibits typical linewidths of 20kHz, resulting in high fidelity in higher-order modulation. These lasers are avail-

able in single and dual micro-ITLA configurations and, when coupled with compact NeoPhotonics micro-ICRs, enable high-density line-card and pluggable module implementations, says the firm.

"Just as our hybrid photonic integration technology is a mainstay in 100G coherent transport implementations, we are pleased to see our products and technologies enabling our customers as they move to 400G systems," comments chairman & CEO Tim Jenks. "Moving from 100G to 400G coherent transport systems requires increased performance coupled with smaller size and lower power, which clearly demonstrates the power of our hybrid photonic integration," he adds.

Separately, for 400G data-center and client applications, NeoPhotonics presented its very high-bandwidth electro-absorptive modulated laser (EML), generating what is claimed to be superior performance in use with high-order modulation (HOM) systems. A joint demonstration with Inphi Corp of Santa Clara, CA, USA (a provider of high-speed mixed-signal ICs for communications, data-center and computing markets) in Inphi's booth demonstrated a full dual-lambda 100G PAM4 solution based on Inphi's PAM4 PHY IC and NeoPhotonics' EML-based Q-TOSA.

Also at ECOC, NeoPhotonics exhibited its suite of standard and small-form-factor PIC-based components and its modular Multi-Cast Switches, both for 100G and 400G coherent line-side applications, along with its 100G client-side CFP2 and CFP4 transceivers and its next-generation transceivers for access networks.

[www.neophotonics.com](http://www.neophotonics.com)  
[www.ecoc2015.org](http://www.ecoc2015.org)

## Inphi demos interoperability of first 400G PAM4 IC chipset with NeoPhotonics' Q-TOSA 100G EML-based modules

At the European Conference on Optical Communications (ECOC 2015) in Valencia, Spain (28–30 September), Inphi Corp of Santa Clara, CA, USA (a provider of high-speed mixed-signal ICs for communications, computing and data-center markets) demonstrated interoperability of what is claimed to be the industry's first 4-level pulse amplitude modulation (PAM4) PHY IC chipset solution for service provider interconnects.

The demonstration showcases 100G dual-lambda optical link performance with 2-10km single-mode fiber (SMF) loopback featuring Inphi's PAM4 IC solutions and the Q-TOSA 100G electro-absorption modulated laser (EML)-based modules of NeoPhotonics Corp of San Jose, CA, USA, a vertically integrated designer and manufacturer of hybrid photonic integrated circuit (PIC)-based optoelectronic modules and subsystems for high-speed communications networks.

As the megatrends of cloud computing, Big Data, Internet of Things (IoT), Social and Web2.0 continue to accelerate and drive the demand for unlimited bandwidth, there is a

need to increase the speed of interconnect pipes while maintaining cloud economics and lowering carbon footprints, says Inphi. PAM4 modulation has now been recognized as the modulation scheme that will take the industry over the next wave of Ethernet deployments for optical and copper interconnects by doubling the bits per symbol at the same baud rate. The demonstration shows that, by transferring the complexity from optics into CMOS electronics with PAM encoding, digital signal processing (DSP) and forward error correction (FEC) technologies, one can attain four times as much bandwidth improvement compared with existing solutions, at a lower cost, adds the firm. Coupled with the availability of its high-speed linear driver and amplifier solutions, the demonstration showcases a complete electronics platform for an eight-lambda IEEE P802.3bs 400G LR8 implementation, says Inphi.

"Our interoperability demo with ecosystem partners such as NeoPhotonics achieves excellent bit-error-rate and optical link budget, and proves that the PAM4

technology is ready and available today to help designers build IEEE P802.3bs 400G LR8 line-cards and modules for next-generation service provider platforms," says Siddharth Sheth, Inphi's vice president of Networking Interconnect.

As part of this demo, NeoPhotonics is showcasing its new 4x28G Q-TOSA module, which incorporates four channels of PIC integrated transmitters utilizing proven high-performance electro-absorptive modulated lasers (EMLs), which meets the stringent ITU-T standard required by Telecom service providers and also satisfies the datacom requirement.

"This joint demo with Inphi PAM4 chip demonstrates the ability of our very high-bandwidth EML to generate superior performance in high-order of modulation (HOM)-based platforms," says NeoPhotonics' CEO Tim Jenks. "It has been proven at both 28GBaud and 56GBaud, which will enable future systems with higher link capacity to serve the continuous market demand for increased bandwidth."

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

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

## Inphi samples smallest SMT quad linear driver for coherent applications, targeting coherent systems growth in 100G/200G

Inphi has announced the sampling of a new product in its 32GBaud linear coherent product family.

The IN3217SZ is a quad linear differential to single-ended Mach-Zehnder (MZ) modulator driver in a surface-mount technology (SMT) package, extending the product portfolio by utilizing cost-effective packaging for higher-volume 100G/200G coherent long-haul and metro optical interconnect applications.

With a 14mm x 9mm small-form-factor package, the IN3217SZ directly interfaces to lithium niobate (LiNbO<sub>3</sub>) or indium phosphide (InP)

MZ modulators, in target systems from line-cards, 4x5 modules, or CFP or CFP2 modules. The new low-power design, together with what is claimed to be industry-leading performance, enables next-generation long-haul and metro networks to address highly integrated line-card designs and advanced pluggable modules.

"With the widespread adoption of coherent technology underway, devices such as the IN3217SZ enable the higher densities and lower-cost solutions the 100G/200G applications require," comments Andrew Schmitt, principal analyst,

Carrier Transport Networking at Infonetics Research.

"The networking market needed new lower-power linear modulator drivers in smaller package footprints to address the high-volume next-generation applications," says Lian Zhao, Inphi's product line manager, Optical Interconnect. "The IN3217SZ expands the Inphi product portfolio again to address the latest market demands for high-performance, long-haul applications and high-density and volume metro applications for 100G/200G coherent systems."

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

# Emcore expands laser and photodiode chip range for 2.5–12.5Gbps telecoms and datacoms

## Focus on merchant chip supply after divesting tunable telecom lasers

Emcore Corp of Alhambra, CA, USA, which provides indium phosphide (InP)-based optical chips, components, subsystems and systems for broadband and specialty fiber-optics markets, has expanded its range of laser diode and avalanche photodiode (APD) optical chips for the high-speed telecom Gigabit passive optical network (GPON) fiber-to-the-home (FTTH) market and uncooled digital datacom applications. The firm's latest chip series supports 2.5-12.5Gbps data-rate transmission at 1310 and 1550nm wavelengths.

"This is the first announcement of Emcore's expanded chip product line that addresses the worldwide demand, particularly in China, for high-data-rate transmission semiconductors for GPON FTTH networks," comments president & CEO Jeffrey Rittichier. "Our core competency is in optical semiconductors, and we are returning to our roots with expanded chip offerings across

a large range of applications in the telecom market," he adds. "With last year's divestiture of our tunable telecom laser module products, we are poised to become a merchant supplier of high-performance chips."

Emcore's laser and APD chips are designed and manufactured at the firm's InP wafer fabrication facility, which features metal-organic chemical vapor deposition (MOCVD) reactors for 3x3" or 6x2" wafers, plus stepper, wafer track, reactive ion etching (RIE), diffusion, metal and dielectric deposition, and cleaving and dicing equipment in a class 1000 cleanroom. The plant also functions as Emcore's anchor for its vertically integrated manufacturing, supporting laser module, transmitter and receiver products.

The latest G1033 series laser chips include GPON 2.5Gbps DFB (distributed feedback) devices with 1310 and 1550nm operating wave-

length options. Each model features advanced digital chip design with a wide operating temperature range and high optical output power. The chips are Telcordia Technologies 468 and RoHS compliant. They are specifically designed to perform as the laser source for uncooled digital applications. In addition, Emcore's chip range includes high-power-gain chips suited to tunable lasers and narrow-linewidth optical sensing applications.

Emcore's APD chips include a 2.5Gbps avalanche photodiode as well as 10Gbps top- and bottom-illuminated APDs. The 2.5Gbps APD is specifically designed to target GPON OLT (optical line terminal) and ONU (optical networking unit) applications. The 10Gbps APD is designed for next-generation PON, as well as other 10Gbps digital applications. The APDs have high responsivity, very low capacitance and are optimized for high-speed performance.

## Emcore showcases DOCSIS 3.1 optical components at Cable-Tec

At the Society of Cable Television's (SCTE) 2015 Cable-Tec Expo in New Orleans (14–16 October), Emcore hosted a demonstration of its Medallion Series CATV transmission system, featuring the 19" rack-mount Medallion Series 1550nm CATV Transmitter, Optical A/B Switch and CATV Fiber Amplifier.

Medallion Series Transmitters are available for direct or external modulation and are based on Emcore's proprietary laser technology. The firm's lasers are designed for low noise, high optical output power and narrow optical linewidth. The transmitters leverage proprietary pre-distortion circuitry to provide what is said to be superior CSO and CTB performance, allowing links up to 150km. Also, the Medallion's SBS suppression levels of over

21dBm through 40km of fiber suits RfOG (radio frequency over glass) and RF overlay in FTTx networks.

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

The Medallion 7000 Series CATV Fiber Amplifiers provides very stable optical outputs over a wide operating temperature range, as well as the exceptionally high power and low noise figures demanded by CATV applications. The Medallion 7100 is packaged in a compact 1 RU housing, while the 7200 is housed in a 2 RU enclosure and is now available with up to 64

ports of 21dBm. Optional integrated WDM filters for RfOG or RF overlay in FTTx further preserves rack space and reduces cost by eliminating a separate network element.

"Our Medallion series of rack-mount CATV transmission equipment is ideal for network systems providers that demand the highest quality, economical delivery of HD video and audio, along with the highest-bandwidth data transmission," says Gyo Shinozaki, director of marketing for CATV products. "The Medallion series is also designed for future DOCSIS 3.1 compliance to support cable operators as they move to the new DOCSIS standard for even higher-speed data transfer over existing CATV networks."

<http://expo.scte.org>  
[www.emcore.com](http://www.emcore.com)

## CdTe to dominate thin-film solar market, reaching nearly 5400MW by 2023

The global market for thin-film solar — e.g. amorphous silicon, cadmium telluride (CdTe) and copper indium gallium selenide (CIGS) — is rising at a compound annual growth rate (CAGR) of 9.4%, from \$9393.78m in 2014 to \$20,995.66m by 2023, forecasts Transparency Market Research in its report 'Solar Cell Films Market — Global Industry Analysis, Size, Share, Growth Trends, and Forecast, 2015 — 2023'. Due to the benefits offered by thin-film solar cells (e.g. low manufacturing costs, zero carbon emissions, and high efficiency), high demand for solar cell films has been seen across the globe over the past decade, notes the report.

Due to high efficiency, longer life span and low manufacturing costs compared with other solar cell films, cadmium telluride dominated the thin-film solar cell market in terms of volume in 2014. Solar energy conversion efficiency for CdTe is 16–18% versus 8–10% for amorphous silicon. High sunlight absorbing power and higher electricity generation rate make CdTe solar cell films a preferred choice over other solar cell films for generating electricity, notes the report. The market for CdTe thin-film solar is forecast to reach \$7783.68m in revenue and 5391.96MW in capacity by 2023, Transparency Market Research reckons.

High demand for thin-film solar has been seen in the commercial sector (e.g. offices, shopping complexes, malls and multiplexes) due to the high electricity demand, especially during peak hours. Significant demand for thin-film solar has also been seen in the residential sector, since significant reduction in emissions and attractive financial savings can easily be achieved, adds the report. Thin-film solar power is also useful for bridging the electricity demand–supply gap to a certain extent in the industrial sector as well.

[www.transparencymarketresearch.com/solar-cell-films-market.html](http://www.transparencymarketresearch.com/solar-cell-films-market.html)

## First Solar installs final module at Broken Hill Solar Plant in New South Wales

Cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA has installed the final modules at the 53MW Broken Hill Solar Plant in New South Wales (NSW) Australia, which is on schedule to be fully operational by the end of the year. Together with the 102MW Nyngan Solar Plant, Australia's two largest utility-scale solar plants will produce about 360,000MWh of electricity annually (enough to power 50,000 average Australian homes).

To date, 677,760 of First Solar's PV modules have been installed. "By combining industry-leading thin-film modules and construction techniques, this project demonstrates First Solar's capability to rapidly develop and construct a solar asset at competitive prices," says Jack Curtis, First Solar's regional manager for Asia Pacific, who adds that the plant's CdTe modules offer significant efficiency and reliability advantages over typical crystalline silicon modules, particularly in a hot climate like Broken Hill.

In September, First Solar and project partners AGL Energy, the Australian Renewable Energy Agency (ARENA) and the NSW Government achieved first generation at the Broken Hill Solar Plant, with an initial 26MW feeding into the National Electricity Market.

"Just six months after Australia's largest solar plant at Nyngan was switched on, we are now another step closer to completing Australia's two largest utility-scale solar plants in the same year," says Curtis. "First Solar's delivery record has set an industry benchmark and this milestone reaffirms the prominent role utility-scale solar PV will continue to play in Australia's energy future," he believes.

"Today the plant generates up to 27MW of renewable energy into the grid and the remaining 26MW is expected to be brought online this month," notes Doug Jackson, AGL's executive general manager Group Operations. "Renewable technology like our Broken Hill Solar Plant and its sister plant at Nyngan play an

important part in AGL's transition towards a decarbonized economy. Broken Hill will contribute to the more than 1900MW of renewable capacity AGL currently has in operation or under development," he adds.

"There is a real sense of momentum driving large-scale solar in Australia today," comments ARENA's acting CEO Ian Kay. "The Broken Hill and Nyngan solar plants are already supplying power to Australian homes and we now have \$350m available through ARENA and the Clean Energy Finance Corporation, which will further accelerate growth in the sector."

First Solar has provided engineering, procurement and construction (EPC) services for both the Broken Hill and Nyngan Solar Plants, and will provide maintenance services for five years once operational. These plants are supported by \$166.7m in funding from ARENA and \$64.9m from the New South Wales Government.

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

## Australia's first commercial diesel displacement solar plant starts operation with 18,000 First Solar PV modules

Cadmium telluride (CdTe) thin-film photovoltaic (PV) module maker First Solar Inc of Tempe, AZ, USA, international mining group Rio Tinto and the Australian Renewable Energy Agency (ARENA) have announced that Australia's first commercial diesel displacement solar plant has begun commercial operation at a remote mine. The Weipa Solar Plant will generate electricity for Rio Tinto's Weipa bauxite mine, processing facilities and township on the Western Cape York Peninsula in Queensland.

"This power purchase arrangement [PPA] is an opportunity to trial the introduction of an alternative power source such as a solar plant into a remote electrical network like the one here in Weipa," says Gareth Manderson, Rio Tinto's general manager, Weipa Operations. "At peak output, the 1.7MW capacity solar plant has the capacity to generate sufficient electricity to support up to 20% of the township's daytime electricity demand," he adds. "We expect the energy from the solar plant will help reduce the diesel usage at Weipa's power stations and save up to 600,000 litres of diesel each year. This will reduce Weipa's greenhouse-gas emissions by around 1600 tonnes per year, equivalent to removing around 700 cars."

The solar plant should produce an average of 2800MW-hr of electricity per year. The electricity from the 18,000 First Solar PV modules that have been connected to Rio Tinto's existing mini-grid will be purchased by Rio Tinto under a 15-year power purchase agreement. First Solar's FuelSmart solutions combine PV generation with a fossil fuel engine generator to provide optimal fuel savings while maintaining system reliability.

"It is already widely acknowledged that solar electricity is typically cheaper than diesel-powered electricity, particularly in remote locations," comments Jack Curtis, First Solar's regional manager for Asia Pacific. "The significance of the Weipa Solar Plant is that it provides the opportunity to demonstrate that PV-diesel hybrid projects can also be as reliable as stand-alone diesel-powered generation," he adds.

"In recent years, attention has been focused on the technical challenges of high-penetration PV-diesel hybrids," continues Curtis. "At the Weipa Solar Plant, First Solar is seeking to deliver a reliable electricity supply without diverting capital costs away from Rio Tinto's critical mine operations. Proving this commercial model has the potential to be a watershed

moment for the diesel hybrid application globally," he adds.

"This is the first time a remote Australian mining operation has been supplied with power from solar PV on such a scale," notes ARENA's CEO Ivor Frischknecht. "The success of phase one is set to create a precedent for industry by demonstrating that solar PV is a viable option for powering off-grid locations, like mine sites, in Australia," he adds.

ARENA provided an initial \$3.5m for this early-mover project, and up to \$7.8m is available for the second phase. "Similar ARENA-supported projects now underway, or in the pipeline, will build on this landmark project to further prove the reliability of integrating renewable energy solutions in off-grid locations while helping to drive down costs and the need for subsidy," Frischknecht says.

Contingent on the success of phase one, the project partners have the option of entering into a second phase that would include a storage component. At 6.7MW, the expanded plant could save about 2,300,000 litres of diesel on average per year, reducing Weipa's greenhouse-gas emissions by around 6100 tonnes per year.

[www.arena.gov.au](http://www.arena.gov.au)  
[www.firstsolar.com](http://www.firstsolar.com)

## First Solar and Indiana Michigan Power break ground on project

First Solar has joined Indiana Michigan Power (I&M) at a groundbreaking ceremony for the Twin Branch Solar Facility in Mishawaka, Indiana. The 2.6MW project is the first of three that First Solar is building for I&M, an operating unit of regional power utility American Electric Power (AEP) of Columbus, OH (one of the largest vertically integrated electric utility companies in the USA). The three projects are expected to be in full commercial operation by the end of 2016, and

will be connected to I&M's existing distribution system.

"AEP is aggressively developing a fleet of renewable energy generation facilities in the region, and their commitment to solar power as a cornerstone of that renewable portfolio is at the forefront of a national trend," says Eran Mahrer, First Solar's senior director of business development — Utilities. Twin Branch's site — about 19 acres in the heart of an industrial park — shows how utility-scale solar can

be integrated into an urban commercial setting.

First Solar will be working with strategic partner GEM Energy of Walbridge, OH, as the engineering, procurement & construction (EPC) contractor for Twin Branch. When commissioned, the power plant will generate enough energy annually to power the equivalent of 350 homes. I&M will own and operate the plant, supported by system monitoring software from First Solar subsidiary skytron energy GmbH.

## First Solar to supply modules to Clean Energy Collective for roofless community solar projects

First Solar Inc of Tempe, AZ, USA, which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services, has executed a module supply agreement (MSA) that facilitates the procurement of modules and other equipment by Clean Energy Collective LLC (CEC) for its growing project pipeline in what is said to be one of the fastest-expanding segments of the solar market. The two firms established a strategic partnership late last year to develop and market community solar offerings to residential customers and businesses directly on behalf of partner utilities.

A solar tech start-up in 2009, CEC claims to have pioneered the model of delivering clean power generation through medium-scale solar PV facilities accessible to all utility customers. Since establishing the first community-owned solar array in the USA in 2010 near El Jebel, Colorado, CEC has built or has under development more than 100 roofless community solar projects with 25 utility partners across 11 states, representing more than 130MW of community solar capacity.

The first four projects to utilize the new MSA are said to demonstrate the variety of benefits available to local communities, as well as versatility in applications of the core technology used for large-scale community solar generation facilities. The portfolio also shows how First

Solar and CEC can meet the unique needs of different types of utilities — investor-owned, public power, and rural electric cooperatives.

A facility serving customers of Black Hills Energy in Pueblo, Colorado, will allow individuals to own portions of a fixed-tilt array using First Solar modules and equipment, all developed and administered by CEC. Owners of solar panels will receive direct credit on their Black Hills Energy electric bill for the power produced. A portion of the power produced will also be made available to low-income residents within Black Hills Energy's service territory. The project is the first 'roofless' community solar park in Pueblo and the surrounding area.

In another first, a community solar project in San Antonio, Texas, using First Solar modules mounted on a single-axis tracking system, developed and administered by CEC, will provide customers of CPS Energy with the opportunity to own local, clean energy generation via a CEC-managed program designed to make solar power more affordable and accessible to residential and commercial customers.

A project with the non-profit NEC Retail (Nueces Electric Cooperative) in Corpus Christi, Texas, will bring community-shared solar to south Texas and will be the first large-scale solar garden in a deregulated market. As a non-profit rural electric cooperative, NEC Retail can serve any consumers in Texas that

have the ability to choose their electric provider, who can purchase solar modules in the 800kW single-axis tracker array to offset their electric usage charges.

First Solar modules using a special anti-reflective coating (ARC) will be used at a project for Holy Cross Energy in Rifle, Colorado, along with balance of system components from other suppliers. This is the fourth community solar project CEC has worked on with Holy Cross Energy.

First Solar says that, combined, these four projects introduce the concept of community solar to nearly 1 million potential residential users, many of whom would not be able to install solar on their own homes.

"Roofless solar allows the greatest number of consumers to participate in and enjoy the benefits of locally produced clean power," says CEC's founder & CEO Paul Spencer. First Solar technology "allows us to provide the most competitive pricing and greatest value to utilities and their customers," he adds.

"The community solar market promises significant growth, and CEC is clearly well-positioned to lead in this space," comments Eran Mahrer, senior director of business development — Utilities for First Solar.

"First Solar's module supply agreement is a tangible demonstration of our ongoing commitment to this strategic partnership."

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

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

## First Solar Japan receives construction loan facility from Mizuho Bank to develop utility-scale solar plants

Mizuho Bank Ltd has extended a low-interest construction loan facility of up to \$33m (4bn yen) in Japan to First Solar Japan GK to develop utility-scale solar power plants. The financing will be available for funding construction of qualified projects in First Solar's development

pipeline in Japan. First Solar will engage with Japanese companies to construct the projects.

"The loan facility offering for PV utility-scale solar projects will further enhance Japan's ongoing efforts to reduce its dependency on imported fossil fuels," says Jack Curtis,

First Solar's regional manager for Asia Pacific. "Mizuho Bank Ltd's support for First Solar's project development is expected to encourage further participation with more private investments in the PV utility-scale solar sector in Japan."

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

## Solar Frontier supplies additional CIS modules to Dutch distributor Home-NRG to meet demand in Netherlands

Munich-based Solar Frontier Europe, a subsidiary of Tokyo-based Solar Frontier — the largest manufacturer of copper indium selenium (CIS) thin-film photovoltaic (PV) solar modules — is supplying additional CIS PowerModules to Home-NRG of Twente, The Netherlands (a subsidiary of Ootmarsum-based medium-size installation business Agro-NRG) to help it meet strong demand in the country.

Solar Frontier has already delivered 8MW to the Dutch distributor for 92 different projects this year, ranging from 10kWp to 150kWp in size. It is now providing Home-NRG with an additional 2MW, bringing total shipments in 2015 to 10MW.

Home-NRG (an authorized Solar Frontier distributor since October 2013) is an established provider of



**Home-NRG's general manager Robert ter Horst and Solar Frontier's head of module & standard systems sales Thomas Haering close the 8MW supply agreement in early 2015.**

small residential and commercial PV solutions in The Netherlands. The firm has a large, nationwide installer network, enabling it to execute PV projects quickly and broadly. Additionally, Home-NRG uses its own test sites with data monitoring systems, enabling it to compare different PV technologies under identical conditions.

