EVG®

invent
innovate
implement

www.EVGroup.com

## Market-Leading Equipment for

# WAFER LEVEL OPTICS MANUFACTURING

- Enabling 3D / Depth Sensors, Biometric Authentication and AR/VR Displays
- Nanoimprint Lithography, Lens Molding / Stacking, Wafer Bonding and Metrology
- High performance equipment combined with the EVG NILPhotonics® Competence Center ensures short time to market

EVG® HERCULES® NIL

**GET IN TOUCH** to discuss your manufacturing needs
**www.EVGroup.com**

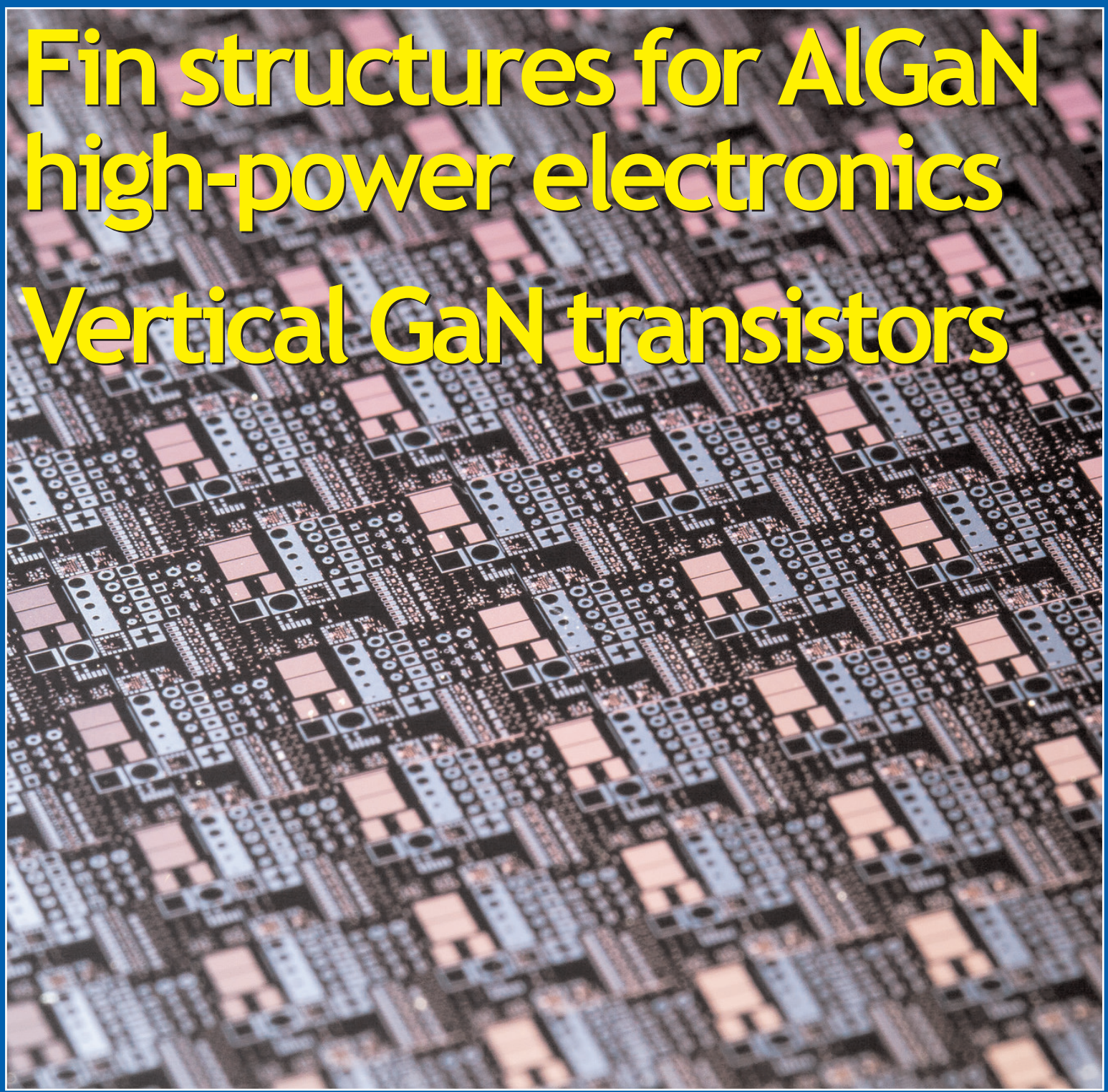
ISSN 1752-2935 (online)

# semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

Vol. 14 • Issue 2 • March/April 2019

www.semiconductor-today.com

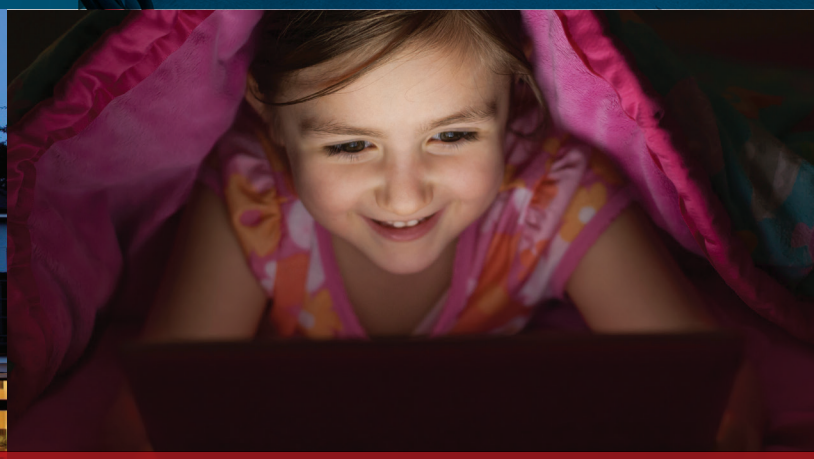


# Fin structures for AlGaN high-power electronics

# Vertical GaN transistors

Qorvo acquiring Active-Semi • Analog Devices invests in UnitedSiC
Cree divests Lighting Products • Kaiam Europe bought by Broadex


# Lower Cost LEDs



# Faster LED Adoption

## Another breakthrough from Veeco. This time it's EPIK.

### Introducing Veeco's new TurboDisc® EPIK700™ GaN MOCVD system

As global consumption for LED general lighting accelerates, manufacturers need bigger, better MOCVD technology solutions that increase productivity and lower manufacturing costs.

The EPIK700 MOCVD system combines Veeco's award-winning TurboDisc reactor design with improved wafer uniformity, increased productivity and reduced operations expenses to enable a cost per wafer savings of up to 20 percent compared to previous systems.

It also features a reactor with more than twice the capacity of previous generation reactors. This increased volume coupled with productivity advancements within the EPIK700 reactor, results in an unmatched 2.5x throughput advantage over previous reactors.

Learn how Veeco's TurboDisc EPIK700 GaN MOCVD system can improve your LED manufacturing process today.

The advantage is not just big. It's EPIK.

Contact us at *www.veeco.com/EPIK700* to learn more.

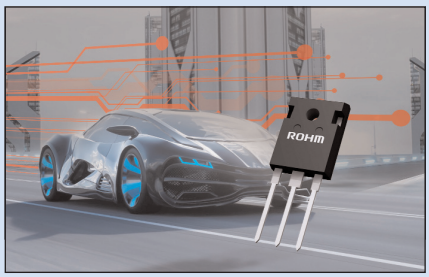

*Veeco's New TurboDisc EPIK700 GaN MOCVD System*

# contents



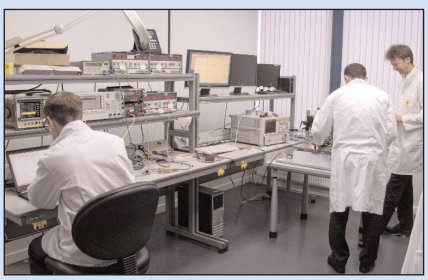

semiconductorTODAY
COMPOUNDS & ADVANCED SILICON

Vol. 14 • Issue 2 • March/April 2019

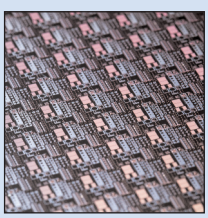




**p12** ROHM has added 10 new AEC-Q101-qualified automotive-grade SiC MOSFETs to its range.

**p18** The leadership team holds a plaque commemorating the opening of the AFRL–Cornell Center for Epitaxial Solutions (ACCESS), which is focusing on beta-gallium oxide (β-$Ga_2O_3$).



**p20** Plextek RFI has extended the RF-on-wafer cleanroom facilities at its design center for evaluating both packaged and unpackaged devices.



Cover: A processed gallium nitride (GaN) wafer, as used by Fraunhofer-IAF to grow lattice-matched ScAlN for high-voltage, high-current transistors. GaN and AlGaN is now also being grown with fin structures for multi-channel and vertical-current-flow devices in high-power electronics. **p62**

# editorial

## US–China trade hitting supply chains

According to industry association SEMI in its 'Worldwide Semiconductor Equipment Market Statistics Report', manufacturing equipment sales rose by 14% to a record $64.5bn in 2018. Although South Korea claimed the largest market share for the second consecutive year, it fell by 1% to $17.71bn while China rose to second largest for the first time (growing by a huge 59% to $13.11bn), overtaking Taiwan (down by 12% to $10.17bn). Behind Japan (up by 46% to $9.47bn), North America rose by just 4% to $5.83bn.

US-based Applied Materials retained its long-term lead of the equipment market although, according to The Information Network, its front-end wafer equipment revenue rose by just 1.1% in 2018. This reduced its market share from 21.2% to 18.8%, so it is now only just ahead of The Netherlands' ASML (which grew by 33.2% to 17.6% share, boosted by the adoption of EUV lithography systems) as well as direct rivals Japan's Tokyo Electron (which grew by 25.8%, rising from 15.1% to 16.7% share) and US-based Lam Research (which grew by 13.7%, though falling slightly from 16.9% to 16.8% share).

Most of these sales are for the silicon-based logic and memory IC markets, with overcapacity in the latter forecast to drive the overall equipment market down from 13.9% growth in 2018 to shrinkage of 29% in 2019. Markets are also likely to be distorted by trade sanctions between the USA and China (Applied Materials' biggest market, contributing 26% of its revenue in its most recent quarter to 27 January).

Although dominated by the silicon sector, such market dynamics are also affecting the compound semiconductor sector.

On 11 April, the US Department of Commerce's Bureau of Industry and Security (BIS) added 37 Chinese companies and research institutions to a red-flag list of 'unverified' entities focused on optics, electronics and machine tools etc that, while not embargoing dealings with them, requires US firms to "treat them with caution". If US suppliers fail to apply for new licences to sell them products or service installed equipment, then significant violations of US trade law could follow, warned the notice.