"Based on this year's experiences, we are confident that we will be able to install even more CIS solutions in the Netherlands in 2016," says Home-NRG's general manager Robert ter Horst.

[www.solar-frontier.com](http://www.solar-frontier.com)

## Solar Frontier's CIS modules chosen for 14MW module supply agreement in midwestern US

Solar Frontier is supplying its CIS PV modules for two projects (each 7MW) being constructed near Indianapolis, IN, USA. (for completion by the end of 2015).

Solar Frontier signed the module supply agreement with a California-based solar developer, investor and long-term owner of solar energy facilities. The projects will be constructed by Vaughn Industries LLC of

Carey, OH, a full-service electrical/mechanical specialty contractor in business for over 50 years.

At the end of August, after signing a module supply agreement with a California-based solar equipment supplier and initiating the first of a series of shipments, Solar Frontier said it is supplying its CIS solar modules for a 26MW project near Raleigh, NC, USA that is also being

constructed by Vaughn Industries. "Solar Frontier is pleased to add this project to our growing footprint in the Americas and, as we expand our presence in the market, to add Vaughn Industries to our expanding network of trusted national construction leaders," commented Solar Frontier Americas' chief operating officer Charles Pimentel.

<http://vaughnindustries.com>

## Solar Frontier sells 15MW project from US development pipeline

Solar Frontier has sold a 15MW project to Southern Power and Turner Renewable Energy. Southern Power is a subsidiary of energy supplier Southern Company and Turner Renewable Energy invests in renewable energy projects in the USA. "Southern Company is a leader in renewable energy development and we are pleased a company of its stature is purchasing Solar Frontier's project."

Sited in Kern County, California,

and part of Solar Frontier's 280MW US solar project development pipeline, the Morelos del Sol project is expected to be built using about 111,744 CIS modules mounted on single-axis trackers.

Project developer Solar Frontier Americas Development LLC, a division of Solar Frontier Americas, consists of a development team with offices in San Francisco, California and Reno, Nevada. They initiated construction on the Morelos

del Sol project in July. Commercial operation is expected in late November. The firm currently has nine PV projects in various stages of development.

"This acquisition fits Southern Power's business strategy of growing the wholesale business by acquiring generating assets and building new units in targeted markets," says Southern Power's president & CEO Oscar C. Harper.

[www.solar-frontier.com](http://www.solar-frontier.com)

# Helmholtz-Zentrum Berlin boosts ultrathin CIGS solar cell efficiency using nanoparticle array

## Dielectric nanoparticle array imprinted between back contact and active layer, supplemented by anti-reflective nanoparticles at front

CIGSe solar cells (made of a thin chalcopyrite layer consisting of copper, indium, gallium and selenium) can reach high efficiencies but, since indium is becoming scarce and expensive, there is an aim to reduce the active CIGSe layer, which strongly decreases the efficiency. Now, Helmholtz-Zentrum Berlin has produced high-quality ultrathin CIGSe layers and increased their efficiency by incorporating an array of nanoparticles between the back contact and the active layer.

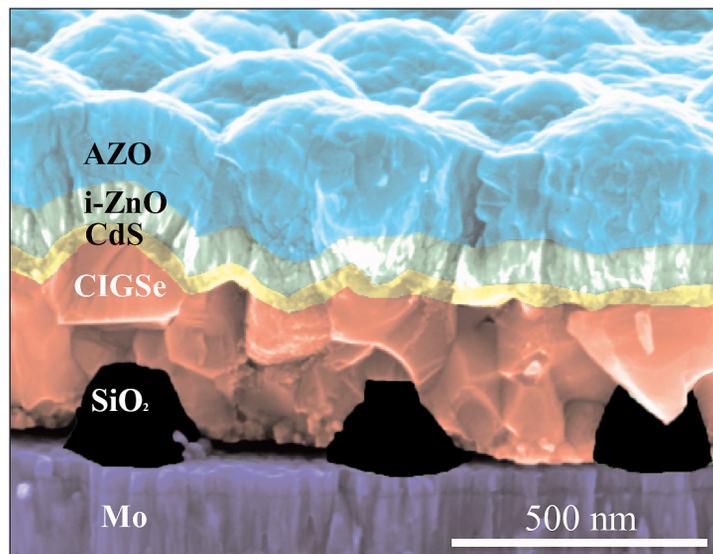
Nanoparticles with sizes the order of a wavelength interact with light in specific ways. A group at Helmholtz-Zentrum Berlin led by professor Martina Schmid is investigating how to use arrangements of such nanoparticles to improve solar cells and other optoelectronic devices. The team has now reported success with ultrathin CIGSe solar cells (M.-C. van Lare et al, 'Light coupling and trapping in ultra-thin Cu(In,Ga)Se<sub>2</sub> solar cells using dielectric scattering patterns', ACS Nano; DOI: 10.1021/acsnano.5b04091).

### Problems add up below 1µm

CIGSe solar cells have proven high efficiencies and are established thin film devices with active layers a few microns thick. But, since indium is a rare element, the active layer should be as thin as possible. This reduces the efficiency, since less light is absorbed. Also, if the active layer is thinner than 1µm, an additional problem arises: more charge carriers meet and recombine at the back contact, getting 'lost'.

### Ultrathin CIGSe cell with efficiencies of 11.1%

"It took me more than one year to be able to produce ultrathin layers of only 0.46µm (460nm) which still reach reasonable efficiencies up to 11.1%," says co-author Guanchao Yin about his PhD project. He then



**SiO<sub>2</sub> nanoparticles (black) have been imprinted directly on the molybdenum substrate (purple) which corresponds to the back contact of the solar cell. On top of this structured substrate the ultrathin CIGSe layer (red) was grown at HZB, followed by all other layers and contacts. Since all layers are extremely thin, even the top layer shows deformations according to the pattern of the nanoparticles. Credit: G.Yin/HZB.**

started to enquire how to implement nanoparticles between different layers of the solar cell. His supervisor Schmid discussed this with professor Albert Polman (a pioneer in nanophotonic) of the Center for Nanooptics (FOM Institute AMOLF) in Amsterdam. They proposed to produce arrays of dielectric nanoparticles by nano-imprinting technologies.

### No big effect with nanoparticles on top

In a first step, the colleagues in Amsterdam implemented a pattern of dielectric TiO<sub>2</sub> nanoparticles on top of Yin's ultrathin solar cells; the idea was that they would act as light traps and increase absorption in the CIGSe layer. However, this did not increase the efficiency as much as proved in silicon-based solar cells. Yin then continued testing and ultimately found out what worked best: a nanoparticle array not on top but at the back contact of the cell.

### Nanoparticles at back contact: efficiency rises to 12.3%

The colleagues in Amsterdam produced an array of SiO<sub>2</sub> nanoparticles, directly on the molybdenum substrate, which corresponds to the back contact of the solar cell. On top of this structured substrate the ultrathin CIGSe layer was grown by

Yin, followed subsequently all the other layers and contacts needed for the solar cell. With this configuration, efficiency

increased from 11.1% to 12.3%, and the short-circuit current density of the ultrathin CIGSe cells rose by over 2mA/cm<sup>2</sup>. With additional anti-reflective nanoparticles, at the front efficiencies raised even to 13.1%.

### Light trapping and prevention of charge carrier loss

"This leads to efficient light trapping and does not deteriorate the cell," Yin explains. Further studies indicate that the nanoarray of dielectric SiO<sub>2</sub> nanoparticles at the back side could also increase efficiency by reducing chances for charge carrier recombination. "This work is just a start, we have now new ideas for further designs to enhance absorption and reduce recombination, thus increasing efficiencies by making use of optical and electrical benefits of the nanoparticles," Schmid says.

<http://pubs.acs.org/doi/abs/10.1021/acsnano.5b04091>  
[www.helmholtz-berlin.de](http://www.helmholtz-berlin.de)

# CNBM breaks ground for largest CIGS solar module production plant in China

## Avancis providing CIGS technology for 1.5GW factory

CNBM (China National Building Materials Group Corp) — the parent company of copper indium gallium diselenide (CIGS) thin-film photovoltaic module maker Avancis GmbH of Torgau, Germany — has celebrated the groundbreaking for one of the largest solar module production lines in China. With the gradual installation leading to an annual capacity of 1.5GW covering a total area of 270,000m<sup>2</sup>, what is reckoned to be the largest solar production plant for CIGS modules will be built in Bengbu, Anhui Province. The CIGS technology for these production sites will be supplied by Avancis.

Founded in 1984, CNBM is China's largest building materials group, with 180,000 staff and a turnover of €58.6bn in 2014. In 2012 it acquired Germany's CTFSolar GmbH, which provides production equipment and plant for manufacturing cadmium telluride (CdTe) thin-film photovoltaic modules. CNBM is now one of the largest manufacturers of highly transparent front glass for solar modules.



**CNBM's groundbreaking in Bengbu.**

The firm is also active in the acquisition, planning and construction of large PV installations via its engineering and project development subsidiary CTIEC. The Chinese government is currently pursuing a program for the development of solar energy, and CNBM aims to play a key role via its acquisition of Avancis in September 2014.

For the Bengbu project, CTIEC, the Bengbu Investment Group and the Bengbu Gaoxin Investment Group plan to invest a total of €1.43bn.

As a manufacturer of CIGS modules, Avancis will provide the technology for the first 300MW production site with a total floor space of 55,000m<sup>2</sup>. The start of production is planned for the 2017.

"In addition to the basic cost benefits of a fully integrated thin-film production, this expansion also enables us to take

advantage of volume effects for further cost reductions," says Avancis' CEO Dr Franz Karg. "With this giant solar project, we also use the unique opportunity to produce and market our thin-film technology locally in the center of the world's largest photovoltaic market," he adds.

Avancis' existing production line in Germany will be continuously expanded in order to serve the European market, as previously planned.

[www.avancis.de](http://www.avancis.de)

# Stion's frameless CIGS PV modules installed at San Francisco Airport

Stion Energy Services, the project development arm of Stion Corp of San Jose, CA, USA, has completed the installation and commissioning of a 172kW commercial rooftop solar array on the 78,000ft<sup>2</sup> West Field Cargo Building, which is the newest commercial building at San Francisco International Airport (SFO). The array is expected to generate 281,128kWh of energy annually and enable LEED (Leadership in Energy and Environmental Design) Gold Certification for SFO's West Field Cargo Building. Stion Energy Services completes solar installation at SFO airport.

Stion Energy Services says that its turn-key solar solution was selected by Hensel Phelps Construction Co through a competitive bid process, in which it was able to demonstrate the overall best value for the project through a combination of offering the highest level of energy production at the most competitive cost.

The West Field Cargo Building did not have a roof facing 180° due south, but Stion says that its CIGS (copper indium gallium selenium) technology generates ample electricity even when the sun's rays do not hit the panel at an ideal perpendicular angle (one of the rea-

sons why its solar system was selected for the project). Stion also utilized a Sollega ballasted roof mount in conjunction with Advanced Energy string inverters.

"We expect SFO to see an attractive return on investment over the lifetime of the solar project," says Stion Energy Services' CEO Jeffery Cheng. "Whereas traditional silicon panels generally incur higher degradation levels that quickly reduce power output, the lower degradation factor of the Stion solution will keep production levels more constant over the lifetime of the system," he adds.

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

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# Transverse-coupled-cavity VCSEL with 30GHz bandwidth at 850nm

Researchers claim record direct modulation bandwidth.

Researchers at Tokyo Institute of Technology in Japan and King Abdulaziz University in Saudi Arabia claim record modulation band-width of 30GHz from an 850nm vertical-cavity surface-emitting laser (VCSEL) with monolithic integration of a transverse-coupled cavity [Xiaodong Gu et al, Appl. Phys. Express, vol8, p082702, 2015].

"The proposed device also shows its great advantage in operating with ultra-low power consumption because of its small bias current and low voltage swing of 500mV<sub>pp</sub>," the

researchers comment. "It is especially important for use in data-centers and supercomputers, where 850nm VCSELs are the core component with a huge volume."

The 850nm VCSEL epitaxial material was grown using metal-organic chemical vapor deposition (MOCVD). The VCSEL and cavity (Figure 1) were formed as a paddle-shaped mesa, described as 'battledore-shaped' in the paper. [I was rather unfamiliar with the term 'battledore', but an internet search turned up [https://en.wikipedia.org/wiki/Battledore\\_and\\_shuttlecock](https://en.wikipedia.org/wiki/Battledore_and_shuttlecock) and, perhaps more relevant given the Japanese origin of most of the authors, <https://en.wikipedia.org/wiki/Hanetsuki>.]

Electrical isolation between the VCSEL and cavity was achieved by a proton implant of a 3µm- or 5µm-wide region through the top distributed Bragg reflector (DBR). Wet oxidation formed the current aperture, which was also 'battledore-shaped'. The VCSEL area of 10µm x 14µm was connected with the 20µm x 24µm cavity. The

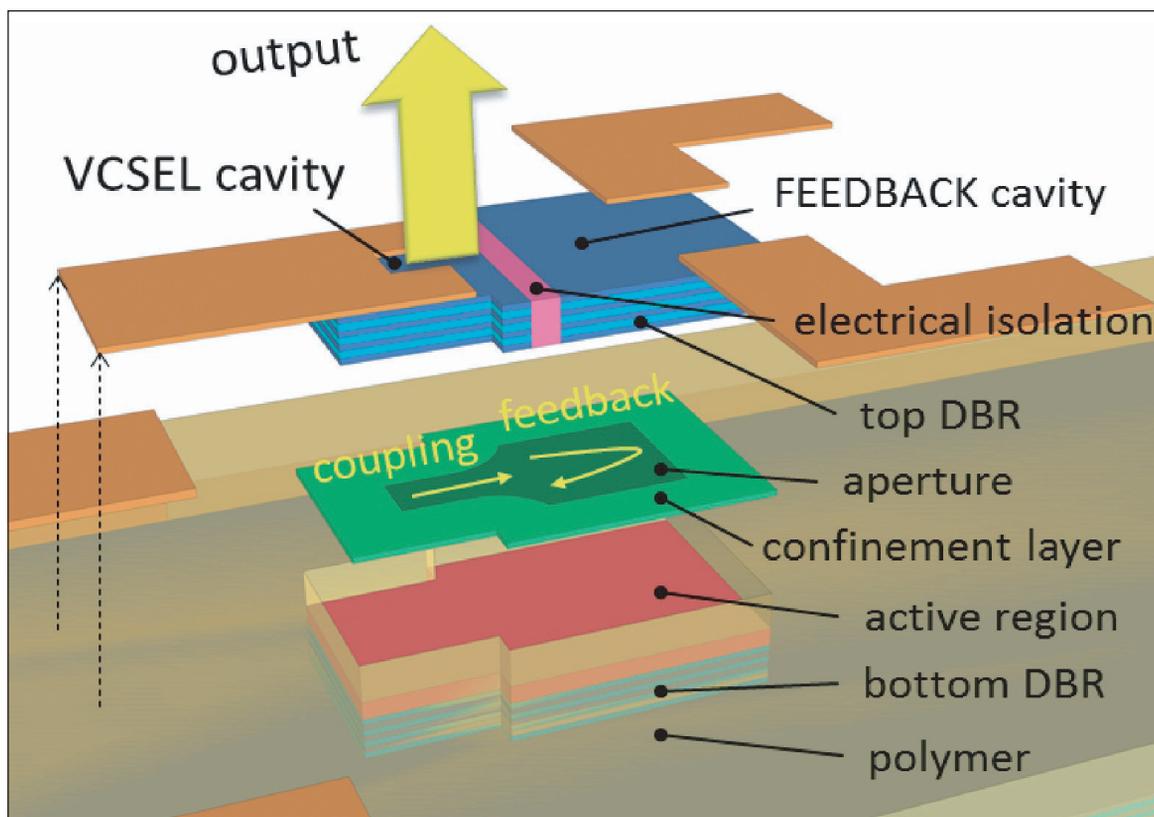


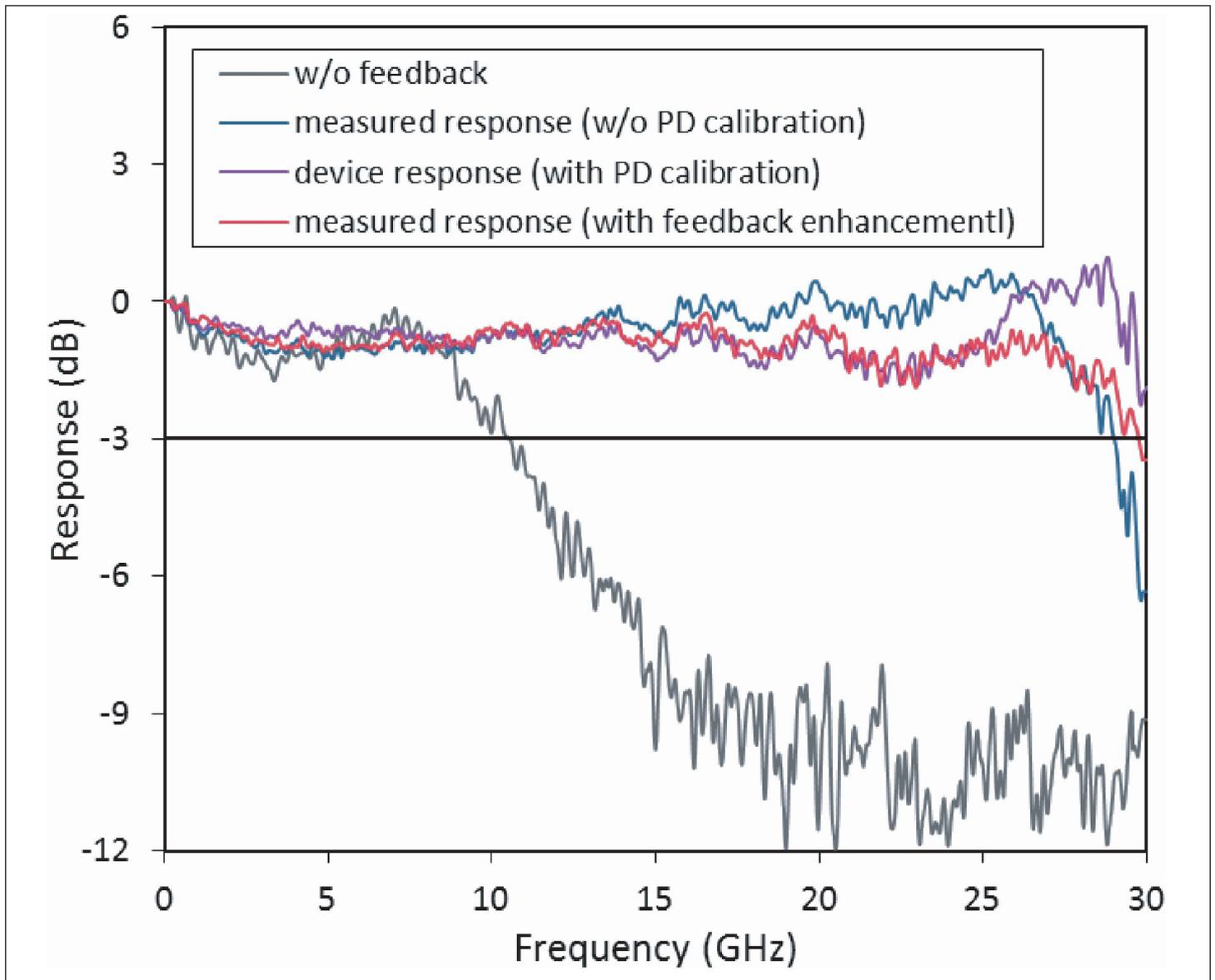
Figure 1. Schematic view of 850nm-band transverse-cavity surface-emitting laser.

oxidation distance was 5µm from the sidewall. The tapered aperture width change between the cavity and VCSEL aimed to enhance lateral coupling of the optical modes. These small dimensions suggest the practicality of high-density integration.

The researchers explain: "The reason is that the cutoff wavelength of the VCSEL side will be red-shifted by the heat, which keeps the light from coupling to the feedback cavity. The length of the feedback cavity is critical for selecting a suitable mode for bandwidth enhancement."

The modulation of the VCSEL was through a direct 40GHz radio frequency probe attached to the ground-signal-ground electrodes.

The researchers claim a record 3dB bandwidth of more than 30GHz with 4.3mA injected into the VCSEL with 5µm-wide proton implant for electrical isolation (Figure 2). The bandwidth was also 3x that for a device without feedback. By injecting 0.3mA into the cavity to



**Figure 2. Small-signal frequency responses of the device for different cases. Feedback is enhanced by injecting a 0.3mA current to the feedback cavity.**

enhance the feedback, the bandwidth was 30GHz, even without calibrating the measuring photodetector's response.

The researchers write: "This means that an enhancement in the response at high frequency compensates well for the drop in detector response. This optical equalization ability demonstrates our device's dynamic adjustability, which enables it to perform in the best condition for a given system."

In addition, recent modeling by the researchers suggests that an even higher bandwidth of more than 50GHz could be obtained by increasing the coupling strength.

At the non-standard 980nm wavelength band, a bandwidth of more than 29GHz has been achieved with a transverse-coupled-cavity VCSEL and 37GHz with single-mode coherent twin VCSELs with resonance tuning. Apart from the non-standard wavelength, these devices required precise fabrication processes, making uniform performance difficult to achieve in

mass production.

Eye-diagrams produced in large-signal modulation on the team's 850nm VCSELs with non-return-to-zero pseudo-binary sequences with 500mV peak-to-peak swing were 'open' from 30Gb/s up to 40Gb/s, indicating acceptable performance. At the higher bit-rates, some noise was seen that prevented clear opening of the diagrams. The researchers comment: "We think part of the noise came from the unstable mode, resulting in fluctuations of the light collected in a multi-mode fiber. Better mode stabilization is necessary for clear eye opening at higher bit-rates."

The researchers believe that stabilizing the coupled mode will lead to higher bit-rate modulation. The IBM Thomas J. Watson Research Center has recently achieved 71Gb/s error-free operation for an 850nm VCSEL-based optical link. ■

<http://dx.doi.org/10.7567/APEX.8.082702>

Author: Mike Cooke

# Auger recombination the primary cause of efficiency droop, say simulations

**Electron leakage cannot explain the thermal degradation of LED performance at high temperature, according to researcher.**

**J**oachim Piprek, founder & president of NUSOD Institute LLC in the USA, has run simulations that he believes eliminate electron leakage as the primary cause of efficiency droop at high current in blue light-emitting diodes (LEDs) [Appl. Phys. Lett., vol107, p031101, 2015]. In particular, Piprek suggests that electron leakage cannot explain the thermal degradation of LED performance at high temperature.