The listed entities include Applied Materials' customers Xi'an Jiaotong University, a unit of the Chinese Academy of Sciences, and Shanghai-listed Xiamen San'an Optoelectronics (the world's biggest LED chipmaker by revenue). According to Nikkei Asian Review, Applied Materials has ordered staff, contractors and other personnel to "immediately stop all pending and future equipment delivery, and cease all service activities at their sites".

The US directive could similarly influence non-US firms, as when the Committee on Foreign Investment in the United States (CFIUS) in late 2016 thwarted the acquisition by Chinese firm Grand Chip Investment of Germany-based MOCVD system supplier Aixtron (whose US subsidiary comprised 20% of its business) on grounds of national security (through the application of gallium nitride MOCVD for defense electronics).

However, since the market dominance of MOCVD system makers Aixtron and US-based Veeco has since been eroded by Chinese MOCVD system makers such as AMEC for GaN-based blue LED manufacturing, it remains to be seen if such protectionism for more complex device technology works in the long term or if restricting trade just adds impetus to China's development of a home-grown supply chain.

**Mark Telford, Editor**
**mark@semiconductor-today.com**

semiconductorTODAY
COMPOUNDS & ADVANCED SILICON

**Editor**
Mark Telford
Tel: +44 (0)1869 811 577
Cell: +44 (0)7944 455 602
Fax:+44 (0)1242 291 482
E-mail: mark@semiconductor-today.com

**Commercial Director/Assistant Editor**
Darren Cummings
Tel: +44 (0)121 288 0779
Cell:+44 (0)7990 623 395
Fax:+44 (0)1242 291 482
E-mail: darren@semiconductor-today.com

**Advertisement Sales**
Darren Cummings
Tel: +44 (0)121 288 0779
Cell:+44 (0)7990 623 395
Fax:+44 (0)1242 291 482
E-mail: darren@semiconductor-today.com

**Original design** Paul Johnson
www.higgs-boson.com

***Semiconductor Today* covers the R&D and manufacturing of compound semiconductor and advanced silicon materials and devices** (e.g. GaAs, InP and SiGe wafers, chips and modules for microelectronic and optoelectronic devices such as RFICs, lasers and LEDs in wireless and optical communications, etc).

**Regular issues contain**:
- news (funding, personnel, facilities, technology, applications and markets);
- feature articles (technology, markets, regional profiles);
- conference reports;
- event calendar and event previews;
- suppliers' directory.

***Semiconductor Today* (ISSN 1752-2935) is published free of subscription charge** in a digital format 10 times per year by Juno Publishing and Media Solutions Ltd, Suite no. 133, 20 Winchcombe Street, Cheltenham GL52 2LY, UK. See: www.semiconductor-today.com/subscribe.htm

news

# 5G to boost cellular RF power amplifier market

## Growth to return to PAs, but with cost and complexity challenges

After a lack-luster past three years, 5G will lead to a return to growth in the power amplifier (PA) market, forecasts Strategy Analytics in a new report covering RF PAs in phones and other cellular user equipment. However, suppliers should expect intense pricing pressure, according to the Strategy Analytics RF & Wireless Components report '5G Will Boost PA Market but Challenge Supplier Pricing'.

The power amplifier module is now the cornerstone for integration and attempts to reduce the parts count in the RF front end and — with new sub-6GHz bands for 5G, license shared access, uplink carrier aggregation and uplink MIMO (multiple-input, multiple-output) just around the corner — PA modules will continue to increase in complexity, putting pressure on Skyworks, Broadcom, Qorvo, Murata, Qualcomm and their supply partners to reduce production costs, says Strategy Analytics.

Based on the architectures of 2G, 3G, LTE and early 5G devices, the report looks at the recent market and provides a forecast to 2023 for market revenue and unit shipments of PAs, including discrete PA modules, PA-duplexers, S-PADs (switches, PAs and duplexers), PAMiDs (power amplifier modules with integrated duplexers) and TRMs (total radio modules).

"With 5G, the contents of PA modules will increase to encompass more bands, with more RF switching, filtering and power amplification elements," says report author Christopher Taylor, director of RF & Wireless Components. As the market evolves, the more complex PA modules will move from flagship smartphones to mid- and low-tier devices, as they have in the past," he adds.

"Having to put almost the entire RF front end covering multiple bands and technologies into a few PA modules has forced most of the smaller PA suppliers out of the market," notes Stephen Entwistle, VP of Strategic Technologies at Strategy Analytics. "The pressure will increase with 5G, likely favoring the top four suppliers with the scale and R&D budgets to keep up with OEMs' demands."

**www.strategyanalytics.com**

# RF power semiconductor market growing at 12.29% CAGR to $32.5bn in 2026

The RF power semiconductor market is rising at a compound annual growth rate (CAGR) of 12.29% from 2018 to $32.51bn in 2026, according to a report available from ResearchAndMarkets.com.

In the rapid development and use of power semiconductors (which are predominantly used for switching applications in electronics circuits), one of the most vital aims is to achieve minimum power losses in operation. RF power semiconductors have seen broad acceptance in wireless communication devices, as they efficiently enable RF power amplification. With the advent of 5G cellular communications, RF power semiconductors are establishing their importance across the wireless communications market. With greater demand for higher bandwidth and operating frequency, demand for RF power semiconductors is expected to rise at a promising rate.

By product type, the RF power amplifier segment is expected to see the highest growth rate due to LTE adoption and enormous demand for increased bandwidth.

By region, in 2017, the Asia-Pacific was the largest market for RF power semiconductors, due chiefly to the evolving electronics sector across the region. China is the world's largest consumer electronics hub, valued at about $300bn in 2017, while the consumer electronics market in Japan accounted for $109.98bn. Further, rapidly growing markets such as India, Korea and Taiwan are expected to drive the market, with the highest growth rate compared with other regions.

The RF power semiconductor market is further supported by the robust technical developments in semiconductors. Organizations are aiming to invest and engage in such advances in order to cater to dynamic requirements of end-users. For example, in 2016, Efficient Power Conversion Corp (EPC) partnered with ASD Technology Ltd to accelerate the process of product conception through to implementation. Correspondingly, EPC launched a wireless multi-mode demonstration system compatible with all wireless power charging standards in 2016. Further, in 2016 the US Army sanctioned $1.1m for Raytheon Company to create and demonstrate gallium nitride (GaN)-based RF semiconductors that can easily integrate with next-generation radar systems.

With growing technology advances and government initiatives, the RF power semiconductor is market expected to see promising growth across the forecast period, concludes the report.

**www.researchandmarkets.com/publication/mzkqvpr/4749571**

# LED materials market growing at 10.92% CAGR to $21,457.3m in 2024

Driven mainly by the increasing demand for energy-efficient lighting in residential and commercial construction activities, the light-emitting diode materials market will rise at a compound annual growth rate (CAGR) of 10.92% to $21,457.3m by the end of 2024, according to 'LED Materials Market Research Report — Forecast to 2024' by Market Research Future (MRFR).

The wafers segment was $4184.7m (40% of the market) in 2017, and is expected to grow at a CAGR of 11.77% during the forecast period due to increasing demand for cost-effective and energy-efficient lighting from numerous end-use industries such as construction, automotive and electrical & electronics. The substrates segment is expected to be the second largest, reaching $5387m by 2024.

The wafers segment has further been divided into sapphire, silicon, silicon carbide, and others. The sapphire sub-segment accounted for the largest market share (growing at a CAGR of 8.25%), while silicon is expected to be the fastest-growing sub-segment due to its growing use as wafer layers.

By application, the general lighting segment of about $4393.9m in 2017 comprised the largest market share (42%), and is expected to grow at a moderate CAGR of 12% to about $9650.6m in 2024 (remaining the major revenue-generating segment), driven by the increasing number of residential and commercial construction activities across the globe. The consumer electronics segment accounted for the second-largest market share and is expected to grow at a CAGR of 9.48% during the forecast period.

Some of the trends among the market players include product development using new LED materials to meet the demand for LED lighting from various industries. For example, in 2015 short-wavelength ultraviolet LED (UV-C LED) research firm CrayoNano AS of Trondheim, Norway developed new technology for layering aluminium gallium nitride (AlGaN) nanowires on graphene using Veeco Instruments Inc's metal-organic chemical vapor deposition (MOCVD) system.


Geographically, the Asia–Pacific region has dominated the global market, with a share of 39% in 2017, and is expected to grow at a high CAGR of 12.23% during the forecast period due to the growing automotive and electronics industries in the region.

China was the leading country in the region with a market share of 37% in 2017 due to the large consumer base and increasing consumption of LED materials in energy-efficient lights and consumer electronics. The North American market was the second largest, at $2626.9m in 2017, and is projected to grow at a substantial CAGR of 9.91% in the coming years. The USA accounted for 77% of the North American market in 2017 due to increased adoption of LED materials in energy-efficient lighting used in buildings to obtain LEED certification.

The European market held a significant market share of 23% and is expected to reach $2388.4m by the end of 2024 due to the expanding automotive industry in the region. Germany comprised 26.7% of the European market in 2017 owing to technical advances and product innovation.

The Middle East & Africa market was $639.2m in 2017 and is expected to grow at a CAGR of 11.31% during the forecast period. Turkey held 36% of this market in 2017 owing to growing demand in major end-use industries.

The Latin American market was $763.7m in 2017 and is expected to grow at a steady CAGR of 10.73%. Brazil dominated this market and is expected to grow at a healthy CAGR of 10.04% due to increasing demand in the auto-motive and consumer electronics industries.

Key players in the LED materials market include AkzoNobel N.V. (The Netherlands), Intematix (US), Osram Opto Semiconductors GmbH, OSRAM (Germany), Nichia Corp (Japan), Epistar Corp (Taiwan), EpiGan (Belgium), Plessey (UK), Sumitomo Electric Industries Ltd (Japan), Cree Inc (North Carolina), MACOM (US), UBE Industries Ltd (Japan), DOWA Electronics Materials Co Ltd (Tokyo), and II-VI Inc (USA).

**www.marketresearchfuture.com/reports/led-materials-market-6228**

# Qorvo to acquire programmable analog/mixed-signal power IC firm Active-Semi

## Acquisition expands addressable markets by over $3bn

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has agreed to acquire Active-Semi International Inc of Dallas, TX, USA, a private fabless supplier of programmable analog/mixed-signal power management and intelligent motor drive ICs.

Qorvo says that Active-Semi's technologies are positioned to intersect multiple long-term secular growth opportunities in 5G, industrial, data-center, automotive and smart-home applications by addressing the increased demand for efficient power solutions. The firm will become part of the Qorvo group IDP (Infrastructure & Defense Products).

"With the acquisition of Active-Semi, Qorvo will expand IDP's product offerings for existing customers and extend our reach into new high-growth power management markets," says Qorvo's president & CEO Bob Bruggeworth. "We see significant opportunities to accelerate adoption of Active-Semi's innovative analog/mixed-signal solutions across multiple markets by leveraging Qorvo's global scale, sales channel and customer relationships."