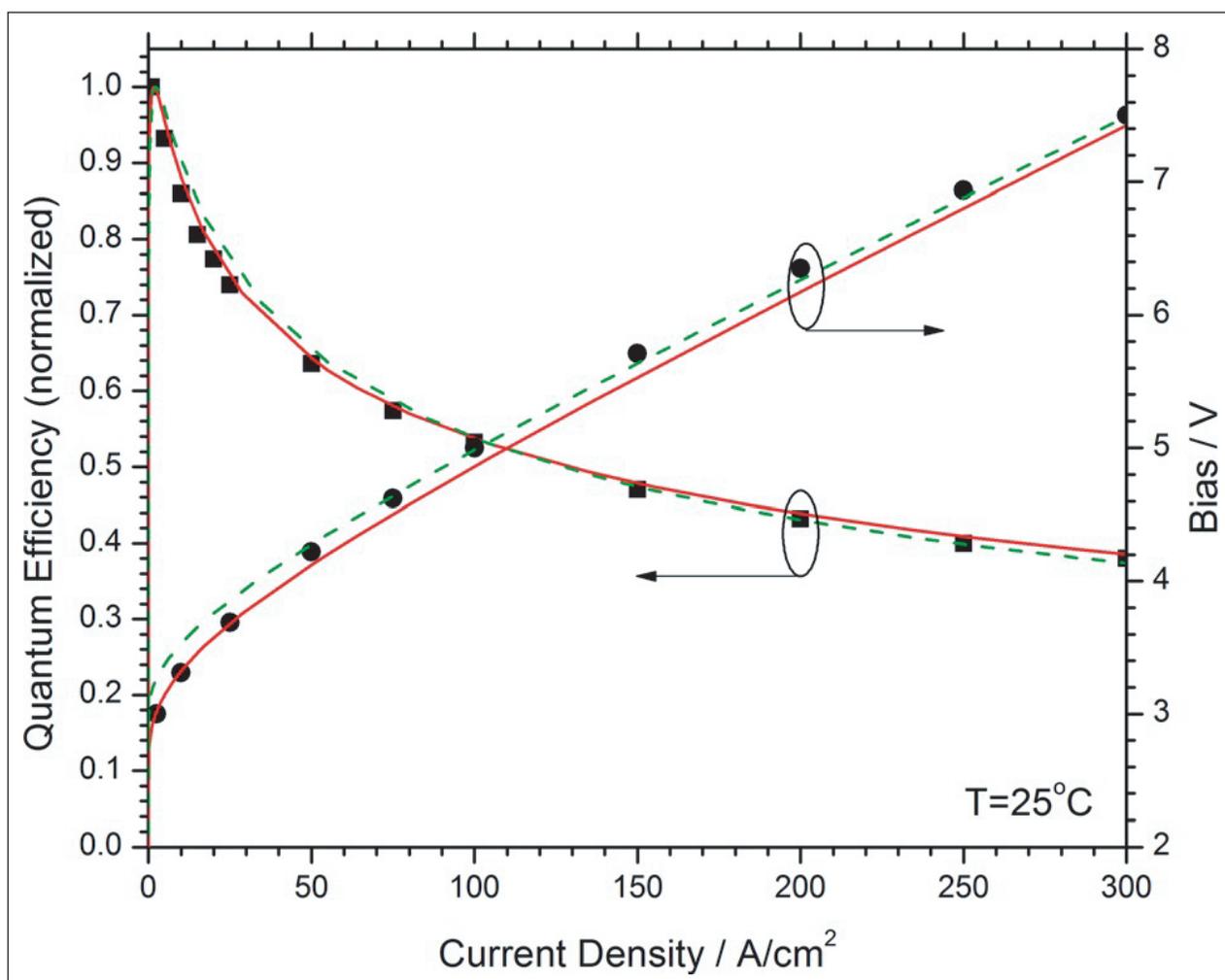
Piprek constructed two models based on different assumptions concerning the source of efficiency droop under pulsed

measurements that avoid self-heating effects. The models are differentiated by the values of the Auger recombination coefficient and acceptor level in an aluminium gallium nitride (AlGaIn) electron-blocking layer (EBL).

The Auger recombination coefficient reflects enhanced non-radiative recombination at high carrier densities in the indium gallium nitride (InGaIn) multiple quantum well

(MQW) active region of blue LEDs. This coefficient is much disputed, since simple microscopic models predict a value too low to account for efficiency droop. The simple models consist of the energy of recombination being transferred to another carrier. Various mechanisms have been suggested that could boost such non-radiative recombination.

Piprek comments; "The surprisingly strong Auger recombination in InGaIn quantum wells is still not fully understood and further investigations are needed to



**Figure 1. Normalized quantum efficiency and bias versus current density at room temperature (symbols — measurement, solid lines — simulation favoring Auger recombination, dashed lines — simulation favoring electron leakage).**

clarify its influence. Recent simulations of compositional quantum-well fluctuations indicate Auger recombination enhancements by local carrier accumulation."

The acceptor level in the EBL alters the electron leakage into the magnesium-doped GaN contact regions. If there is a large density of ionized acceptors, the negative charge compensates positive polarization

charges at the MQW/EBL interface. In reality, the

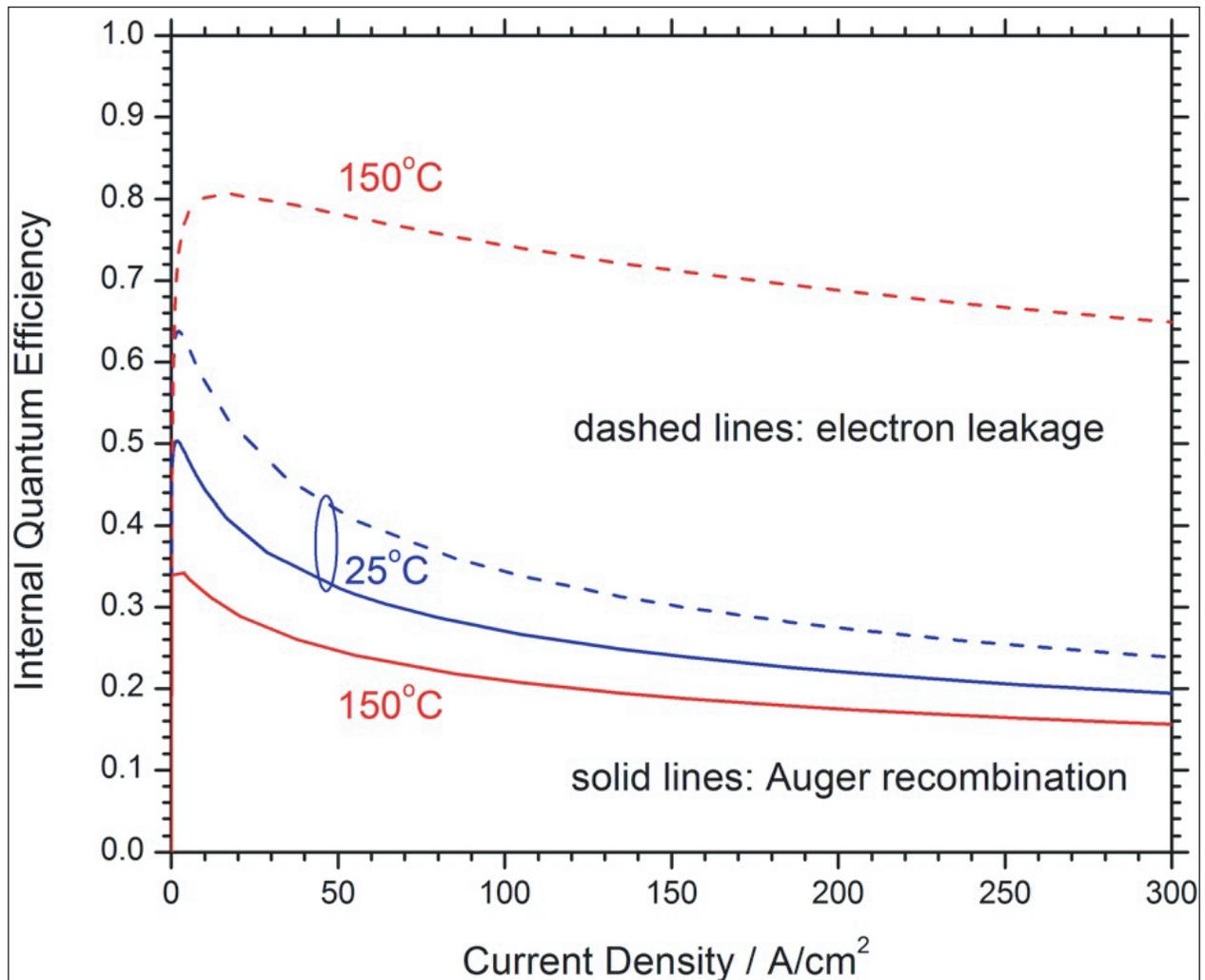
ionization of p-AlGaIn acceptors is low due to a high activation energy of the magnesium atoms. Electrons are accelerated towards the positive polarization charges and injected into the p-GaN cladding, where they recombine non-radiatively with holes.

The simulations were of a 440nm-wavelength device with five 3nm InGaIn wells, p-Al<sub>0.13</sub>Ga<sub>0.87</sub>N EBL, and p-GaN cladding.

One model had a high ionized acceptor level of 10<sup>19</sup>/cm<sup>3</sup> and high Auger coefficient of 5x10<sup>-30</sup>cm<sup>6</sup>/s. The high acceptor level effectively blocked electrons from entering the p-GaN cladding, and the efficiency droop was primarily caused by Auger recombination.

The second model had low ionization of the acceptors (2.6x10<sup>18</sup>/cm<sup>3</sup>) and low Auger recombination (10<sup>-34</sup>cm<sup>6</sup>/s), in line with expectations from simple microscopic considerations. Here, the droop was primarily from electron leakage into the p-GaN region.

Both models were able to simulate room-temperature experiments performed by Rensselaer Polytechnic Institute (RPI) in Troy, NY, USA and South Korea's Samsung Electro-Mechanics (see Figure 1). To disting-



**Figure 2. Internal quantum efficiency versus current density calculated at different ambient temperatures (solid lines — simulation favoring Auger recombination, dashed lines — simulation favoring electron leakage).**

uish between the models, Piprek increased the temperature to 150°C.

The efficiency of the Auger recombination model decreased, but the efficiency of the electron leakage model increased (Figure 2). Since experiment shows reduced efficiency of blue LEDs, Piprek concludes that the Auger recombination model is the primary cause of droop, although other factors, such as electron leakage, could have secondary influences.

Piprek admits that the increase in efficiency at high temperature for the electron leakage model is contrary to common assumptions. The reduced leakage in the model is due to enhanced hole transport emanating from increased acceptor ionization at high temperature.

The self-consistent simulations were based on advanced APSYS software and included a wide range of physical effects. NUSOD Institute LLC runs the annual International Conference on Numerical Simulation of Optoelectronic Devices. ■

<http://dx.doi.org/10.1063/1.4927202>

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

Author: Mike Cooke

# Reducing damage in gallium nitride inductively coupled plasma etch

**Process avoids photoluminescence degradation to within 71nm of multiple quantum well, and enables air-gap cladding alternative in laser diode.**

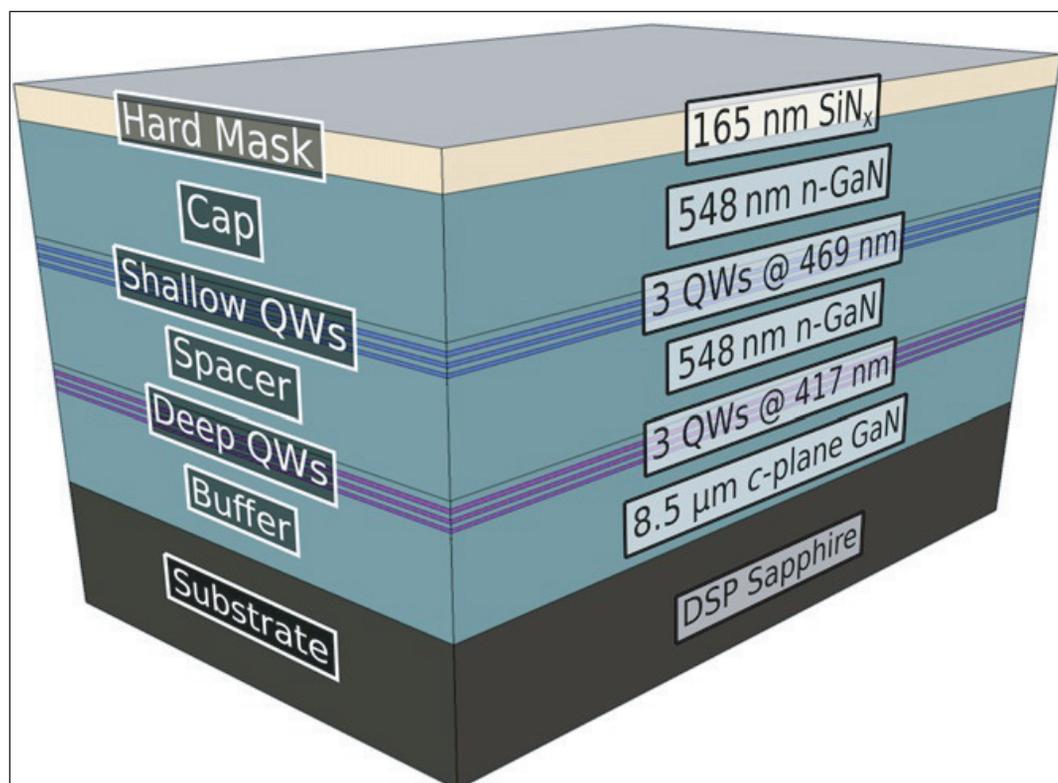
University of California Santa Barbara in the USA and Ecole Polytechnique in France have developed a low-damage dry etch for III-nitride semiconductors that was effective to within 71nm of an active region [Joseph G Nedy et al, *Semicond. Sci. Technol.*, vol30, p085019, 2015]. The process was used on test structures and for creating an air-gap cladding in a laser diode (LD) as an alternative to complex aluminium gallium nitride/gallium nitride (AlGaN/GaN) superlattice (SL) structures.

Dry etching with plasma causes damage with ion bombardment. In many compound semiconductor processes, wet etch is preferred because it causes much less damage. However, for III-nitride semiconductors a simple wet alternative is unavailable.

The test structure comprised two indium gallium nitride (InGaN) multiple quantum well (MQW) regions grown on double-side polished (DSP) c-plane sapphire (Figure 1). Photoluminescence (PL) from the different depth MQWs was used to analyze the damage from the dry etch procedure.

The test wafer was cleaved into 6mmx12mm pieces, and mesa stripes were defined by lithographic patterning on the silicon nitride (SiN<sub>x</sub>) top-layer hard mask. The pattern was transferred to the SiN<sub>x</sub> with inductively coupled plasma (ICP) etch with methane/carbon tetrafluoride. The power was low so that the underlying GaN served as an etch stop.

The GaN etching was performed on a Unaxis VLR high-temperature ICP system. The chamber was cleaned



**Figure 1. Schematic of c-plane epitaxial growth (by MOCVD) with sputtered SiN<sub>x</sub> on top and double-sided polished (DSP) sapphire substrate.**

and seasoned before the samples were etched. Care was taken to avoid etch byproducts from the silicon carrier wafer and edge effects. A pre-treatment consisting of boron trichloride etch was applied before both the seasoning and main GaN etch runs to remove native oxide and for better etch uniformity.

The GaN etch chemistry was chlorine/argon. Low power was used to minimize sub-surface damage. The ICP was generated at 200W and the forward power was 5W. The low pressure of 2mTorr avoided re-deposition of etch products on the sidewalls and to allow high aspect ratios to be achieved in future. The substrate was heated to 200°C. The etch process parameters were at the lower limit before etch rates became unmeasurable. With the given parameters the etch rate was 26nm/minute on c-plane material.

The use of two MQWs for PL creates an in-situ control,

reducing problems from changes in measurement set up and the effects of thinning and surface roughening from the etch. The PL from the deep MQW (417nm) after 500nm etch was a factor of 150% times that of before. The PL from the shallow well (469nm) was therefore normalized according to the change in the PL from the deep well, assuming that it was too far away from the etch to be affected.

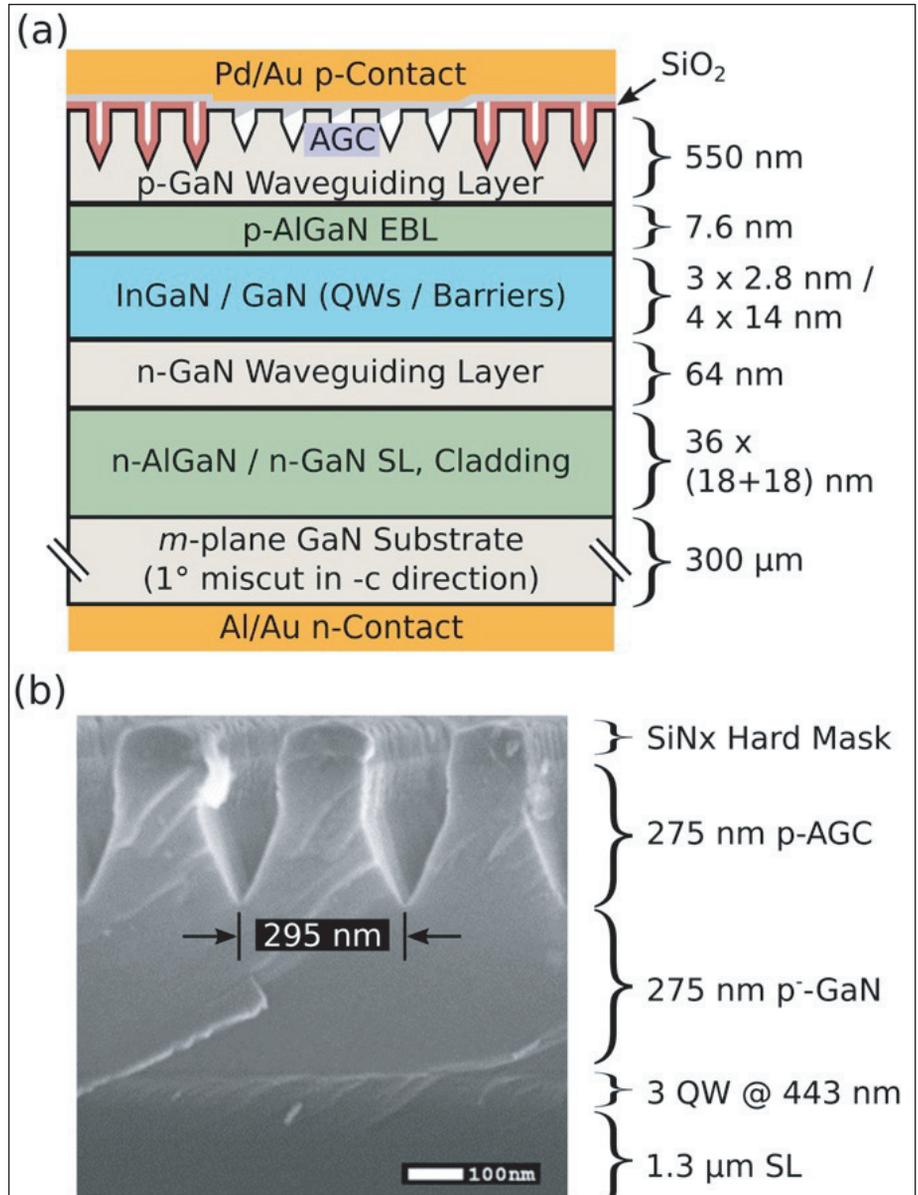
The effect of the etch on the shallow-well PL was found to be negligible to within 71nm of this active region. After that point, the PL from the shallow well reduced to near 0% at 25nm, indicating precipitous deterioration of the MQW quality.

Etching into c-plane is expected to be the most difficult, due to 'channeling effects', where ions penetrate more deeply into a crystal lattice in certain directions. The researchers explain: "The crystallographic direction of ion bombardment leads to a greatly elongated tail of ion penetration along the [0001] direction. The c-plane orientation of GaN has the deepest etch damage penetration depth due to channeling effects and is therefore the worst-case scenario for etch damage in a buried active region."

The etch process was applied to an air-gap-cladding (AGC) laser diode structure on m-plane GaN (Figure 2). The upper 275nm of the p-GaN cladding layer was etched with air gaps to create optical confinement in the MQW active region. Etching was also used to create the laser diode ridges. The dielectric isolation material was silicon dioxide. The top p-contact metal was palladium. The facets were also etched, after lithographic patterning.

Applying the etch to the m-plane of the laser diode material, the researchers noticed that the etch rate increased to 45nm/minute and, unlike the c-plane case, there was no preferential etching of pits associated with dislocations.

The aim of AGC was to reduce the overlap of the laser mode with the absorptive p-GaN layer, giving lower threshold gain and higher differential efficiency. The AGC trenches were 150nm wide with 300nm spacing, parallel to the lasing direction. The etching for the AGC was 275nm away from the active region. The researchers report: "Previous attempts at dry-etched features within 300nm reduced the  $\eta_{IQE}$  and light emission if no subsequent re-growth or anneal was performed. By



**Figure 2. (a) Schematic cross-section of AGC LD design. Lasing direction oriented out of page. (b) SEM micrograph of laser diode ridge cross-section after air-gap dry etch. Air-gap depths outside ridge are 50nm deeper than in ridge.**

employing the low-damage dry etch, the active region of this device was unaffected by etch damage."

Room-temperature lasing was achieved at 443nm wavelength with pulsed operation (0.25μsec, 0.25% duty cycle). A 6μm x 300μm device had a threshold current density of 26kA/cm<sup>2</sup> and differential efficiency from a single facet of 11%. The transition from non-lasing at 90% of threshold was indicated by a narrowing in linewidth from 7.4nm to 2nm above threshold.

In addition to the AGC application, the researchers see potential for the creation of photonic crystals and distributed Bragg reflectors, which could be formed by etching into the top GaN layer to improve LED and laser diode performance. ■

<http://dx.doi.org/10.1088/0268-1242/30/8/085019>

Author: Mike Cooke

# Plasma pre-treatment for gallium nitride chemical mechanical polishing

Surface roughness has been reduced to 1.00nm peak-to-valley and 0.11nm root-mean-square.

**O**saka University in Japan has developed a plasma pre-treatment for chemical mechanical polishing (CMP) on gallium nitride (GaN) that avoids creating enlarged etch pits [Hui Deng et al, Appl. Phys. Lett., vol107, p051602, 2015].

Surface atomic structure, roughness and sub-surface damage can adversely impact electronic performance. CMP is widely used to create atomic-level flatness in microelectronics. However, wide-bandgap materials — such as GaN, diamond, and silicon carbide — tend to be much harder than the mainstream electronic material of silicon for which CMP was developed.

A further problem for GaN CMP is that it is usually grown on foreign substrates such as sapphire, silicon carbide, or silicon. Lattice and thermal expansion mismatching between GaN and the substrate leads to crystal defects. Etching or CMP tends to preferentially remove material around dislocations, giving etch pits. Indeed, the density of etch pits is a common measure of the dislocation density of GaN.

The process was performed on commercial substrates with an 8µm undoped GaN epilayer on 2-inch sapphire.

The CMP was performed with 2000 rotations per minute and 3.74kPa pressure on the suede-type polishing pad from FILWEL Co Ltd (NP178). Two types of commercial slurry were tested — one containing silica (SiO<sub>2</sub>) and the other ceria (CeO<sub>2</sub>).