Power efficiency is increasingly a core requirement in electronic applications in IDP's existing markets, including 5G base stations, active phased arrays for defense, automotive, and Internet of Things (IoT). Active-Semi's programmable mixed-signal power solutions provide simplicity, efficiency and design flexibility — resulting in smaller footprints, lower bill of material costs and reduced time to market, says Qorvo.

"The combination of Active-Semi's programmable analog power solutions with Qorvo's leading product and technology portfolio opens up vast opportunities to accelerate revenue, develop more highly integrated system solutions and target new high-growth markets, like 5G infrastructure," comments Active-Semi's CEO Larry Blackledge.

Qorvo expects the acquisition to be accretive to non-GAAP gross margin and non-GAAP EPS in the first year. The acquisition is subject to regulatory approval and customary closing conditions and is expected to close in Qorvo's fiscal first-quarter 2019 (ending 29 June).

**www.active-semi.com**

# Qorvo adds Taiwan-based distributor Answer Technology for design creation and customer logistics support of IDP products

Qorvo has entered into a channel agreement for Taiwan-based Answer Technology Co Ltd to focus on selling Qorvo's IDP (Infrastructure & Defense Products) solutions through design creation and customer logistics support.

Established in 2000, ANStek is dedicated to serving customers in Taiwan, across markets including automation & energy, instrumentation, aerospace, communications, automotive and healthcare.

"Qorvo is committed to making our customers' jobs easier with innovative technology and products, world-class business processes and key channel partners," says IDP sales VP Christian Lepiane. "Our new partnership with Answer Technology will help Qorvo better serve our customers and expand our market presence in Taiwan."

**www.anstek.com.tw**

# Honored for helping to drive the global adoption of 5G

Qorvo says that, during the Mobile World Congress (MWC 2019) in Barcelona, Spain, its director of carrier liaison and standards Paul Cooper was recognized by the Global TD-LTE Initiative (GTI) as a 2019 Honorary Award recipient at its GTI Night celebration.

Paul has worked for several years to further the cause of the GTI 2.0 mission to establish a 5G RF front-end sub-6GHz ecosystem, supporting member carriers in the USA, China and Europe. The Qorvo Carrier Program team coordinated test and marketing staff to provide data in support of 3GPP New Radio (NR) standards that will drive global adoption of 5G. The award was the culmination of work by Qorvo's 3GPP RAN4 standards team and engineering teams providing lab test data.

**Paul Cooper and a cross-company collaborative team accept a GTI Honorary Award at MWC19.**

"We're proud to be among a team of experts from multiple companies, including Qorvo, Skyworks, Sprint, Qualcomm and LG, that are helping our customers' customers — the wireless carriers — address the RF challenges of 5G," said Qorvo.

**www.qorvo.com**

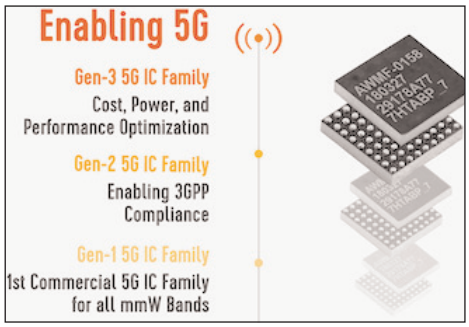
# Anokiwave launches third-generation family of mmW 5G ICs

Anokiwave Inc of San Diego, CA, USA — which provides highly integrated silicon core chips and III-V front-end integrated circuits for millimeter-wave (mmW) markets and active antenna-based solutions — has launched the first product in its family of third-generation 5G silicon ICs.

The AWMF-0151 is a 28GHz quad-core IC that can operate as a dual-polarization 4-channel beamformer IC or as a single-polarization 8-channel beamformer IC. As part of the firm's strategy to enable mmW 5G systems by commercializing planar active antennas with silicon core ICs, Anokiwave is planning to extend its 5G IC family by offering a complete signal chain solution from IF to antenna in each 5G mmW band.

The AWMF-0151 operates over the 3GPP n257 (26.50–29.50GHz) and n261 (27.50–28.35GHz) frequency bands. With low-cost materials, embedded ZERO-CAL, fast beam steering and KINETIC-GREEN technologies, field health monitors for remote monitoring as well as the continued drive to higher power efficiency, the new IC family can enable service providers to manage the capital expenses and operating expenses of making ubiquitous 5G a reality, says the firm.

"Anokiwave's new Gen-3 5G silicon IC family enables powerful and efficient active antennas while adding new and enhanced features to




make 3GPP-compliant cutting-edge performance even easier," says chief systems architect David Corman. "The system architecture behind the family allows us to address multiple-use cases ranging from infrastructure to consumer equipment," he adds. "By harnessing the highest levels of integration, three generations of active antenna IC learning and cost structures only available on 300mm silicon processes, we've enabled base-stations and small cells to reach price points on par with Wi-Fi access points."

The AWMF-0151 is packaged in a 5.2mm x 4.0mm WLCSP (wafer-level chip-scale package), fitting within the typical 5.3mm lattice spacing at 28GHz.

For ease of adoption of the technology and capabilities, Anokiwave offers evaluation kits that include boards with the IC, USB-SPI interface module with drivers, and all required cables. Pilot production deliveries are available in first-quarter 2019.

**www.anokiwave.com/5g**

# MACOM's CFO resigns

MACOM's senior VP & chief financial officer Robert McMullan has resigned for personal reasons, transitioning to an advisory role and supporting MACOM in the next two months to ensure an orderly transition. MACOM has engaged an executive search firm to assist with finding a replacement.

"Bob was instrumental in rebuilding and reshaping MACOM through numerous acquisitions and divestitures, as well as corporate financing transactions," notes president & CEO John Croteau.

Conor Hegarty has been made principal financial officer & principal accounting officer. In 22 years with MACOM, he was senior international finance director from March 2011 to August 2016 and, since then, VP of financial planning & analysis.

**www.macom.com**

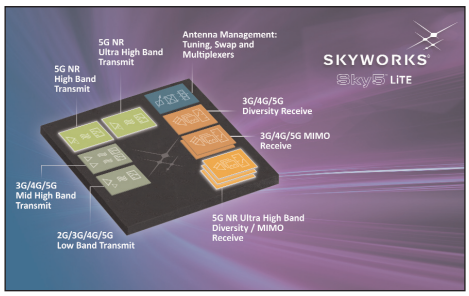
# Skyworks launches Sky5 LiTE front-end for universal 5G cellular deployment

Skyworks has launched Sky5 LiTE — claimed to be the industry's first fully integrated front-end solution for mass-tier 5G cellular applications.

With improved RF performance in a compact package, Skyworks' new device simplifies designs, enabling faster deployment. The baseband-agnostic platform supports up to 100MHz-wide bandwidth of 5G new radio (NR) waveforms with flexible power management options, delivering high-speed network operation with optimized efficiency and near-zero latency.

Targeted for mass markets, Sky5 LiTE interfaces with all leading chipset providers and equips early 5G adopters with differentiated architectures for an open ecosystem (the favored approach compared with closed, sole-sourced RF front-end products). With the recent launch of Sky5 Ultra for premium applications, Skyworks claims that it offers the most comprehensive 5G portfolio on the market.

"Sky5 LiTE exceeds the performance requirements demanded by next-generation devices while accelerating 5G implementation," says Kevin Walsh, VP of marketing. "Skyworks is offering truly turnkey,




regionally optimized, easily deployable solutions purposefully designed to deliver all of the transmit and receive functionality in a highly integrated form factor," he adds. "Our Sky5 portfolio is powering revolutionary applications across mobile, automotive and the Internet of Things."

According to the Global Mobile Suppliers Association, 201 operators in 83 countries are investing in 5G mobile and fixed wireless access networks in the form of tests, trials, pilot deployments and launches.

All Sky5 solutions support new 5G NR waveforms and spectrum as well as enhanced carrier aggregation and 4G/5G dual connectivity, while delivering high levels of integration and performance. Functional core blocks include:

**Primary transmit (Regional)**

- SKY5-8255 – dual-chain N77/N79 ultra-high-band power amplifier with integrated low-noise amplifier and filters (LPAMiF);
- SKY5-8254 – N41 high-band power amplifier with integrated filter (PAMiF);
- SKY5-8091-11 – low-band 4G/5G power amplifier module with four integrated duplexers (PAMiD) and 2G support;
- SKY5-8095-11 – mid/high-band PAMiD with eight integrated duplexers/filters;
- SKY5-8096-11 – mid/high-band PAMiD with nine integrated duplexers/filters and antenna swap functionality.

**Diversity/MIMO (Regional)**

- SKY5-3735 – low/mid/high-band diversity receive (DRx) module;
- SKY5-3728 – ultra-high-band N77/79 DRx/MIMO module with SRS support.

**Antenna management core**

- SKY5-9269 – SP4T 80v aperture tuning and RF distribution switch;
- SKY5-9256 – 4 x SPST 45v aperture tuning switch;
- SKY5-9699 – DPDT antenna swap switch;
- SKY5-9260 – SP4T 60v aperture tuning and RF distribution switch.

**www.skyworksinc.com/Sky5**

# Skyworks unveils Sky5 Ultra platform for 5G cellular front-ends

Skyworks has launched Sky5 Ultra for 5G cellular architecture, as a fully integrated, baseband-agnostic solution that combines all of the critical front-end functionality required to enable high-performance 5G mobile devices with global coverage in a compact form factor.

The platform features what are said to be best-in-class transmit and receive capabilities with high efficiency and output power, enabling highly reliable network connections while optimizing battery life (both critical for 5G applications). Also, the Sky5 Ultra leverages DSBGA packaging, reducing the footprint, and TC-SAW and BAW filtering, uniquely providing what is claimed to be the best performance at each targeted frequency band. The solution also supports up to 100MHz-wide bandwidth, maximizing data throughput at ultra-fast speeds.

With momentum accelerating towards 5G, the Sky5 portfolio is a highly flexible and customizable suite designed to meet global requirements, says Joel King, senior VP & general manager of Mobile Solutions. "Sky5 Ultra represents another breakthrough in simplifying the growing complexity of 5G device development — delivering unmatched performance while expediting deployment through full integration and optimized form factors," he clams. "We are empowering top mobile device manufacturers and network providers with complete, turnkey solutions that will ultimately bring 5G to realization."

5G rollouts have begun and will ramp up over the next few years. The Global Mobile Suppliers Association says 11 worldwide operators have announced limited 5G service launches and seven others have turned on 5G base stations, with commercial services to follow.