The plasma for the 30-minute pre-treatment (Figure 1) consisted of carbon tetrafluoride in helium carrier gas at atmospheric pressure. The distance between the plasma generation electrode and the GaN surface was 1.6mm. The electrode was 3mm in diameter.

The action of the 18W 13.56MHz radio-frequency radiation was to dissociate fluorine radicals from the reactive part of the gas. Such radicals are known to react with GaN. X-ray photoelectron spectroscopy (XPS) found that the modified layer consisted of GaF<sub>3</sub>. This layer was about 30nm thick, according to cross-sectional transmission electron microscopy (XTEM).

Without the pre-treatment, the CMP with either slurry resulted in enlarged pits at dislocation sites. The effect was particularly bad for silica slurry.

The researchers only applied ceria slurry in the CMP tests on pre-treated material, since it was found to give

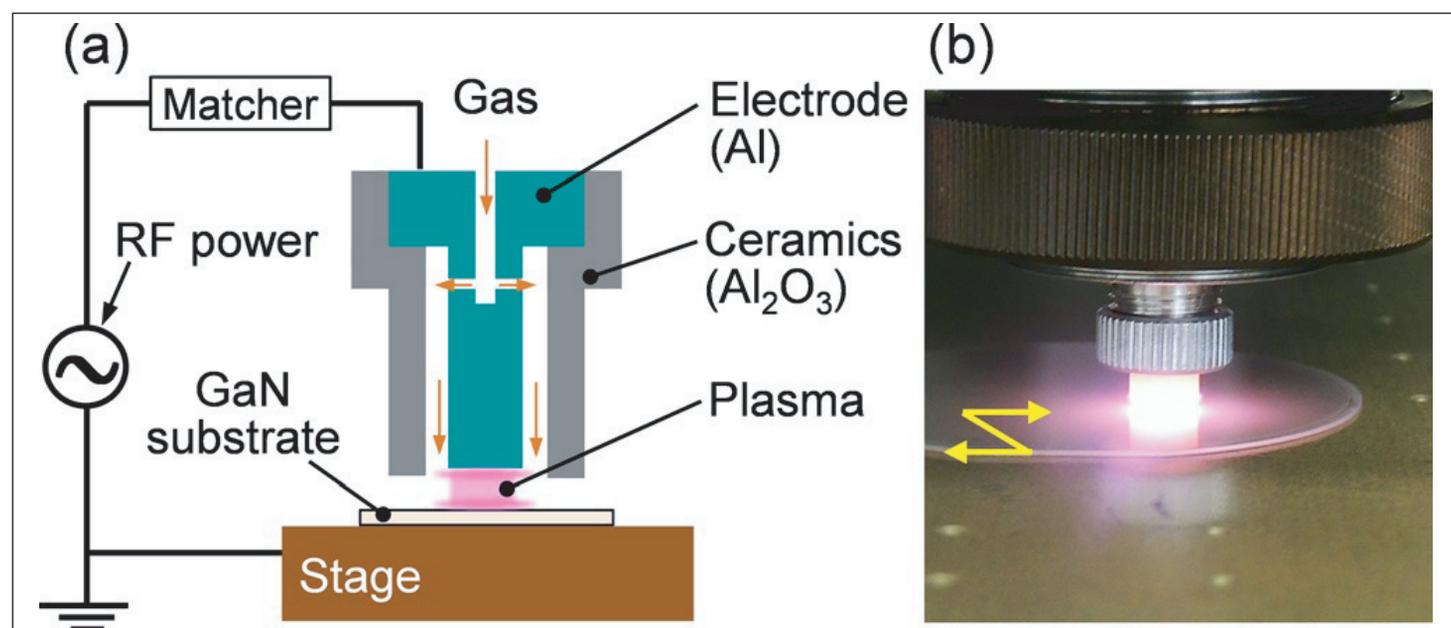


Figure 1. (a) Schematic of experimental setup for plasma irradiation. (b) Image of atmospheric-pressure CF<sub>4</sub> plasma.

better results on untreated GaN. After 8 minutes the protection layer was removed, but no enlarged pits were formed around the dislocations ('just-polished'). Continuing the CMP beyond this ('over-polished') created enlarged pits. Performing CMP for shorter than 8 minutes resulted in some of the GaF<sub>3</sub> protection layer remaining on the substrate ('under-polished').

The 8-minute CMP resulted in peak-to-valley surface roughness of 1.00nm (Figure 2). The root-mean-square roughness was 0.11nm.

The researchers expect high device performance in their future work from the combination of plasma pre-treatment and time-controlled CMP. ■

<http://dx.doi.org/10.1063/1.4928195>

Author: Mike Cooke

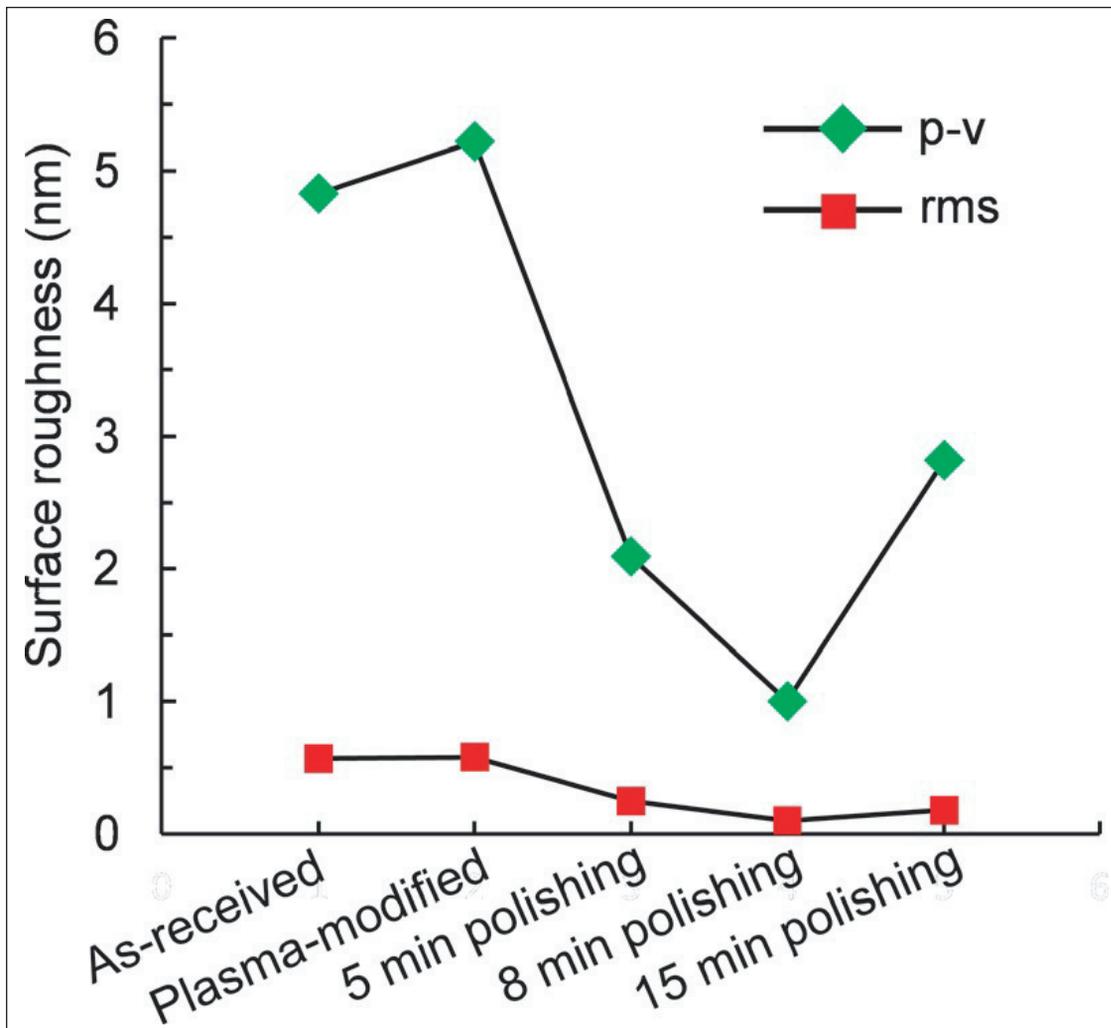


Figure 2. Change in surface roughness of GaN processed by plasma irradiation and CMP.

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# Microwave anneal process for gallium nitride transistors

**On/off current ratios, lower gate leakage, and maximum drain current has been improved compared with rapid thermal annealing.**

**F**udan University in China claims the first reported application of microwave annealing (MWA) to the formation of ohmic source-drain contacts to aluminium gallium nitride/gallium nitride (AlGaN/GaN) high-electron-mobility transistors (HEMTs) [Lin-Qing Zhang et al, IEEE Electron Device Letters, published online 28 July 2015]. The MWA process improved on/off current ratios, lower gate leakage, and maximum drain current, compared with devices fabricated using rapid thermal annealing (RTA).

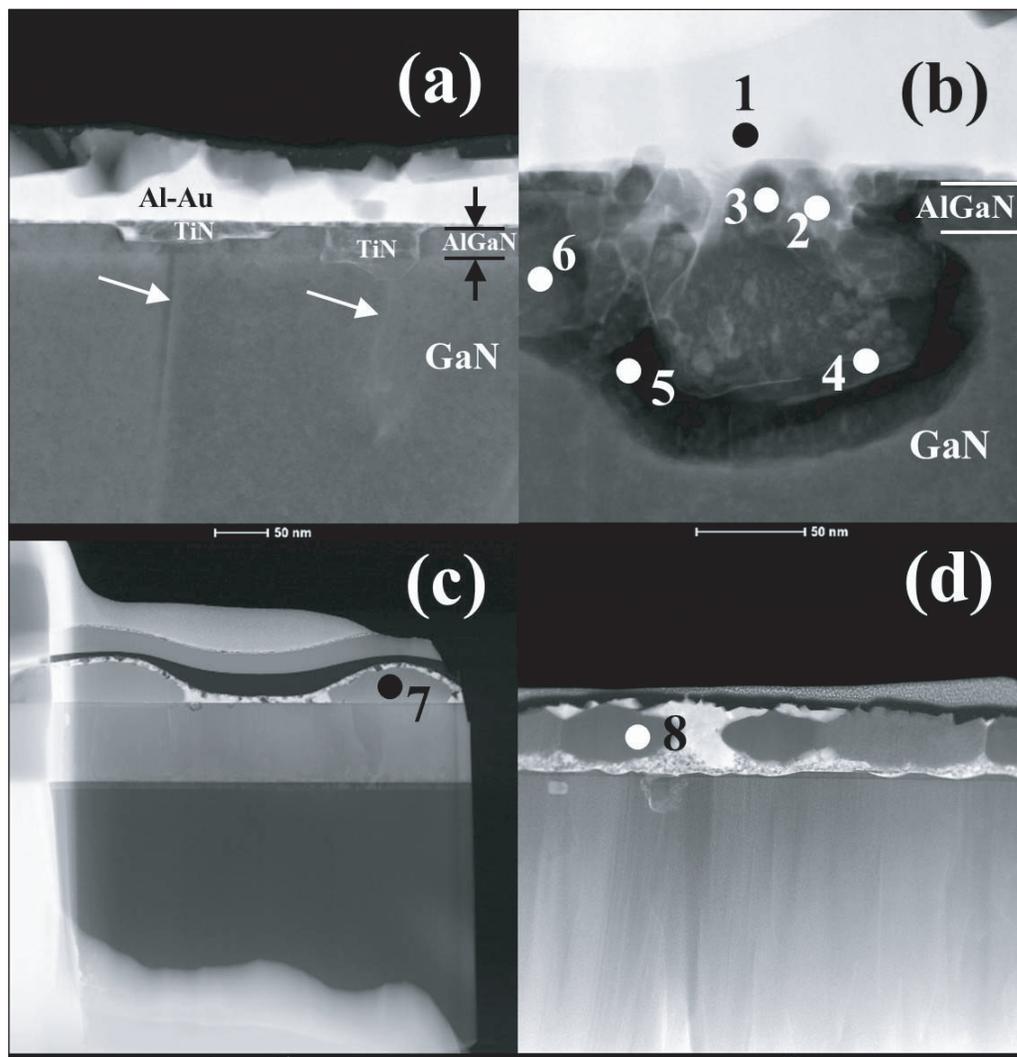
GaN HEMTs are being developed for high-power, high-voltage and high-frequency applications.

The device structure consisted of a silicon substrate, 2.5µm carbon-doped GaN buffer, 500nm intrinsic GaN channel, 1nm AlN interlayer, 23nm undoped Al<sub>0.25</sub>Ga<sub>0.75</sub>N barrier, and 5nm GaN cap. Fabrication began with mesa isolation plasma etch.

A titanium/aluminium/nickel/gold ohmic contact stack was deposited using evaporation and patterned using lift-off lithography. The 5.8GHz MWA was carried out using 4200W power for 20 minutes in nitrogen.

A comparison device was also produced using rapid thermal annealing (RTA) at 840°C for 30 seconds in nitrogen.

The Ohmic contact resistance, as derived from transmission-line method structures, was 0.4Ω-mm for RTA and 0.6Ω-mm for MWA. Before annealing, Hall measurements gave a channel sheet resistance of

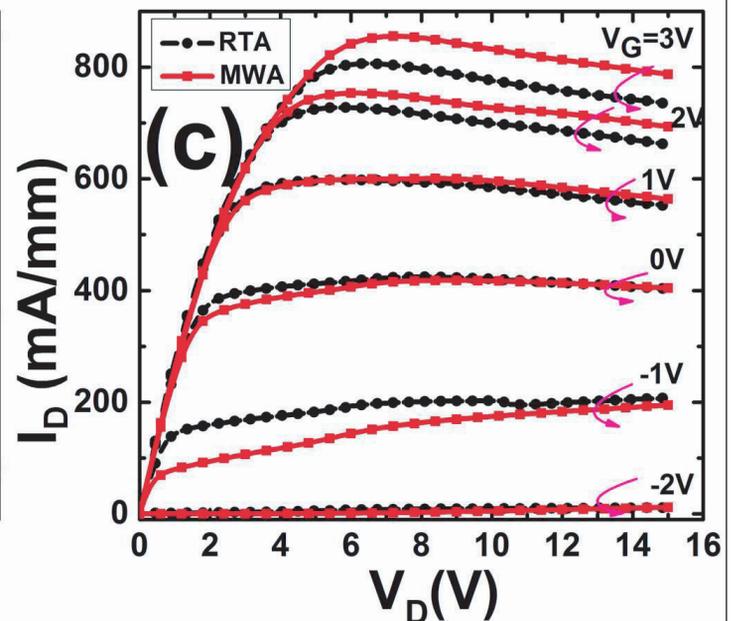
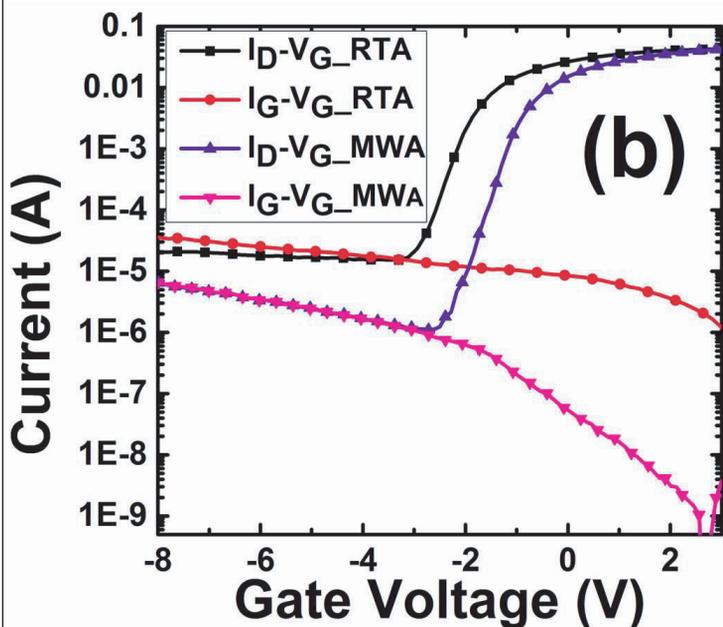
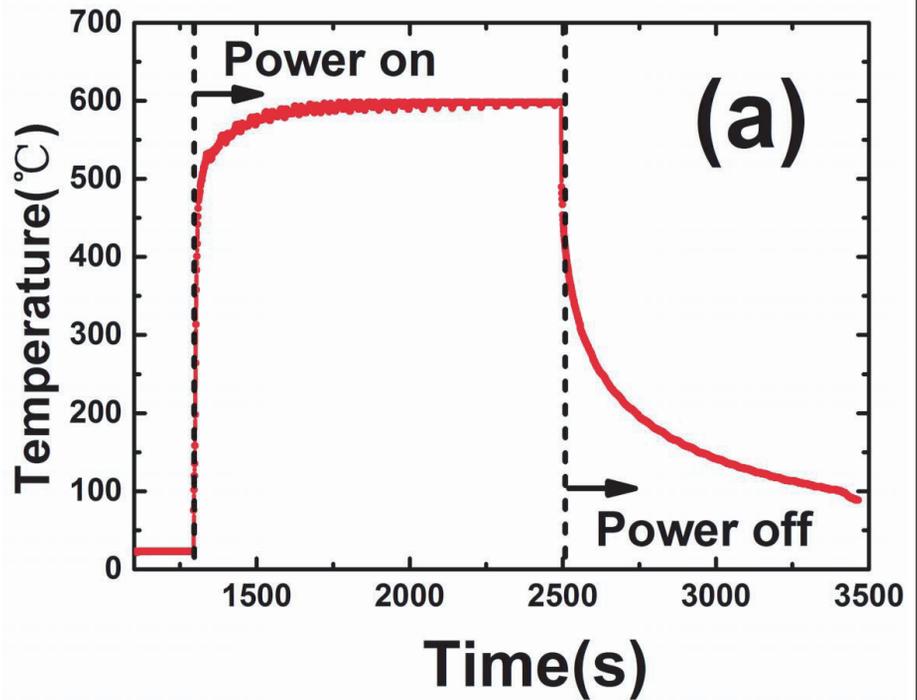


**Figure 1. (a) TEM image of post-annealing structure by MWA where arrow markings indicate dislocations. (b) Magnified image of interface. (c) TEM image of bulge area of alloyed ohmic contact treated by RTA. (d) TEM image of bulge area of alloyed ohmic contact treated by MWA.**

435Ω/square. For RTA, this was increased to 474Ω/square. The MWA process had a smaller increase to 464Ω/square.

Microscopic inspection of the contacts showed a dark bumpy surface for the RTA process, as opposed to a smoother brighter appearance under MWA. The researchers attribute the difference to the lower

Figure 2. (a) Temperature profile of MWA process at 4200W power. (b) Comparison of transfer characteristics of samples treated by MWA and RTA. (c) Output characteristics of samples treated by RTA and MWA.



process temperature of 597.6°C for MWA. Atomic force microscopy (AFM) over a 10 $\mu\text{m}$ ×10 $\mu\text{m}$  area gave a root-mean-square roughness of 63.5nm for MWA contacts and 101nm for RTA.

While RTA heats the surface region, MWA penetrates more deeply into the structure, allowing lower peak temperatures to achieve its effect. High-resolution transmission electron microscopy (HR-TEM) suggests that contact with the GaN channel layer is made through titanium nitride spike protrusions that form along dislocations (Figure 1).

The transistors were completed with a T-shaped nickel/gold gate. The footprint was 100nm with 60 $\mu\text{m}$  gate width. One effect of using MWA is to decrease off-current leakage, improving the on/off current ratio to

4 $\times 10^4$  at 10V drain bias (Figure 2). The on-current was measured at +2V gate potential and the off-current at -2.5V.

The source of off-current leakage was mainly through the gate. The researchers comment: "It is shown that the gate leakage current of MWA-HEMT is significantly lower than that of RTA-HEMT. The suspected cause is that MWA has better ability in repairing defects of AlGaN surface."

The MWA device also had a larger maximum drain current of 850mA/mm, compared with 800mA/mm for RTA. ■

<http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7169554>

Author: Mike Cooke

# Improving aluminium nitride barriers with low-temperature pulsed MOCVD

**Lower growth temperature results in better two-dimensional electron gas at AlN/GaN barrier/buffer interface, promising higher-performance transistors.**

**X**idian University in China has applied pulsed metal-organic chemical vapor deposition (PMOCVD) to improve the quality of aluminium nitride (AlN) barrier layers on gallium nitride (GaN), compared with traditional MOCVD [JunShuai Xue et al, Appl. Phys. Lett., vol107, p043503, 2015]. Although better-quality AlN barriers can be achieved with molecular beam epitaxy (MBE), MOCVD is preferred for manufacturing.

The hope is to increase the carrier density in the two-dimensional electron gas (2DEG) that forms at the interface of AlGaN/GaN structures from the order of  $10^{13}/\text{cm}^2$  to ultimately around  $6.4 \times 10^{13}/\text{cm}^2$  for AlN/GaN.

Such 2DEG regions lie at the heart of most nitride semiconductor transistors being developed for high-voltage, high-power and high-frequency electronics with potential application in power conversion and mobile communication network amplifiers.

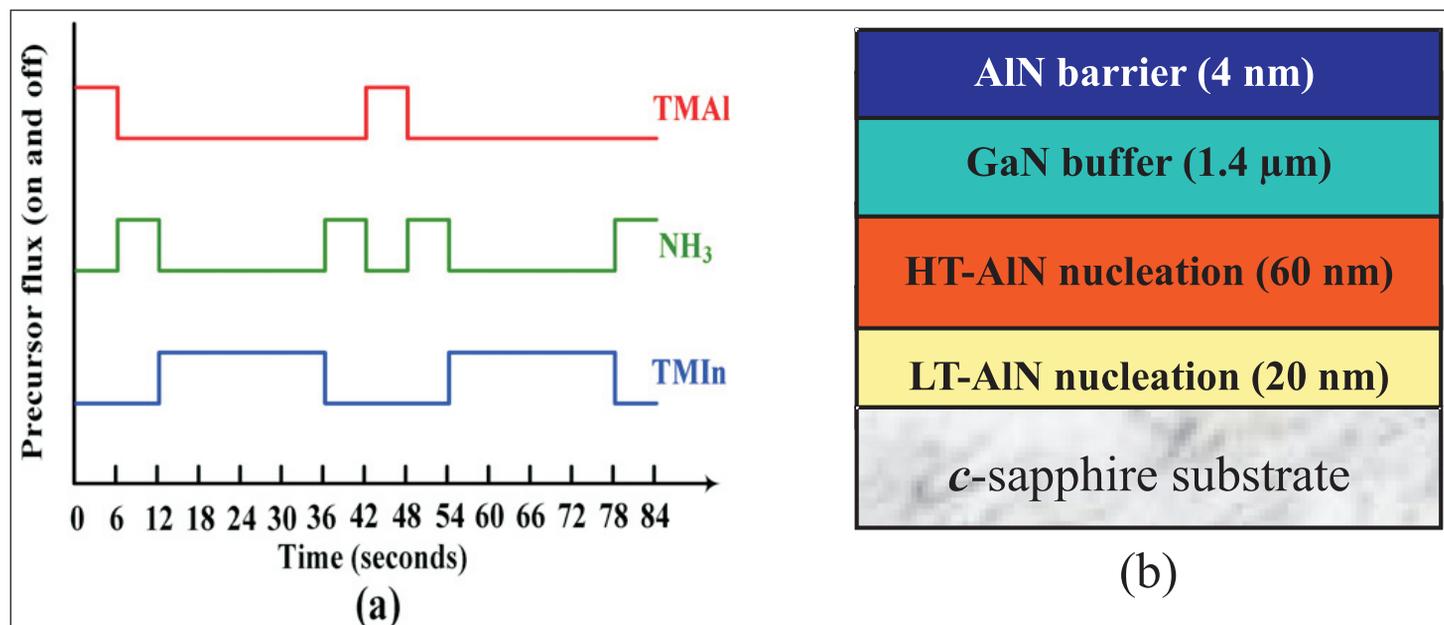
The 2DEG forms as a result of the difference in spontaneous and strain-dependent charge polarization between the barrier and underlying GaN. AlN has the

largest such difference with GaN. But these materials also have a large 2.4% lattice mismatch, which severely limits the thickness and quality of AlN barriers. In some cases, physical cracks become apparent.

The MBE process produces better-quality AlN barriers because it uses a much lower growth temperature than MOCVD. Lower temperature avoids effects from the decomposition of the GaN channel layer, such as roughening of the interface, which impacts the performance of the 2DEG.

Pulsed MOCVD allows the growth temperature of MOCVD to be lowered as a result of enhanced migration of growth precursors. The technique has been applied to indium aluminium nitride (InAlN) growth, resulting in high-performance high-electron-mobility transistors (HEMTs).

The researchers used a homemade close-coupled showerhead MOCVD reactor with quartz chamber and silicon-carbide-coated susceptor. The substrate was 2-inch c-plane sapphire. The group III metal precursors were trimethyl-organics. The nitrogen source was ammonia.



**Figure 1. (a) Schematic diagram of PMOCVD pulse sequence for growth of AlN barrier and (b) schematic cross-section of AlN/GaN heterostructure.**

The growth was initiated with annealing and nitridation of the sapphire substrate at 1060°C. The nitride semiconductor layers (Figure 1) consisted of 620°C 20nm AlN, 1075°C 60nm AlN, 940°C 1.4µm GaN, and 830°C 4nm AlN barrier. All the layers, except for the barrier, were created using MOCVD in hydrogen.

The ambient gas for the PMOCVD barrier growth was changed to nitrogen. Also, indium was used as surfactant during the PMOCVD to improve adatom migration and improve surface quality. Atomic force microscopy (AFM)

gave a root-mean-square roughness of 0.15nm, compared with 0.24nm from 4nm AlN grown by plain MOCVD at 830°C.

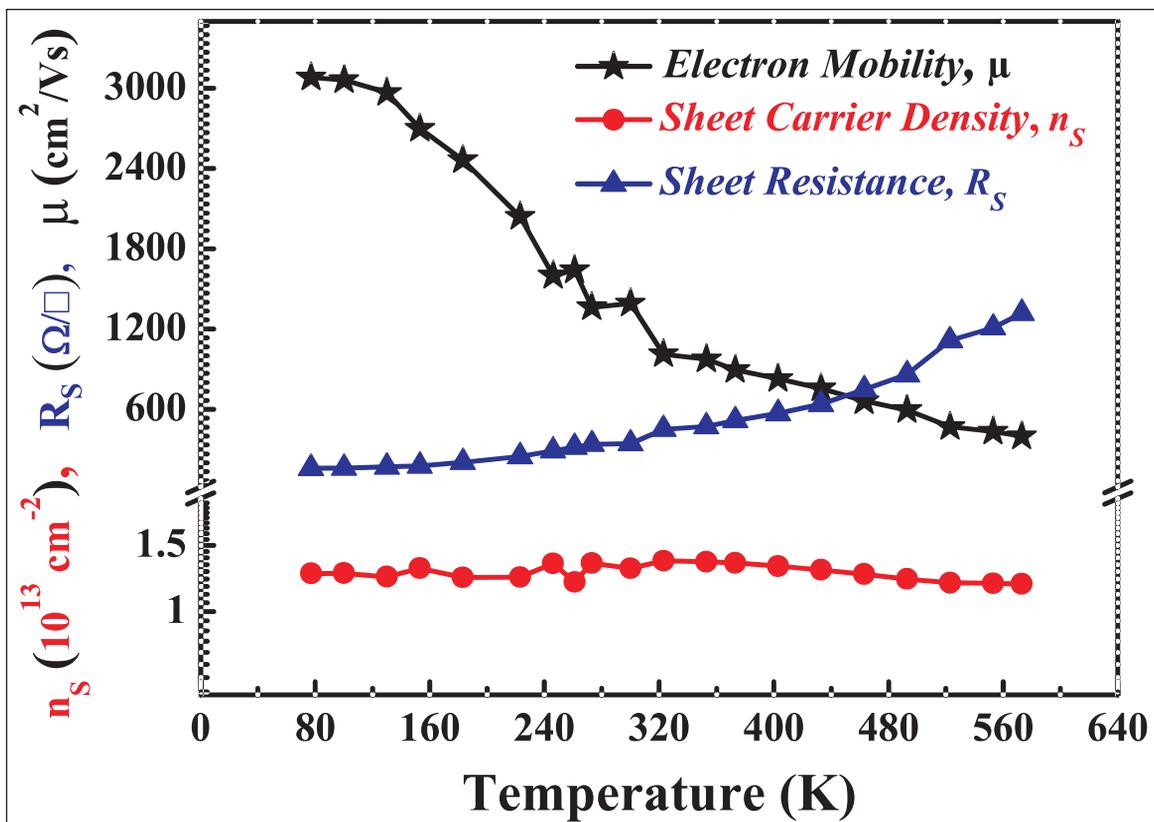
PMOCVD has been used to grow InAlN — by increasing the growth temperature, the indium incorporation is decreased. At 830°C, the indium incorporation is negligible, giving a quasi-binary AlN. This was confirmed by x-ray diffraction (XRD) and x-ray photoelectron spectroscopy (XPS) — see Table 1.

The presence of oxygen and carbon is attributed to residue from the metal-organic precursors, native oxide, solvent treatment, etc. The gallium incorporation is most likely due to residue on the hot reactor walls from the previous processes, according to the researchers.

Also, the temperature is higher than for MBE so, while the unintentional gallium is reduced compared with higher-temperature MOCVD processes, it is not entirely removed, as in MBE-grown AlN.

The 2DEG at the AlN barrier interface with the GaN had, at room temperature, 1398cm<sup>2</sup>/V-s mobility and 1.3x10<sup>13</sup>/cm<sup>2</sup> carrier density, giving a 344Ω/square sheet resistance (Figure 2). These values are comparable with results from AlGaIn/GaN MOCVD heterostructures and an improvement on previous AlN/GaN material produced by MOCVD.

The researchers comment: "This improvement is attributed to the enhanced quality of AlN barrier and heterointerface due to effectively avoiding etch and



**Figure 2. Temperature-dependent electron transport properties of AlN/GaN heterostructures with 4nm AlN barrier grown by PMOCVD.**

**Table 1. XPS results for AlN/GaN heterostructure with 4nm AlN barrier, giving atomic percentage (%) of various species.**

Al	Ga	In	N	C	O
33.44	2.84	0.24	35.52	12.50	15.46

decomposition of underlying GaN channel in PMOCVD process under low growth temperature. So, the interface roughness scattering is remarkably reduced, thus leading to a considerably improved electron mobility. Further increase of carrier density would be expected by surface treatment such as deposition of SiN or oxide passivation layer on the AlN barrier surface."

HEMT devices were produced with titanium/aluminium/nickel/gold source-drain electrodes and a nickel/gold/nickel Schottky gate. The gate length was 0.6µm and the width was 2x50µm (i.e. 100µm total). The gate-drain separation was 2.5µm. The gate-source spacing was 0.9µm. There was no silicon nitride passivation.

The maximum drain current was 305mA/mm. The peak extrinsic transconductance of 95mS/mm was achieved at 10V drain bias and 1.8V gate potential. The researchers believe these values could be improved with better ohmic contact for the source-drain electrodes and the adoption of more advanced fabrication, such as electron-beam lithography. ■

<http://dx.doi.org/10.1063/1.4927743>

Author: Mike Cooke

# Forward-bias gate breakdown in HEMTs with enhancement-mode p-GaN gate electrodes

The temperature dependency of forward gate breakdown has been characterized for the first time, claim researchers.

Researchers in Belgium have studied forward gate breakdown of enhancement-mode aluminium gallium nitride/gallium nitride (AlGaN/GaN) high-electron-mobility transistors with p-type GaN gate electrodes [Tian-Li Wu et al, IEEE Electron Device Letters, published online 5 August 2015]. The team from imec, KU Leuven, and Centre for Microsystems Technology (CMST) comments: "To the best of our knowledge, it is the first time that the temperature dependency of the forward gate breakdown has been characterized."

Somewhat unexpectedly, the research found a positive temperature dependence where a higher temperature leads to a higher gate breakdown voltage.

Enhancement-mode, normally-off transistors are preferred for the target application of power switching. Without special processing, AlGaN/GaN HEMTs are depletion-mode, normally-on. Enhancement-mode should give fail-safe operation and low power consumption. The use of p-GaN in the gate stack is one

promising approach for shifting AlGaN/GaN HEMTs to enhancement-mode operation.

AlGaN/GaN HEMTs with p-GaN gates have not been extensively studied from stability and reliability perspectives. Gate breakdown is an important aspect of such assessments that up to now has not been intensively reported.

The epitaxial material for the HEMT (Figure 1) consisted of 2.4µm (Al)GaN buffer, 300nm GaN channel, 15nm AlGaN barrier, and 70nm magnesium-doped p-GaN. The substrate for the metal-organic chemical vapor deposition (MOCVD) was 200mm-diameter silicon (111). (Al)GaN was used for the buffer to enable high-voltage operation.

The gate consisted of a titanium nitride electrode on the p-GaN, forming a Schottky contact. After the gate metal was deposited, a selective etch with silicon nitride masking the gate structure was carried out down to the AlGaN barrier. The silicon nitride mask was removed before depositing silicon nitride passivation.

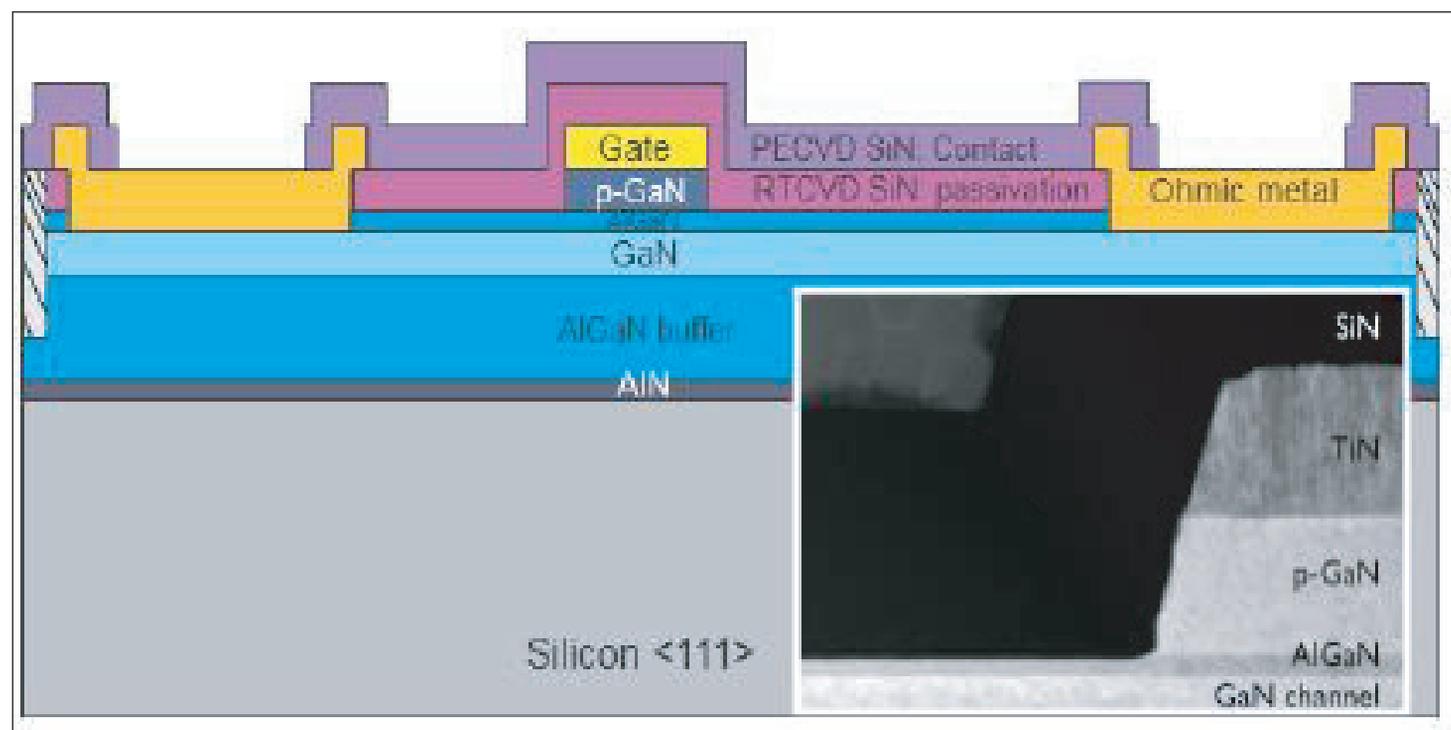


Figure 1. Cross-section of Schottky metal/p-GaN gate AlGaN/GaN HEMT and TEM picture of gate region (inset).

Finally, the gold-free ohmic contacts, along with interconnects, were formed. The metallization included a thick power line.

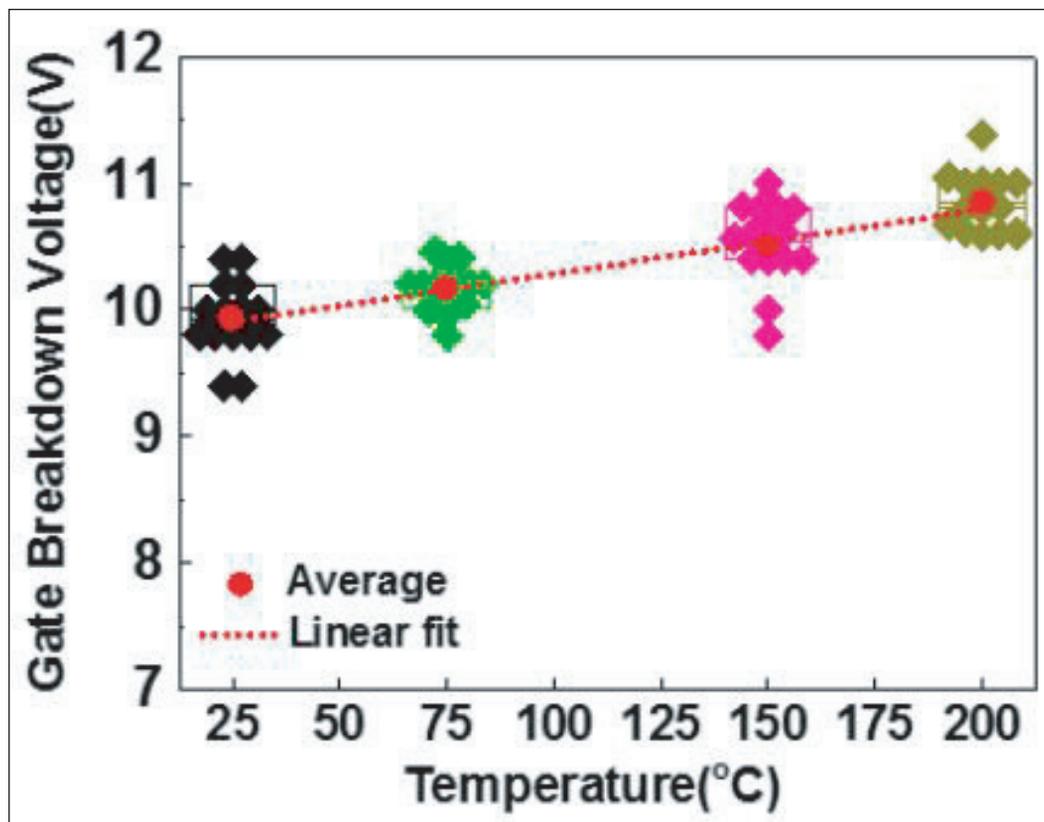
The gate length was  $0.7\mu\text{m}$ . The gate-drain and gate-source distances were both  $0.75\mu\text{m}$ . The gate width was  $10\mu\text{m}$ .

The threshold voltage was  $+1.6\text{V}$ , giving enhancement-mode, normally-off operation. With  $8\text{V}$  gate potential and  $1\text{V}$  drain bias, the drain current was  $90\text{mA/mm}$  and the gate leakage  $5 \times 10^{-7}\text{mA/mm}$ . The subthreshold swing was  $90\text{mV/decade}$ .

The gate hard breakdown characteristics were measured at  $0\text{V}$  drain bias at temperatures up to  $200^\circ\text{C}$ . Each measurement used a fresh device. The results for the four measurement temperatures ( $25^\circ\text{C}$ ,  $75^\circ\text{C}$ ,  $150^\circ\text{C}$ ,  $200^\circ\text{C}$ ) consisted of averages over 15 devices. The gate breakdown voltage increased with temperature at the rate of  $+5 \times 10^{-3}\text{V}/^\circ\text{C}$  — a  $+1\text{V}$  difference between  $25^\circ\text{C}$  and  $200^\circ\text{C}$  (Figure 2).

Such a positive dependence has never been seen with metal-insulator-semiconductor AlGaIn/GaN HEMTs. However, such behavior is seen in silicon CMOS transistors and depletion-mode (normally-on) AlGaIn/GaN HEMTs. In these cases, the mechanism for gate breakdown is thought to be avalanche breakdown triggered by impact ionization. GaN pn diodes under reverse bias also breakdown by this mechanism.

The researchers comment: "This suggests that such a positive temperature forward gate breakdown characteristic we observed first time on Schottky metal/p-GaN gate AlGaIn/GaN HEMTs could be related



**Figure 2. Gate breakdown voltage versus temperature. Voltage extracted at  $10^{-3}\text{mA/mm}$  leakage current.**

to avalanche breakdown as well."

The team explains, further: "Such a gate breakdown phenomenon can be explained by avalanche multiplication in the space charge region of the Schottky metal/p-GaN junction. Once the electrons transfer to the p-GaN region, they can be accelerated by a high electrical field in the depletion region, yielding impact ionization."

The researchers also observed luminescence when the gate voltage was close to hard breakdown. Such light emission is indicative of avalanche luminescence from impact ionization, although some of the photons could also come from band-to-band transitions. ■

<http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7180329>

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# High-performance GaN on low-resistance silicon

Highest frequency performance for transistors on low-resistance silicon substrate.

University of Glasgow and University of Cambridge in the UK have claimed the highest frequency performance to date for gallium nitride (GaN) high-electron-mobility transistors (HEMTs) on low-resistivity (LR) silicon (Si) [A. Eblabla et al, IEEE Electron Device Letters, published 23 July 2015]. The researchers see the technology as making viable cost-effective X-band and higher-frequency applications. The team also sees potential for such GaN devices in mobile communications where power management and radio frequency functions could be integrated on silicon. Normally, high-resistivity (HR) substrates are preferred for high-frequency devices to avoid losses from coupling with RF signals. However, even high-resistance silicon is costly.

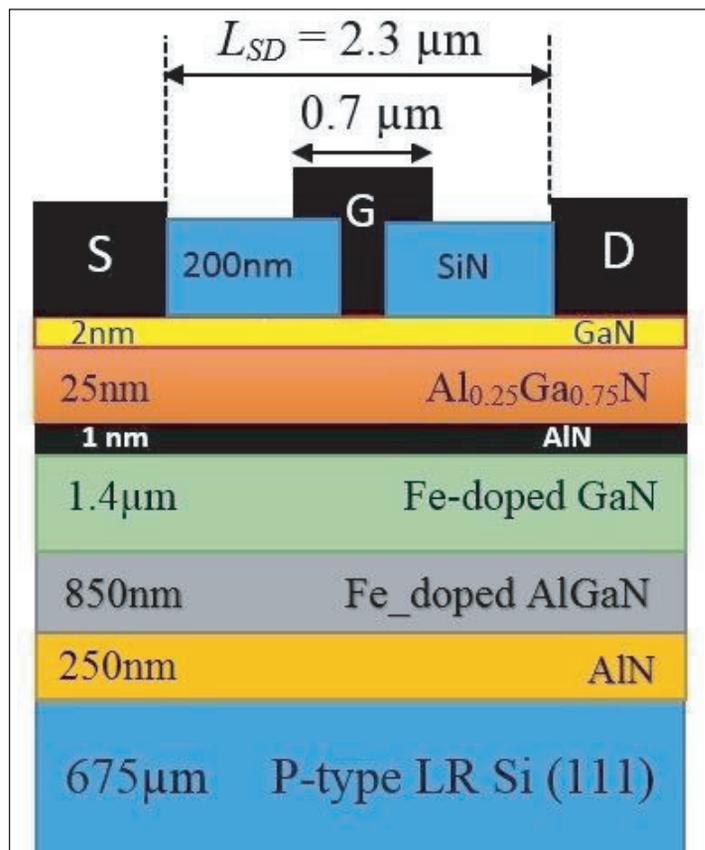
The devices (Figure 1) were grown on 150mm silicon with resistivity less than  $10\Omega\text{-cm}$ , using metal-organic chemical vapor deposition (MOCVD). The 850nm iron-doped aluminium gallium nitride (AlGaN) buffer was graded to accommodate lattice and thermal expansion mismatch between GaN and Si. The  $1.4\mu\text{m}$  GaN buffer was also iron-doped, yielding an insulating character.

The researchers report: "The wafer was completely crack free with wafer bow after cooling from the growth temperature ( $1050^\circ\text{C}$ ) of  $22\mu\text{m}$  (concave). This demonstrates that the lattice and thermal mismatch strains are well managed in the buffer layers and the wafer bow is compatible with processing through a commercial silicon fab." Hall measurements on the two-dimensional electron gas (2DEG) in the GaN channel region gave  $8.1 \times 10^{12}/\text{cm}^2$  carrier density,  $1700\text{cm}^2/\text{V}\cdot\text{s}$  mobility and  $412\Omega/\text{square}$  sheet resistance.

The transistor was fabricated using electron-beam lithography. The ohmic source-drain contacts consisted of titanium/aluminium/molybdenum/gold alloy. Following mesa isolation, silicon nitride was deposited as passivation and then nickel-chromium/gold for the T-gate.