Sky5 Ultra incorporates high-efficiency transmit, diversity receive (DRx) and MIMO modules with what is said to be industry-leading noise figure and low insertion loss, in addition to an array of aperture tuners and antenna swap switches for optimal antenna management. Like all Sky5 solutions, the front-end platform supports new 5G NR waveforms and spectrum as well as enhanced carrier aggregation and 4G/5G dual connectivity, while delivering high levels of integration and performance. Functional core blocks include:

**Primary transmit (Global)**

- SKY5-8255 – dual-chain N77/N79 ultra-high-band power amplifier with integrated low-noise amplifier and filters (LPAMiF);
- SKY5-8254 – N41 high-band PA with integrated filter (PAMiF);
- SKY5-8265 – mid/high-band power amplifier with integrated low-noise amplifier and duplexers (LPAMiD) with DSBGA packaging;
- SKY5-8211 – low-band LPAMiD;
- SKY5-8212 – low-band LPAMiD with DSBGA packaging;
- SKY77365 – GSM power amplifier.

**5G diversity/MIMO (Global)**

- SKY13725 – low-band DRx module with DSBGA packaging;
- SKY13726 – mid/high band DRx module with DSBGA packaging;
- SKY13727 – mid/high band MIMO module with DSBGA packaging;
- SKY5-3728 – Ultra-high-band N77/79 DRx/MIMO module with SRS support.

**Connectivity (GPS, Wi-Fi, Bluetooth) modules**

- SKY65725-81 – shielded GPS;
- SKY65728-11 – L5 shielded GPS;
- SKY85819-11 – WLAN/GPS antenna share module;
- SKY85817-11 – dual-band LAA/WLAN;
- SKY85774-11 – 5GHz LAA/WLAN.

**Antenna management**

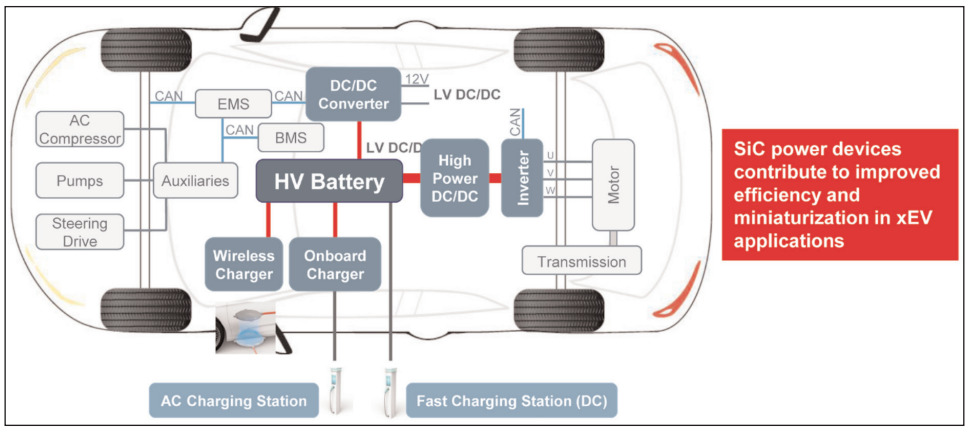
- SKY5-9269 – SP4T 80v aperture tuning and RF distribution switch;
- SKY5-9256 – 4 x SPST 45v aperture tuning switch;
- SKY5-9699 – DPDT antenna swap switch.

**www.skyworksinc.com/Sky5**

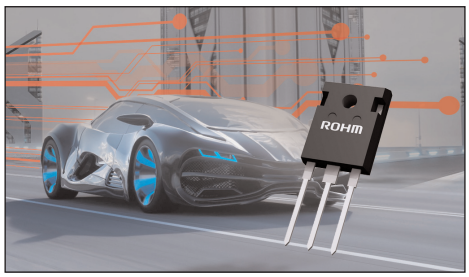
# ROHM adds automotive-grade SiC MOSFETs

Power semiconductor maker ROHM of Kyoto, Japan has announced the addition of 10 new automotive-grade silicon carbide (SiC) metal-oxide-semiconductor field-effect transistors (MOSFETs). The SCT3xxxxxHR series allows ROHM to offer what it claims is the industry's largest lineup of AEC-Q101-qualified SiC MOSFETs that provide the high reliability necessary for automotive on-board chargers and DC/DC converters.

In recent years, in response to growing environmental awareness and rising fuel costs, an increasing number of automotive makers have been offering electric vehicles (EVs). However, although EVs are becoming more widespread, their relatively short driving range remains problematic. To improve driving distance, batteries are trending towards larger battery capacities with shorter charging times. This, in turn, demands high-power and high-efficiency on-board chargers such as 11kW and 22kW, leading to the increased adoption of SiC MOSFETs. In addition, higher-voltage batteries (800V) require power devices featuring low loss and higher withstand voltages.




SiC power devices contribute to improved efficiency and miniaturization in xEV applications




To meet these needs, ROHM has added 10 new models to its lineup of AEC-Q101-qualified MOSFETs that utilize a trench gate structure. The result is the industry's largest portfolio, available in both 650V and 1200V variants. ROHM says that also, going forward, it aims to further improve quality and strengthen its lineup to increase device performance, reduce power consumption, and achieve greater miniaturization.

www.rohm.com/web/global/sic-mosfet

# ON Semiconductor adds industrial- & automotive-qualified SiC MOSFETs

ON Semiconductor of Phoenix, AZ, USA — which supplies power management, analog, sensors, logic, timing, connectivity, discrete, system-on-chip (SoC) and custom devices — has introduced two new silicon carbide MOSFET devices. The industrial-grade NTHL080N120SC1 and AEC-Q101 automotive-grade NVHL080N120SC1 bring the enabling, wide-ranging performance benefits of wide-bandgap technology to important high-growth end-application areas such as automotive DC–DC and onboard charger applications for electric vehicles (EVs) as well as solar and uninterruptible and server power supplies.