The maximum saturation current was  $1.4\text{A}/\text{mm}$  at 10V drain and +1V gate for a device with  $0.3\mu\text{m}$  gate length and  $2 \times 100\mu\text{m}$  width. The pinch-off at -4V is described as 'well-behaved'. The on-resistance was  $2.76\Omega\text{-mm}$ . The maximum transconductance of  $425\text{mS}/\text{mm}$  was achieved at 5V drain and -3.2V gate bias. The leakage current was  $18.5\text{nA}/\text{mm}$  for 10V drain and -3.5V gate.

The researchers comment: "The excellent performance of these GaN-on-LR Si devices is the result of a well-engineered material growth, device layout and fabrication process quality in addition to proper passivation techniques. Moreover, these excellent results are competitive



**Figure 1. Fabricated T-gate AlGaN/AIN/GaN epilayer grown on LR p-type Si (111) with  $\text{Si}_3\text{N}_4$  passivation.**

with other reported GaN HEMTs on high-resistivity substrates including sapphire and HR Si substrates."

For frequency measurements, the small-signal gain was maximized by the bias point of 5V drain and -3.2V gate. The maximum current gain frequency ( $f_T$ ) was 55GHz and the maximum oscillation frequency ( $f_{\text{max}}$ ) was 121GHz, correcting ('de-embedding') for parasitic pad capacitances and inductances.

"To our knowledge these are the best RF performance of GaN-based HEMTs on LR Si to date," the researchers write. Their RF results exceed in certain respects reports of devices on sapphire and high-resistivity silicon. For example, the  $f_T$  of GaN HEMTs on high-resistivity silicon have reached 54GHz, while  $f_{\text{max}}$  was 184GHz.

Improved performance could be achieved with shorter gate lengths, thinner  $\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$  top-barrier, thicker GaN buffer and lower-resistance ohmic contacts. ■

<http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7165603>

Author: Mike Cooke



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# Working to roll out GaN electronics applications

**Mike Cooke** looks at how some companies are preparing for increased commercialization in gallium nitride RF and power-switching markets.

**G**allium nitride (GaN) electronic devices such as high-electron-mobility transistors (HEMTs) have been developing at a rapid pace in the past few years. However, the deployment in real-world applications has been slower than hoped by investors and engineers working to roll out GaN electronics. As always, a new technology has to compete with incremental developments of existing infrastructure (gallium arsenide, silicon, etc).

The properties of GaN combine a wide bandgap ( $\sim 3.4\text{eV}$ ) and high electron mobility ( $\sim 900\text{cm}^2/\text{V}\cdot\text{s}$ ). The wide bandgap implies a high critical electric field for breakdown. The mobility allows higher switching frequencies and higher-speed operation for RF. These properties also allow for reduced amounts and sizes of auxiliary components (inductors, transformers, capacitors, heat-sinks, fans, cooling, etc) and casings.

Potential GaN electronics generally divides into two areas: radio frequency (RF) power amplification, and high-voltage power switching.

GaN RF power amplifiers (PAs) can be deployed in wireless network base-stations connected to the telecom network. Further applications can be found in general and tactical military communications, jamming, radar, and satellites.

The main focus for GaN power-switching has been for implementation in power supplies, motor drives, battery chargers, and DC-AC inverters deployed over many specific applications such as heating, ventilation & air conditioning (HVAC), solar panels, uninterruptible power supply (UPS) systems, battery management, power factor correction (PFC), electric vehicles, and ultra-small power supplies (AC adapters, PCs, servers, telecom). GaN could also be used to amplify audio signals by pulse-width modulation through high-speed switching rather than through linear gain. Such 'class D' amplifiers are more efficient than analog systems, creating less heat in the switching transistors.

The two target application areas lead to somewhat different approaches to implementation. For RF, it is hoped that superior performance will significantly increase power density and reduce auxiliary demands for cooling compared with alternative silicon and gallium arsenide (GaAs) systems. Also, some of the potential markets — one thinks of military customers

here — are traditionally less cost-sensitive and more demanding of performance. Power-switching applications are more mass market, and cost looms larger in investment calculations.

The difference is often seen in the substrate used — silicon carbide (SiC) for RF power and silicon for power-switching. GaN grown on SiC is generally higher quality due to smaller lattice mismatch ( $\sim 3\%$ ) compared with (111)Si ( $\sim 17\%$ ). An additional advantage of SiC is a higher thermal conductivity of  $\sim 4\text{W}/\text{cm}\cdot\text{K}$ , compared with  $\sim 1.3\text{W}/\text{cm}\cdot\text{K}$  for Si.

The significant disadvantage of SiC is cost due to much more difficult production (75x that of silicon on one estimate, although this depends on the balance of power between supplier and customer). Also, silicon can be produced as larger-diameter wafers — presently up to 200mm (8 inches), with 300mm (12 inches) being worked on in research and development. GaN-on-SiC wafers are available up to 100mm (4 inches), with 150mm being rolled out (since 2012).

Some market researchers predict a market for GaN power conversion of the order of \$1bn by 2024 — others are less sanguine. Meanwhile, Strategy Analytics suggests that the RF GaN market could reach \$560m by 2019.

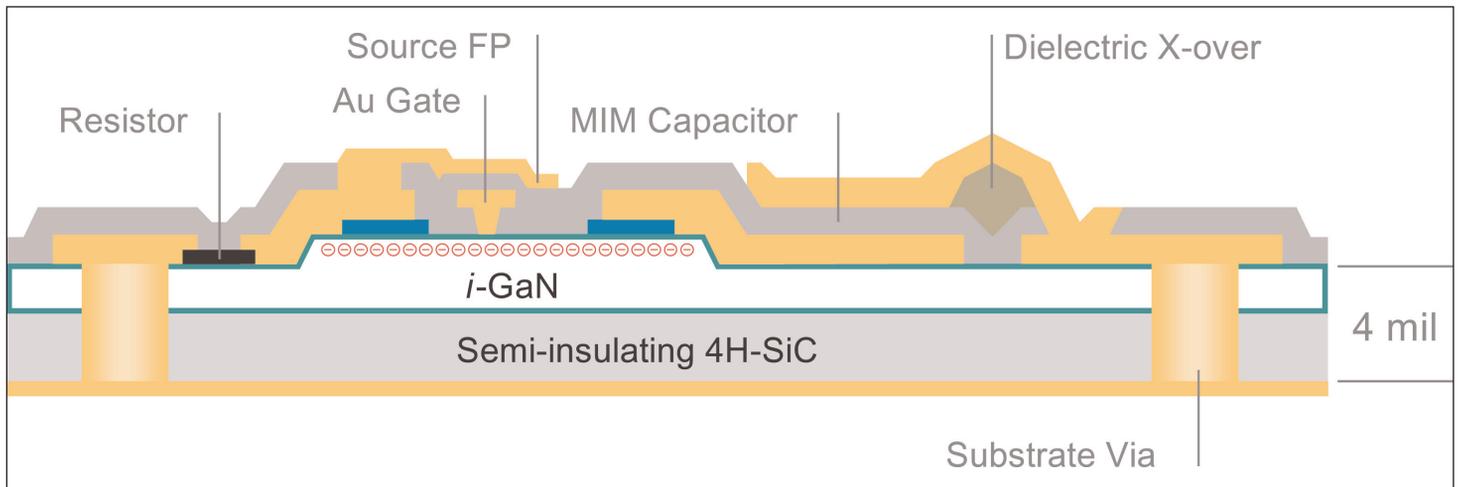
Here we look at how some companies are approaching these markets.

## Cree and Wolfspeed

Cree Inc of Durham, NC, USA has been developing GaN RF devices alongside its SiC power electronics business for some time. In May it announced that this division would be spun off as a standalone company with the aim of "innovation and commercialization of next-generation power and wireless systems based on silicon carbide and gallium nitride". The new company is called Wolfspeed and an initial public offering is expected by June 2016.

The new company's main focus for GaN is RF devices on SiC substrates, while devices aimed at the power-switching market are pure SiC. This is not too surprising considering that Cree's core and founding technology is growth and marketing of SiC substrates.

Wolfspeed inherits two basic families in its GaN HEMT monolithic microwave integrated circuit (MMIC)



**Figure 1. Cree's GaN MMIC process schematic.**

foundry service for 0.4 $\mu\text{m}$  and 0.25 $\mu\text{m}$  gate lengths (Figure 1). The 0.4 $\mu\text{m}$  HEMT enables operation at up to 50V drain bias. The 0.25 $\mu\text{m}$  gate process allows biases up to 40V. Transistors built on these processes can handle power densities up to 8W/mm with high reliability up to 225 $^{\circ}\text{C}$  operating junction temperatures. The company also markets its own range of discrete and MMIC components.

### Fabless and foundries

In 2013, Japan's Fujitsu and Transphorm Inc of Goleta, near Santa Barbara, CA, USA agreed to integrate their GaN power supply electronics businesses. At the beginning of 2015, the companies reported that mass production had begun at Fujitsu Semiconductor group's CMOS-compatible, 150mm silicon wafer fab in Aizu-Wakamatsu, Japan.

The companies commented: "The large-scale, automotive-qualified facility, which is providing exclusive GaN foundry services for Transphorm, will allow dramatic expansion of Transphorm's GaN power device business. This stepped up production can satisfy the increasing market demands for GaN devices, thereby enabling the next wave of compact, energy-efficient power conversion systems."

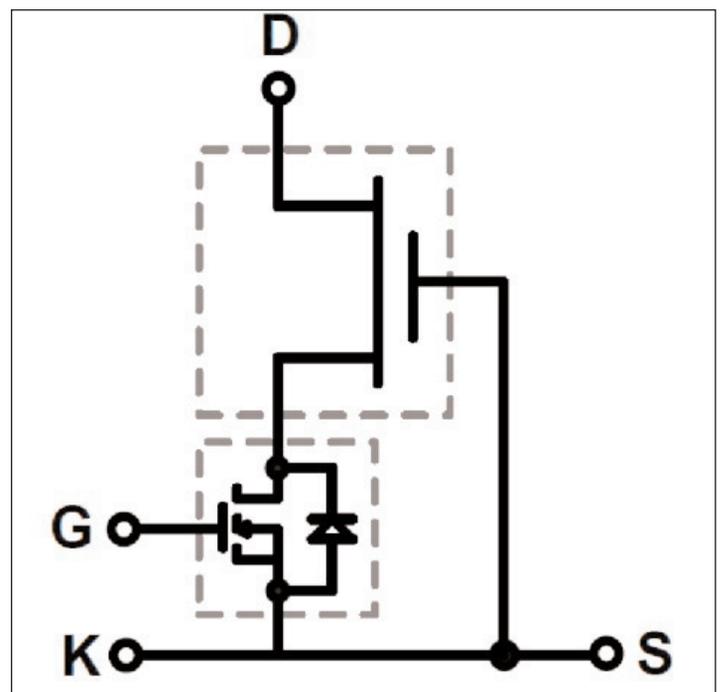
Transphorm claims that its ultra-efficient power solutions eliminate up to 90% of all electric conversion losses. Transphorm also claims the first and only JEDEC-qualified 600V GaN device platform and the world's first photovoltaic power conditioner products using GaN modules.

ON Semiconductor of Phoenix, AZ, USA is among the partners of Transphorm. Together, the two companies introduced co-branded JEDEC-qualified 600V GaN cascode transistors and a 240W reference design. The transistors in optimized TO-220 packages have typical on-resistances of 290m $\Omega$  and 150m $\Omega$ . The packaging of GaN HEMTs with silicon transistors in a cascode circuit gives normally-off rather than normally-on operation (Figure 2).

An evaluation board for the reference design targets a smaller footprint and better efficiency than power supplies using traditional devices. The boost stage delivers 98% efficiency with power factor correction. The DC-DC stage uses an inductor-inductor-capacitor (LLC) transformer topology and a resonant mode controller to achieve 97% full-load efficiency at more than 200kHz, while also meeting stringent EN55022 Class B EMC performance. GaN HEMTs are used as switches both in the boost and DC-DC stages.

GaN Systems Inc of Ottawa, Ontario, Canada is a fab-less company that designs and supplies a range of GaN high-power transistors for power conversion. The company made a GaN-on-silicon foundry agreement with RF Micro Devices Inc of Greensboro, NC, USA in 2013.

RFMD has since combined with Triquint Semiconductor Inc of Hillsboro, OR, USA to become Qorvo Inc. Qorvo's



**Figure 2. Cascode circuit to give normally-off operation of GaN HEMT.**

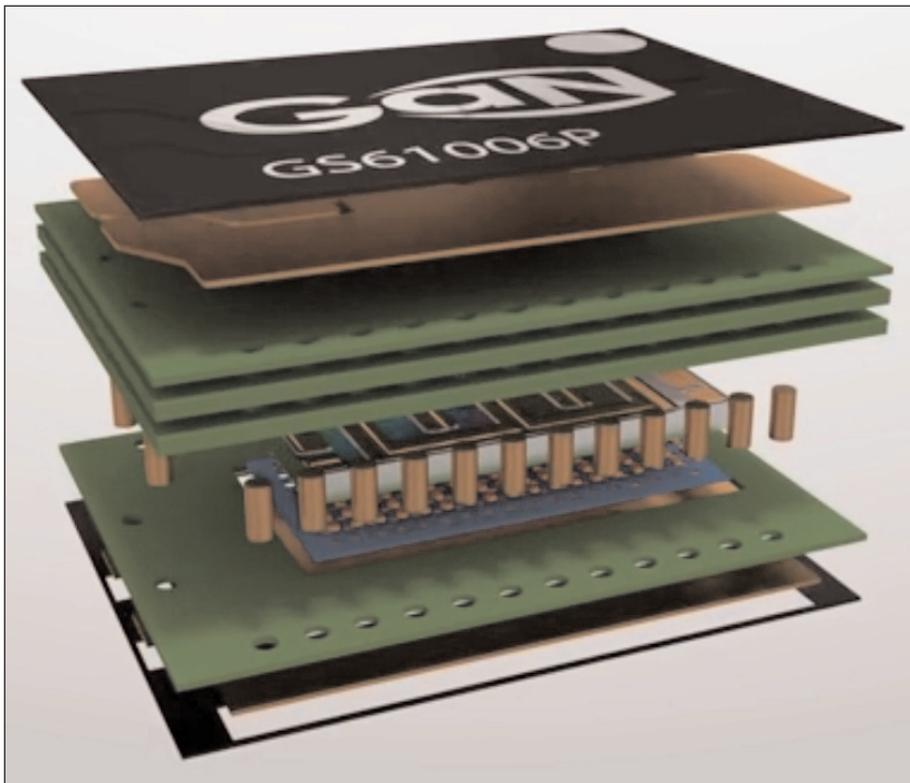


Figure 3. Exploded view of GaN Systems' GaNPX packaging.

process is 0.5µm AlGaN/GaN. The foundry promotes GaN/SiC for RF power amplifiers with operation up to 48V continuous wave and 65V pulsed. Power density can reach 8W/mm. The company also has extensions with greater linearity and higher breakdown voltages.

GaN Systems has two particular pieces of packaging intellectual property. First, an island structure that aims to reduce the size and cost of GaN devices, while transferring substantial current from on-chip metals to a separate carrier. Second, GaNPX packaging targets extreme speed and current (Figure 3). GaNPX is a near-chip-scale embedded package with no wire bonds. The company claims high current density, low profile and low inductance with optimal thermal performance. The last factor allows the elimination or reduction of thermal management measures such as heat-sinks or fans, creating more compact, low-cost equipment.

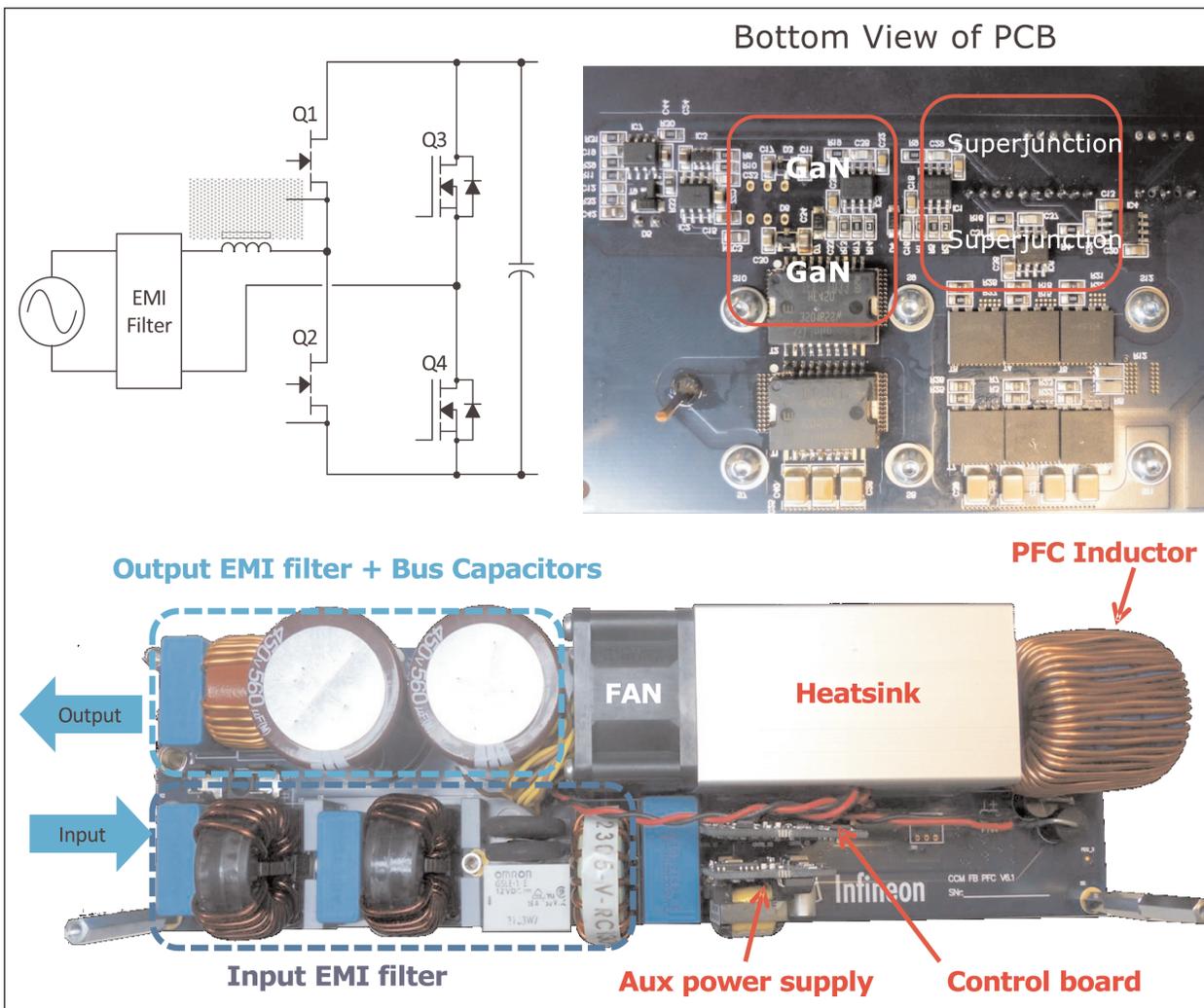


Figure 4. Infineon's totem-pole PFC full-bridge proof-of-concept circuit and photos.

GaN Systems estimates that a typical silicon-based converter for electric vehicles will be optimally 95% efficient with a loss of about 5kW. The firm says that its GaN converters can achieve up to 99% efficiency, allowing a shift from water-cooling to air-cooling. Further, silicon efficiency of 95% at low load drops to around 70%, while GaN Systems claims that it can maintain efficiencies higher than 90%.

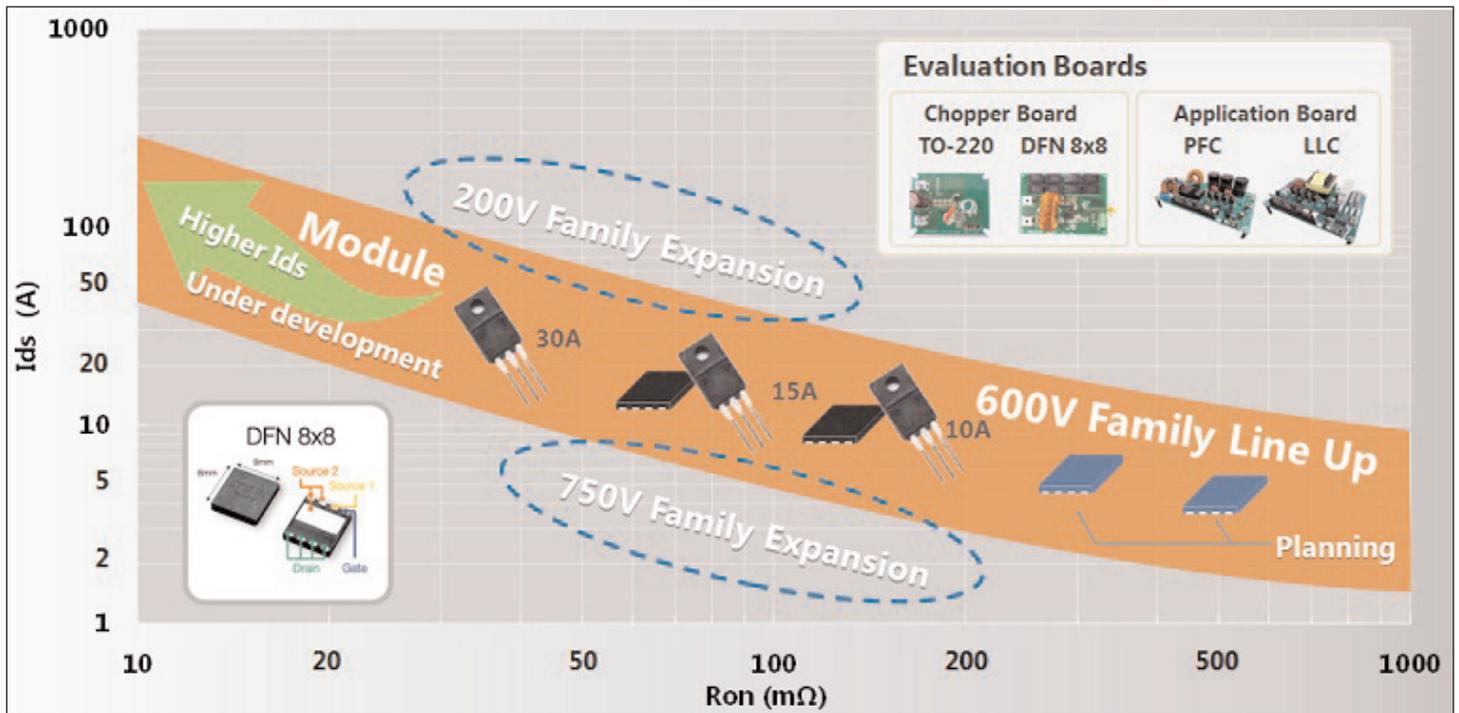


Figure 5. Panasonic's GaN roadmap.

### Combining RF and power-switching

Germany's Infineon Technologies AG introduced its first devices in a family of GaN-on-SiC RF power transistors in September. Infineon claims that the new RF power transistors achieve 10% higher efficiency, five times the power density, and twice the RF bandwidth of silicon LDMOS transistors. The greater bandwidth should allow one power amplifier to support multiple operating frequencies. Increased instantaneous bandwidth offers higher data rates via data aggregation techniques specified for 4.5G cellular networks. Engineering samples and reference designs are available for the Infineon devices.

Infineon has also been broadening its patent portfolio related to GaN, expanding GaN-on-silicon (GaN/Si) with an epitaxy process and 100–600V technologies resulting from the acquisition of International Rectifier. Also, in March the company announced a strategic partnership with Japan's Panasonic aimed at integrating enhancement-mode GaN-on-silicon transistor structure into Infineon's surface-mount device (SMD) packages.

Infineon offers both enhancement-mode and cascode configuration energy-efficient GaN-based power-supply platforms. Andreas Urschitz, president of Infineon's Power Management & Multimarket Division, comments: "Using our GaN technology, a laptop charger found on the market today could be replaced by one that is up to four times smaller and lighter."

A recent application example from Infineon is a 2.5kW totem-pole PFC full-bridge circuit that combines GaN HEMTs with silicon superjunction field-effect transistors (Figure 4). GaN devices are used for the boost stage, allowing 70m $\Omega$  maximum resistance in

enhancement-mode. The circuit handles 230V AC input and outputs 6.25A at 400V DC.

The Infineon/Panasonic partnership will use Panasonic's normally-off (enhancement-mode) GaN-on-silicon transistor structure integrated into Infineon's SMD packages, resulting in 600V GaN power devices from dual sources.

Meanwhile, in May Panasonic claimed the industry's smallest enhancement-mode GaN power transistors in its own specially designed X-GaN 8mm x 8mm x 1.25mm dual-flat no-lead (DFN) surface-mount package. The transistor breakdown rating is 600V and the switching speed is 200V/ns. The on-resistance ranges from 54m $\Omega$  to 154m $\Omega$  (Figure 5). The company was to ship samples in July of 10A and 15A devices. One advantage of SMD packaging is reduced parasitic inductance. Also, the footprint is decreased by 43% compared with Panasonic's conventional TO-220 package.

Finally, a company that has some GaN products is NXP Semiconductors N.V. of Eindhoven, The Netherlands, which has a focus on GaN RF power devices for base-station, industrial scientific & medical (ISM) and aerospace & defense applications. On its website, the company claims best-in-class linearity, but this may be a historical statement. A back-end assembly facility packages the high power density of GaN into smaller and more broadband circuitry, according to NXP. ■

Author:

Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.

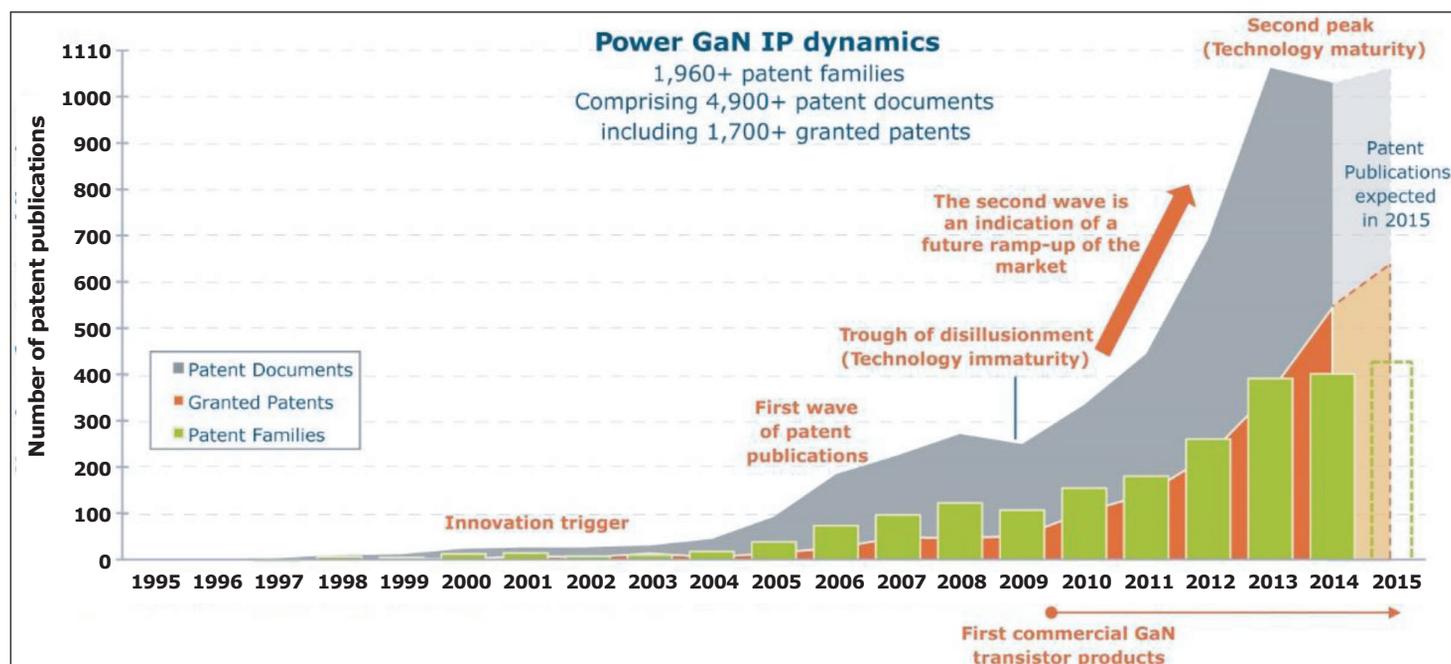
# Power GaN device IP dynamics heralds future ramp-up of market

Market forecasted to grow at a CAGR of 93% to \$300m in 2020.

There are currently only a few players selling power GaN products (e.g. Infineon/IR, EPC, GaN Systems, Transphorm) and the market is still small, estimated to be \$10m in 2015 in the report 'GaN and SiC devices for power electronics applications' from Yole Développement. However, the potential energy efficiency savings from the adoption of GaN power semiconductor devices has led to significant research and development that is now beginning to be realized in commercially available devices, and the device market will ramp up from 2016 at a compound annual growth rate (CAGR) of 93% to more than \$300m in 2020 in the baseline 'nominal' scenario, forecasts the market research firm.

In preparation for this significant growth, the gallium nitride power industry is consolidating, and GaN technology is spreading across the value chain. This can be seen in recent mergers and acquisitions (e.g. Infineon/International Rectifier, Transphorm/Fujitsu's GaN Power Conversion business), license agreements (Infineon/Panasonic, Transphorm/Furukawa) and the will of several firms to move onto the mass-production stage (Transphorm/Fujitsu).

As GaN power devices are now poised for rapid market adoption, a strong intellectual property (IP) position is essential for companies to grow their GaN business, says KnowMade, partner of Yole Développement. In today's power GaN market, it is crucial to

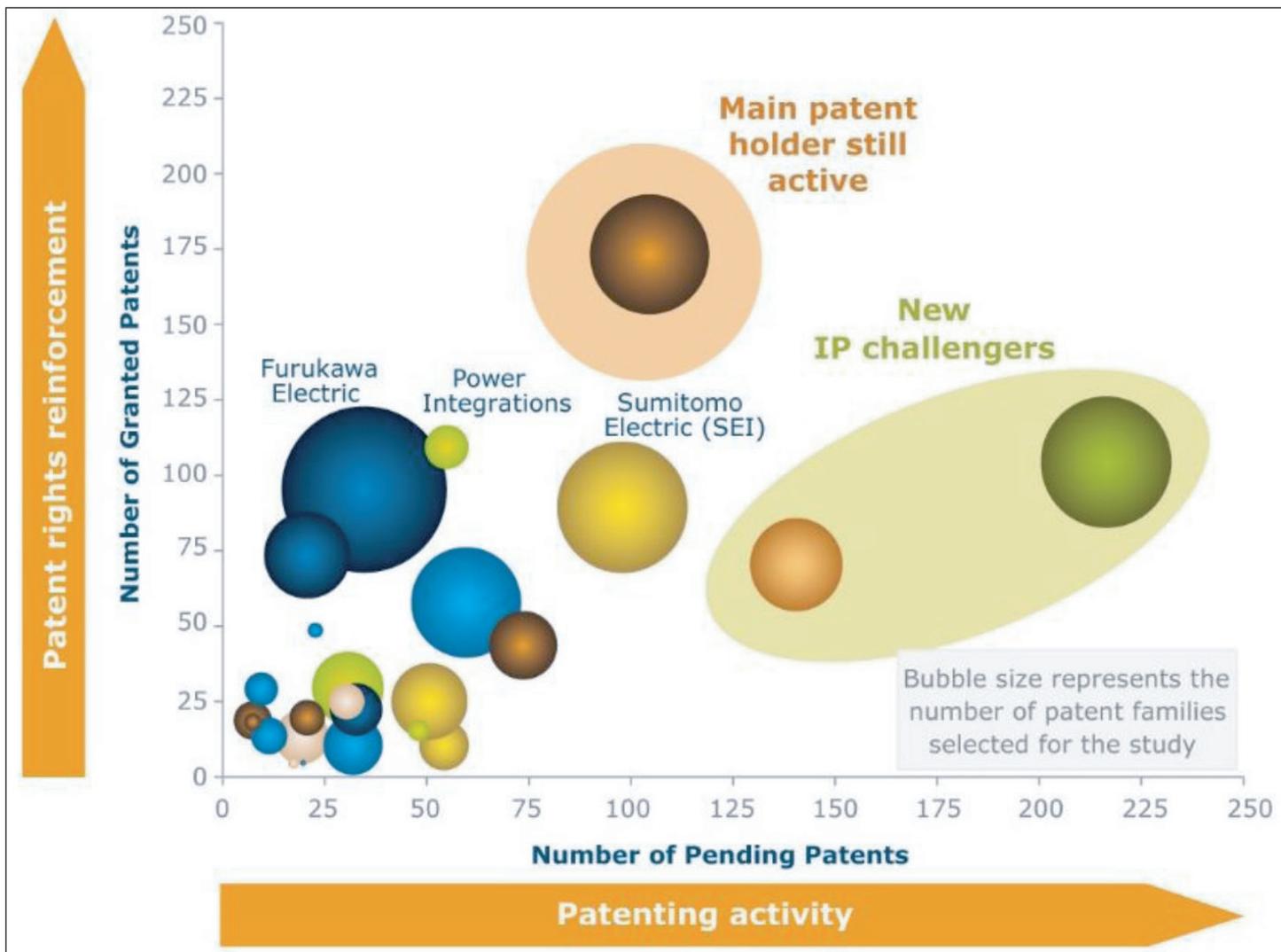


A [patent family](#) is set of patents filed in multiple countries by a common investors(s) to protect a single invention.

A [patent document](#) is a patent filed in one country (1st application or extensions).

Note: the patent search was done in March 2015, thus the data corresponding to the year 2015 are not complete.

**Power GaN IP dynamics.** (Source: 'GaN Devices for Power Electronics Patent Investigation, KnowMade, September 2015.)



**IP leadership of patent assignees for GaN devices. (Source: 'GaN Devices for Power Electronics Patent Investigation, KnowMade, September 2015.)**

understand the global patent landscape, enabling firms to anticipate changes, harvest business opportunities, mitigate risks and make strategic decisions to strengthen their market position and maximize the return on their IP portfolio, KnowMade adds.

Up to April 2015, more than 1960 patented inventions related to GaN power electronics have been published worldwide. The first patents were published in the mid-1990s by silicon power companies (Furukawa Electric, International Rectifier, Infineon etc). But the take-off of patenting activity was really observed ten years later with a first wave of patent publications over the 2005–2009 period, due mainly to US-based companies (International Rectifier, Power Integrations) and Japanese companies (Panasonic, Rohm, Furukawa Electric, Sumitomo Electric, Toshiba, Toyota). A second wave of patent publications began in 2010, originating mainly from Mitsubishi Electric, Fujitsu, Transphorm, Avogy and Infineon, while the first commercial products, collaborations, mergers and acquisitions emerged. Recently, LED pure-players like Seoul Semiconductor have entered the power GaN IP arena.

The time evolution of patent filings has reached a peak, and KnowMade expects a slowdown in new patent applications. Meanwhile, following successful prosecution of the many pending patent applications, granted patents worldwide should increase. KnowMade believes that the second peak of patent filings, combined with the significant ratio of patents in force and the large number of patent applications still in the pipeline worldwide, is an indication of the technology maturity heralding a future ramp-up of the GaN power market.

### Key players and new IP challenges

More than 200 patent applicants are involved in power GaN IP, estimates KnowMade. Most of the major silicon power players are present in the list of the top patent applicants, including International Rectifier/Infineon, Panasonic, Furukawa Electric, Sumitomo Electric, Fujitsu, Mitsubishi Electric, Toshiba, Sharp, Fuji Electric, Rohm and Power Integrations. This indicates strong interest from power players in the GaN business, KnowMade notes. So far, only IR/Infineon has commercialized GaN devices but, armed with strong IP,

	DEVICE				OPERATING			PACKAGING		
	D-mode (Normally-on)	E-mode (Normally-off)	Cascode (N-off circuit-based approach)	Vertical Device (CAVET)	Current Collapse	Dynamic R-on	Gate Charge (Miller effect)	Low Stray Inductance Package	Thermal Management (package, module)	Chip-Scale Package
GaN-on-XX	GaN-on-SiC	MITSUBISHI ELECTRIC power integrations	Panasonic transpherm	transpherm		transpherm			MITSUBISHI ELECTRIC	
	GaN-on-Si	MITSUBISHI ELECTRIC power integrations GaN Systems	FURUKAWA ELECTRIC IQR Infineon EPC FUJITSU Panasonic transpherm	IQR Infineon SHARP GaN Systems transpherm	IQR	FURUKAWA ELECTRIC Panasonic	IQR transpherm	IQR EPC Panasonic SHARP	IQR Infineon MITSUBISHI ELECTRIC	IQR GaN Systems
	GaN-on-Sapphire	power integrations ROHM								
	Bulk GaN			Avogy Sumitomo Electric						

Patent differentiation of key players for GaN power transistors. (Source: 'GaN Devices for Power Electronics Patent Investigation, KnowMade, September 2015.)

other traditional power players are able to disrupt and reshape the market, says the market research firm.

The report provides a ranking and analysis of the relative strength of the top patent holders derived from their portfolio size, patent citation networks, countries of patents filing and current legal status of patents. Yole reveals the IP strength of key power

GaN players and depict their competitive positioning.

It can be safely assumed that International Rectifier (IR) has the best patent portfolio in power GaN, and that the combined company IR/Infineon has the strongest IP, putting them in the position to lead GaN power market growth, reckons KnowMade. However, this IP leadership position could evolve in the future since newcomers like Transphorm, Fujitsu and Mitsubishi Electric are becoming major forces and may reshape the power GaN patent landscape, KnowMade adds.

Transphorm is the most important IP challenger in the power GaN arena (ahead of other GaN start-ups like EPC and GaN Systems). Its patent portfolio and partnerships with the likes of Furukawa, Fujitsu and On Semiconductor have put it in a strong position to take a leading role in the GaN device market, reckons KnowMade. Furukawa Electric has an ample IP portfolio with a significant 'blocking potential', but the company has not yet been able to commercialize the technology

**Power GaN IP is just beginning to be leveraged by companies to negotiate licensing and supply agreements such as those between Infineon and Panasonic and between Transphorm and Furukawa Electric**

on its own. By giving Transphorm exclusive licensing rights on its GaN patent portfolio, Furukawa Electric has found a strategic partner to bring its technology to market.

Fujitsu and Mitsubishi Electric have demonstrated an interest in power GaN technology since 2010 with a strong increase in their patenting activity these last three years, heralding substantial future IP portfolios.

### Patented technology and IP strategy

The 1960-plus patented inventions selected for KnowMade's study have been manually categorized by technology segment. The existing power GaN IP covers the whole of the value chain, from epitaxial wafers and power semiconductor devices to discrete components, power modules, packaging, circuits and systems. The dataset of patents has been organized into various technical challenges (E-mode, cascode, E/D-mode monolithic, vertical devices, current collapse, dynamic  $R_{on}$ , gate charge, breakdown voltage, stray inductance, thermal issues, chip-scale package) and type of substrate for GaN epitaxy (SiC, silicon, bulk, sapphire). A special focus is provided on power semiconductor devices (transistors and diodes at the semiconductor level) and power components (discrete components, power modules and packaging).

KnowMade says that power GaN IP is just beginning to be leveraged by companies to negotiate licensing and supply agreements such as those between Infineon and Panasonic and between Transphorm and Furukawa Electric. To date, no litigation cases related to the power GaN domain have been filed, but this should change as the market expands, expects KnowMade. ■

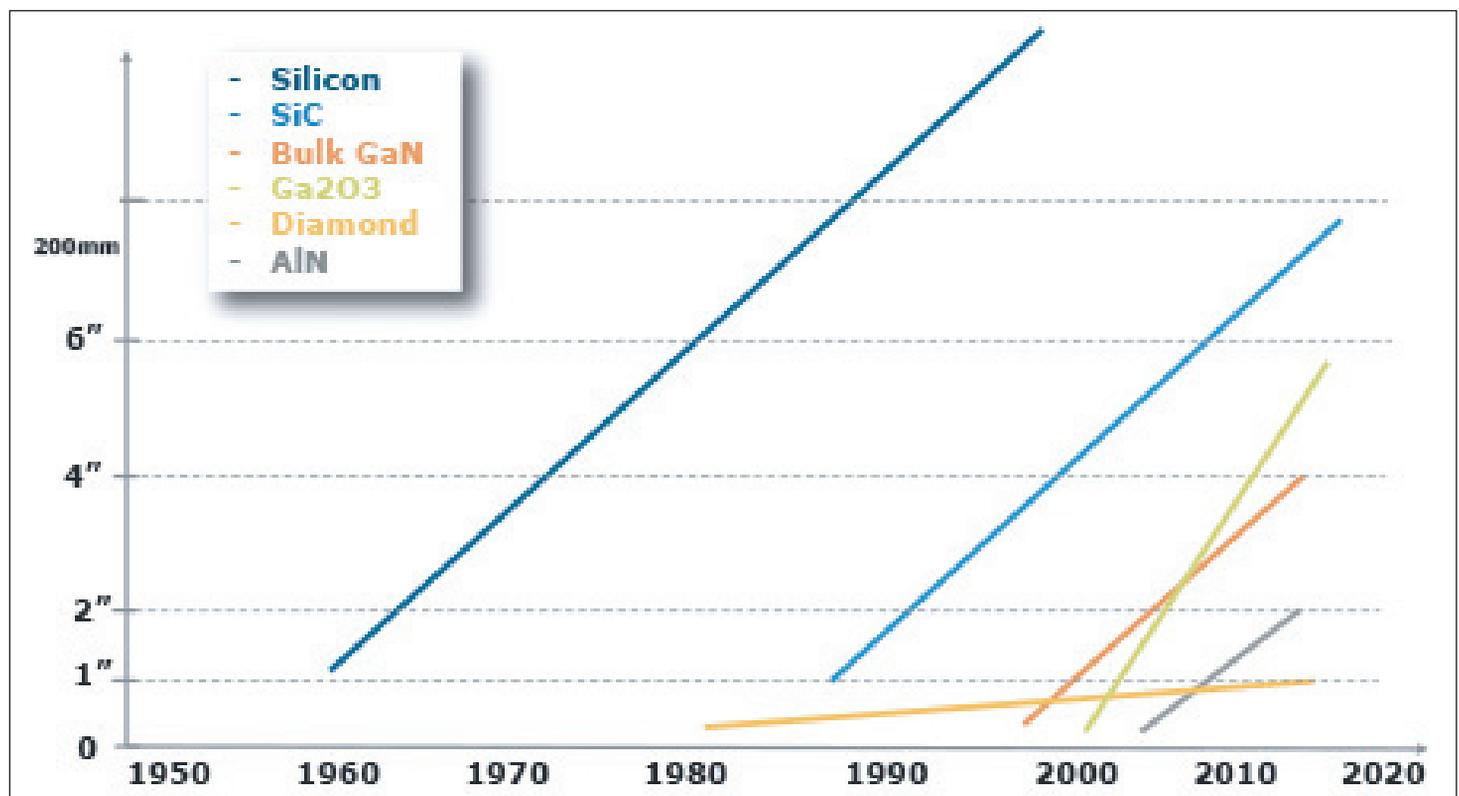
[www.i-micronews.com/component/hikashop/product/gan-devices-for-power-electronics-patent-investigation.html](http://www.i-micronews.com/component/hikashop/product/gan-devices-for-power-electronics-patent-investigation.html)

# SiC, GaN and other wider-bandgap materials present new choices for power electronics

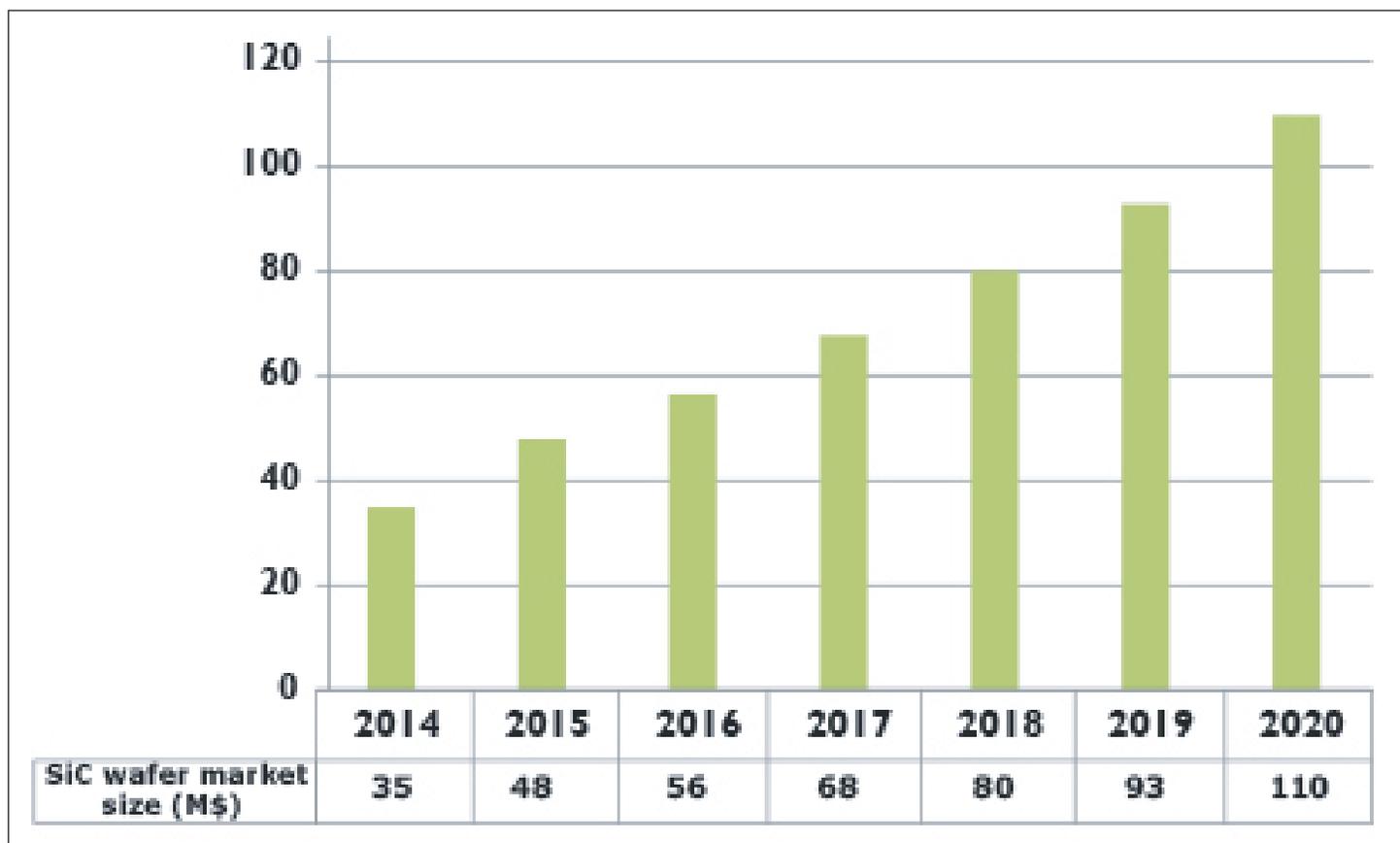
SiC n-type wafer market to grow at 21% to \$110m by 2020; GaN-on-Si being commercialized; and Japan to remain dominant in bulk GaN, reckons **Yole Développement**.

**W**hen people think about wide-bandgap (WBG) semiconductor materials for power electronics applications, they usually think of gallium nitride (GaN) or silicon carbide (SiC) – which is not surprising, since SiC and GaN are currently the most advanced WBG technologies for power electronics applications. However, market research firm Yole Développement notes in its report 'SiC, GaN, and other Wide Band Gap (WBG) materials for power electronics applications' that there are materials with an even larger bandgap that can further increase power device performance:

- Due to its high bandgap and possibility of doping at room temperature, gallium oxide ( $\text{Ga}_2\text{O}_3$ ) has been proposed for power electronics applications. Compared to existing SiC and bulk GaN technology, its key selling point is the possibility of using melt growth to make large, inexpensive wafers.
- Diamond is the ideal candidate for power electronic applications, due to a combination of unique properties.
- Having initially targeted ultraviolet (UV) LED applications but finding subpar demand, some aluminium nitride (AlN) suppliers are now targeting the power market in order to diversify their activities. AlN's key



Different crystal diameter expansion.



Projected SiC n-type substrate market size (in \$m) through 2020.

value proposition for power applications is the fact that it has the largest band gap.

### SiC n-type wafers to grow at 21% CAGR to \$110m by 2020

Driven by the SiC-based power devices market, the market for n-type SiC substrates is expected to rise at a compound annual growth rate of 21% from about \$35m in 2014 to \$110m in 2020.

The market's preferred product for power electronic applications is still 4" wafers. However, some suppliers can now provide 6" wafers with good enough quality for power devices — and an 8" SiC wafer was demonstrated by II-VI Inc towards mid-2015.

The average price for 6" is still 2.25x higher than 4", but the price continues to fall and will drop below the threshold in late 2015 or early 2016. The transition to 6" is beginning; in fact, SiC device maker Rohm has just announced that it is beginning mass production on 6" wafers in third-quarter 2015.

The n-type SiC substrate market player rankings have recently stabilized, says Yole. Cree remains the market leader, with Dow Corning, SiCrystal and II-VI right behind. There are now four Chinese SiC suppliers, and their current announced capacity is more than 150,000 wafers per year, with further increases expected. Also, in early 2015 Beijing-based TankeBlue Semiconductors demonstrated a 6" n-type wafer. Yole views these Chinese players as serious market challengers.

### Many players competing on GaN-on-Si epiwafer open market. What will happen?

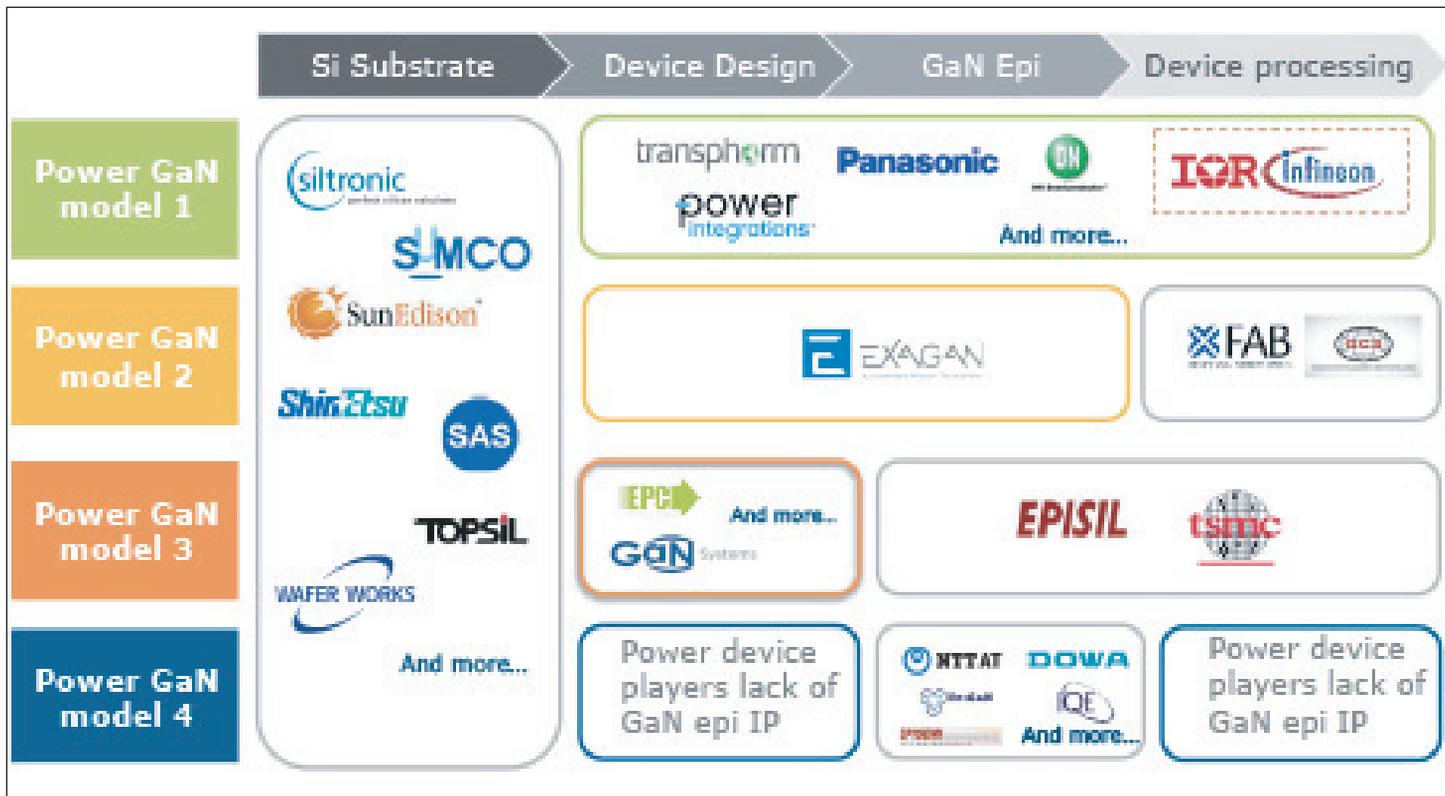
GaN-on-silicon technology is very challenging due to large mismatches both the lattice constants and coefficients of thermal expansion (CTE) between GaN and silicon. That said, GaN-on-Si's main issues have been resolved and several companies have begun commercializing power devices based on this technology, notes Yole.

Attracted by the device market's potential, players with different origins are active on the open market for GaN-on-Si epiwafers and thinking of selling epiwafers to device players. These players are:

- silicon substrate suppliers wanting to move up the value chain, i.e. Siltronic;
- device foundries like Episil that want to move down the value chain;
- some LED chip suppliers, i.e. China's San'an Optoelectronics;
- large epi houses like IQE;
- Epigan and other pure GaN epi houses.

Since the power GaN device business is only in its early stages, the related GaN epiwafer open market is not yet well-established, notes Yole. Competition is very intense, and the bankruptcy of AZZURRO Semiconductors of Dresden, Germany in 2014 has illustrated the risks faced by start-up GaN epi houses.

The report includes a detailed description of the GaN-on-Si epiwafer market and Yole's vision for its future.



GaN-on-Si epiwafer business model.

### Status of bulk GaN wafer production

Almost all commercial bulk GaN wafers are produced by hydride vapor phase epitaxy (HVPE), used mainly for optoelectronics applications. However, HVPE GaN substrates have an undesirably high dislocation density that restricts their usefulness for power switches, Yole notes.

Ammonothermal growth is expected to be more competitive with the arrival of a new acidic ammonothermal method developed by Japan's Mitsubishi Chemical and US-based LED maker Soraa. Na-flux LPE growth also seems to be promising for power electronics devices, adds the market research firm.

The bulk GaN wafer market is dominated by Japanese companies. Sumitomo Electric, Mitsubishi Chemical, and Hitachi Metals (now Sumitomo Chemical) lead in

HVPE production. Mitsubishi is actively developing ammonothermal growth, while NGK is developing Na-flux growth. Non-Japanese players are currently in small-volume production or in the R&D stage, and most of them are developing HVPE methods to target the LED market. If GaN-on-GaN technology is adopted by the power electronics market, Japanese players will maintain their leading position, reckons Yole.

The report also provides information on the alternative solutions being proposed to produce much cheaper bulk GaN and SiC wafers, which could potentially disrupt the GaN and SiC market, concludes Yole. ■

[www.i-micronews.com/component/hikashop/product/sic-gan-and-other-wide-band-gap-wbg-materials-for-power-electronics-applications.html](http://www.i-micronews.com/component/hikashop/product/sic-gan-and-other-wide-band-gap-wbg-materials-for-power-electronics-applications.html)

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 Northants NN8 4PE,  
 UK

Tel: +44 1933 220626  
 Fax: +44 1933 227814

[www.MCP-group.com](http://www.MCP-group.com)

### Umicore Indium Products

50 Simms Avenue,  
 Providence, RI 02902,  
 USA

Tel: +1 401 456 0800  
 Fax: +1 401 421 2419

[www.thinfilmpducts.umicore.com](http://www.thinfilmpducts.umicore.com)

### United Mineral & Chemical Corp

1100 Valley Brook Avenue,  
 Lyndhurst, NJ 07071,  
 USA

Tel: +1 201 507 3300  
 Fax: +1 201 507 1506

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

## 2 Bulk crystal growth equipment

### MR Semicon Inc

PO Box 91687,  
 Albuquerque,  
 NM 87199-1687,  
 USA

Tel: +1 505 899 8183  
 Fax: +1 505 899 8172

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

## 3 Substrates

### AXT Inc

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 Fremont,  
 CA 94538,  
 USA

Tel: +1 510 438 4700  
 Fax: +1 510 683 5901

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

Supplies GaAs, InP, and Ge wafers using VGF technology with manufacturing facilities in Beijing and five joint ventures in China producing raw materials, including Ga, As, Ge, pBN, B<sub>2</sub>O<sub>3</sub>.



### CrystAI-N GmbH

Dr.-Mack-Straße 77,  
 D-90762  
 Fürth,  
 Germany

Tel: +49 (0)911 650 78 650 90  
 Fax: +49 (0)911 650 78 650 93  
 E-mail: [info@crystal-n.com](mailto:info@crystal-n.com)

[www.crystal-n.com](http://www.crystal-n.com)

### Crystal IS Inc

70 Cohoes Avenue  
 Green Island, NY 12183, USA

Tel: +1 518 271 7375  
 Fax: +1 518 271 7394

[www.crystal-is.com](http://www.crystal-is.com)

### Freiberger Compound Materials

Am Junger Loewe Schacht 5,  
 Freiberg, 09599, Germany

Tel: +49 3731 280 0  
 Fax: +49 3731 280 106

[www.fcm-germany.com](http://www.fcm-germany.com)

### Kyma Technologies Inc

8829 Midway West Road,  
 Raleigh, NC, USA

Tel: +1 919 789 8880  
 Fax: +1 919 789 8881

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

**MARUWA CO LTD**

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Owariasahi, Aichi 488-0044,  
Japan

Tel: +81 572 52 2317

[www.maruwa-g.com/e/  
products/ceramic](http://www.maruwa-g.com/e/products/ceramic)



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**sp3 Diamond Technologies**

2220 Martin Avenue,  
Santa Clara, CA 95050, USA

Tel: +1 877 773 9940

Fax: +1 408 492 0633

[www.sp3inc.com](http://www.sp3inc.com)

**Sumitomo Electric  
Semiconductor Materials Inc**

7230 NW Evergreen Parkway,  
Hillsboro, OR 97124,  
USA

Tel: +1 503 693 3100 x207

Fax: +1 503 693 8275

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

**III/V-Reclaim**

Wald 10,  
84568 Pleiskirchen, Germany

Tel: +49 8728 911 093

Fax: +49 8728 911 156

[www.35reclaim.de](http://www.35reclaim.de)

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**Umicore Electro-Optic Materials**

Watertorenstraat 33,  
B-2250 Olen, Belgium

Tel: +32-14 24 53 67

Fax: +32-14 24 58 00

[www.substrates.umicore.com](http://www.substrates.umicore.com)

**Wafer World Inc**

1100 Technology Place, Suite 104,  
West Palm Beach, FL 33407,  
USA

Tel: +1-561-842-4441

Fax: +1-561-842-2677

E-mail: [sales@waferworld.com](mailto:sales@waferworld.com)

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

**4 Epiwafer foundry****Spire Semiconductor LLC**

25 Sagamore Park Drive,  
Hudson, NH 03051,  
USA

Tel: +1 603 595 8900

Fax: +1 603 595 0975

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

**Albemarle Cambridge Chemical Ltd**

Unit 5 Chesterton Mills,  
French's Road, Cambridge CB4 3NP,  
UK

Tel: +44 (0)1223 352244

Fax: +44 (0)1223 352444

[www.camchem.co.uk](http://www.camchem.co.uk)

**Intelligent Epitaxy Technology Inc**

1250 E Collins Blvd,  
Richardson,  
TX 75081-2401,  
USA

Tel: +1 972 234 0068

Fax: +1 972 234 0069

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

**IQE**

Cypress Drive,  
St Mellons, Cardiff  
CF3 0EG,  
UK

Tel: +44 29 2083 9400

Fax: +44 29 2083 9401

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

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**5 Deposition  
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[metalorganicsAP@akzonobel.com](mailto:metalorganicsAP@akzonobel.com)

**Americas:**

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USA

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**Europe, Middle East and Africa:**

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Fax: +31 33 467 6101

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**Cambridge Chemical Company Ltd**

Unit 5 Chesterton Mills,  
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Cambridge CB4 3NP,  
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Fax: +44 (0)1223 352444

[www.camchem.co.uk](http://www.camchem.co.uk)

**Dow Electronic Materials**

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Tel: +1 978 557 1700

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**Matheson Tri-Gas**

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Tel: +1 510 793 2559  
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[www.mathesonrigas.com](http://www.mathesonrigas.com)

**Mining & Chemical Products Ltd**  
 (see section 1 for full contact details)

**Praxair Electronics**  
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 NY 10962,  
 USA  
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 Fax: +1 845 398 8304  
[www.praxair.com/electronics](http://www.praxair.com/electronics)

**SAFC Hitech**  
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 Wirral, Merseyside CH62 3QF,  
 UK  
 Tel: +44 151 334 2774  
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**Materion Advanced Materials Group**  
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 Buffalo, NY 14214,  
 USA  
 Tel: +1 716 837 1000  
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[www.williams-adv.com](http://www.williams-adv.com)

## 6 Deposition equipment

**AIXTRON SE**  
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[www.aixtron.com](http://www.aixtron.com)

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 Fax: +41 81 403 8001  
[www.evatecnet.com](http://www.evatecnet.com)

**Ferrotec-Temescal**  
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 Positas Rd,  
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**SVT Associates Inc**  
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**Veeco Instruments Inc**  
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## 7 Wafer processing materials

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**MicroChem Corp**  
 1254 Chestnut St. Newton,  
 MA 02464, USA  
 Tel: +1 617 965 5511  
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[www.microchem.com](http://www.microchem.com)

**Praxair Electronics**

(see section 5 for full contact details)

**8 Wafer processing equipment****EV Group**

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[www.logitech.uk.com](http://www.logitech.uk.com)**Oxford Instruments  
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**Plasma-Therm LLC**

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**SAMCO International Inc**

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Fax: +1 408 734 0961

[www.samcointl.com](http://www.samcointl.com)**SPTS Technology Ltd**

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Newport NP18 2TA,  
UK  
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Fax: +44 (0)1633 414141  
[www.spts.com](http://www.spts.com)

**SUSS MicroTec AG**

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85748 Garching,

Germany

Tel: +49 89 32007 0  
Fax: +49 89 32007 162  
[www.suss.com](http://www.suss.com)

**Veeco Instruments Inc**

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**9 Materials & metals****Goodfellow Cambridge Ltd**

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UK  
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Fax: +44 (0) 1480 424900  
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Cambridge CB3 8SQ,  
UK  
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[www.cambridge-fluid.com](http://www.cambridge-fluid.com)

**CS CLEAN SYSTEMS AG**

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**11 Process monitoring  
and control****k-Space Associates Inc**

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Fax: +49 7723 9197 22

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

## 12 Inspection equipment

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Karlsruhe, 76187,  
Germany

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Fax: +49 (0)721 595 4587

[www.bruker-axs.de](http://www.bruker-axs.de)

## 13 Characterization equipment

### J.A. Woollam Co. Inc.

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

## 14 Chip test equipment

### Keithley Instruments Inc

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USA

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Fax: +1 440.248.6168

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

## 15 Assembly/packaging materials

### ePAK International Inc

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Austin, TX 78759,  
USA

Tel: +1 512 231 8083  
Fax: +1 512 231 8183

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

### Gel-Pak

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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

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Carlsbad, CA 92010,  
USA

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[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

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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

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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

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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,  
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Fax: +1 770 808 8308  
[www.ClassOneEquipment.com](http://www.ClassOneEquipment.com)

**23 Services****Henry Butcher International**

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

**M+W Zander Holding AG**

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[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****Al Shultz Advertising Marketing for Advanced Technology Companies**

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San Jose, CA 95134, USA  
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Fax: +1 408 428 9600  
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Shenzhen Exhibition Center, China

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Valencia, Spain

**E-mail:** [electricalengineering@conferenceseries.net](mailto:electricalengineering@conferenceseries.net)

<http://electricalengineering.global-summit.com>

**4–6 November 2015**

## Successful Semiconductor Fabless 2015: Technology & supply chain challenges for fabless semiconductor companies

Paris, France

**E-mail:** [leroy@yole.fr](mailto:leroy@yole.fr)

[www.i-micronews.com/events/yole-events/eventdetail/44/-/successful-semiconductor-fabless-2015.html](http://www.i-micronews.com/events/yole-events/eventdetail/44/-/successful-semiconductor-fabless-2015.html)

**8–13 November 2015**

## ISGN-6: 6th International Symposium on Growth of III-Nitrides

Act City Hamamatsu, Hamamatsu, Japan

**E-mail:** [secretary@isgn6.jp](mailto:secretary@isgn6.jp)

[www.isgn6.jp](http://www.isgn6.jp)

**10–12 November 2015**

## 12th Avionics Fiber-Optics & Photonics Conference (AVFOP)

Santa Barbara, CA, USA

**E-mail:** [m.figueroa@ieee.org](mailto:m.figueroa@ieee.org)

[www.avfop-ieee.org](http://www.avfop-ieee.org)

**17–19 November 2015**

## 6th annual Strategies in Light (SIL) Europe 2015 (co-located with LuxLive 2015)

ExCeL London Exhibition and Convention Center, UK

**E-mail:** [registration@pennwell.com](mailto:registration@pennwell.com)

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

**7–9 December 2015**

## 2015 IEEE International Electron Devices Meeting (IEDM)

Washington Hilton, Washington DC, USA

**E-mail:** [iedm@his.com](mailto:iedm@his.com)

[www.ieee-iedm.org](http://www.ieee-iedm.org)

**16–18 December 2015**

## SEMICON Japan 2015

Tokyo Big Sight, Tokyo, Japan

**E-mail:** [jcustomer@semi.org](mailto:jcustomer@semi.org)

[www.semiconjapan.org/en](http://www.semiconjapan.org/en)

**27–29 January 2016**

## SEMICON Korea 2016

COEX, Seoul, South Korea

**E-mail:** [semiconkorea@semi.org](mailto:semiconkorea@semi.org)

[www.semiconkorea.org/en](http://www.semiconkorea.org/en)

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**13–18 February 2016**

**SPIE Photonics West 2016**

Moscone Center San Francisco, CA, USA

**E-mail:** customerservice@spie.org

<http://spie.org/SPIE-PHOTONICS-WEST-conference>

**1–3 March 2016**

**SIL 2016:**

**Strategies in Light,  
co-located with The LED Show**

Santa Clara Convention Center, CA, USA

**E-mail:** registration@pennwell.com

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

**15–17 March 2016**

**SEMICON China 2016**

Shanghai New International Expo Centre, China

**E-mail:** semichina@semi.org

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

**19–24 March 2016**

**APEC:**

**2016 IEEE Applied Power Electronics  
Conference and Exposition**

Long Beach Convention Center, CA, USA

**E-mail:** apec@apec-conf.org

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

**4–7 April 2016**

**SPIE Photonics Europe 2016**

SQUARE Brussels Meeting Centre, Brussels, Belgium

**E-mail:** info@spieeurope.org

<http://spie.org/SPIE-PHOTONICS-EUROPE-conference>

**13–16 April 2016**

**LED Taiwan 2016 and  
Taiwan International Lighting Show**

Taiwan World Trade Center, Taipei, Taiwan

**E-mail:** sluo@semi.org

[www.ledtaiwan.org](http://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

<http://spie.org/SPIE-DCS-conference>

<http://spie.org/SPIE-DCS-Defense+Security>

<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

[www.cpv-12.org](http://www.cpv-12.org)

**6 May 2016**

**31st annual Reliability Of Compound  
Semiconductors (ROCS) Workshop 2016**

Hyatt Regency Miami, FL, USA

Abstract deadline: 29 February 2016

**E-mail:** rocs@jedec.org

[www.jedec.org/home/gaas](http://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

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

**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)

**12–14 July 2016**

**SEMICON West 2016**

Moscone Center, San Francisco, CA, USA

**E-mail:** spoblete@semi.org

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

**13–17 June 2016**

**2016 Symposia on VLSI Technology and  
Circuits**

Hilton Hawaiian Village, Honolulu, HI, USA

Paper submission deadline: 25 January 2016

**E-mail:** vlsi@vlsisymposium.org

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

**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

Abstract deadline: 8 February 2016

[www.csw-jpn.org](http://www.csw-jpn.org)

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