The launch strengthens the firm's growing SiC ecosystem that features complementary devices including SiC diodes and SiC drivers, plus vital resources such as device simulation tools, SPICE models and application information to help design and systems engineers meet high-frequency circuit development challenges.

ON Semiconductor says that its 1200V, 80mΩ, SiC MOSFETs are rugged and align with the needs of modern high-frequency designs. They combine high power density with highly efficient operation that can significantly reduce operating costs and overall system size due to smaller device footprints. These characteristics also mean that less thermal management is required, further reducing bill of materials (BoM) costs, size and weight.

Key features and associated design benefits of the new devices include low leakage current, a fast intrinsic diode with low reverse recovery charge (which gives steep power loss reduction and supports higher-frequency operation and greater power density) and low $E_{on}$ and $E_{off}$/fast turn ON and OFF combined with low forward voltage to reduce total power losses and therefore cooling requirements. Low device capacitance supports the ability to switch at very high frequencies, which reduces troublesome EMI issues. Meanwhile, higher surge, avalanche capability and robustness against short-circuits enhances overall ruggedness, gives improved reliability and longer overall life expectancy.

ON Semiconductor says that a further unique benefit of its new SiC MOSFET devices is a patented termination structure that adds to reliability and ruggedness and enhances operational stability. The NVHL080N120SC1 has been designed to withstand high surge currents and offers high avalanche capability and robustness against short circuits. The AEC-Q101 qualification of the MOSFET (plus other SiC devices offered) ensures that they can be fully utilized in the growing number of in-vehicle applications emerging as a result of increasing electronic content and electrification of powertrains. A maximum operating temperature of 175°C enhances suitability for use in automotive designs as well as other target applications where high density and space constraints are pushing up typical ambient temperatures.

"Increasingly, the most important applications and current mega trends demand all-round performance beyond that of regular silicon devices," says Gary Straker, VP & general manager, Power MOSFET Division, Power Solutions Group. "ON Semiconductor's comprehensive SiC portfolio, enhanced by the introduction of these two new MOSFETs and supported by an ecosystem of tools and resources, means that not only can we provide the complete wide-bandgap component solution but that we can lead engineers through the development and design-in process to achieve a solution that performs to expectations, is cost-effective and has reliability coupled with longevity."

The firm plans to launch further wide-bandgap devices through 2019.

**www.onsemi.com**

# Littelfuse launches 650V SiC Schottky diodes with new package sizes and current ratings from 6A to 40A

At the Applied Power Electronics Conference & Exposition (APEC 2019) in Anaheim, CA (17–21 March), Littelfuse Inc of Chicago, IL, USA, which provides circuit protection technologies (including fuses, semiconductors, polymers, ceramics, relays and sensors), introduced two additions to its expanding line of second-generation 650V, AEC-Q101-qualified silicon carbide (SiC) Schottky diodes.

Both series offer power electronics system designers performance advantages over traditional silicon-based devices, including negligible reverse recovery current, high surge capability and a maximum operating junction temperature of 175°C, making them suitable for applications in which improved efficiency, reliability and thermal management are desirable.

The LSIC2SD065DxxA Series SiC Schottky diode is available with current ratings of 6A, 10A or 16A in a TO-263-2L package. The LSIC2SD065ExxCCA Series SiC Schottky is available with current ratings of 12A, 16A, 20A or 40A in a TO-247-3L package. Both are available in tape-and-reel format, with a minimum order size of 800 devices.

The SiC Schottky diodes dissipate less energy and can operate at higher junction temperatures than alternative solutions such as standard silicon bipolar power diodes. They also require smaller heatsinks and support a smaller system footprint. These advantages offer end-users the benefits of more compact, energy-efficient systems and a potential lower total cost of ownership, says the firm.


**Littelfuse's 6Amp LSIC2SD065D06A and 12Amp LSIC2SD065E12CCA SiC Schottky diodes.**

Typical applications for the new 650V SiC Schottky diodes include: electric vehicle charging stations; buck/boost stages in DC–DC converters; free-wheeling diodes in inverter stages; high-frequency output rectification; and power factor correction (PFC).

"These additions to our fast-growing 650V SiC Schottky diode family allow us to offer a broader selection of current ratings and package designs suitable for a wider range of applications," says Silicon Carbide product marketing manager Christophe Warin. "These new SiC Schottky diodes enable a variety of design optimization opportunities, including increased power density, higher efficiency and potentially lower bill of materials costs."

The 650V SiC Schottky diodes are said to offer the following benefits:

- AEC-Q101-qualified diodes exhibit exceptional performance in demanding applications.
- Suitable for high-frequency power switching.
- Safe operation and ease of paralleling for reduced stress on the opposing switch.
- Larger design margin and relaxed thermal management requirements due to 175°C maximum operating junction temperature.

**www.littelfuse.com**

# Analog Devices makes strategic investment in UnitedSiC in exchange for long-term supply deal

Fabless silicon carbide (SiC) FET and diode power semiconductor provider United Silicon Carbide Inc (USCi) of Monmouth Junction, NJ, USA has announced a strategic investment and long-term supply agreement from Analog Devices Inc (ADI) of Norwood, MA, USA (which provides mixed-signal ICs for cable access).

"From our first meeting with the ADI Power team, they instantly understood the value of our SiC technology and the ease with which the devices could be scaled and utilized in their power platforms," says UnitedSiC's president & CEO Chris Dries. "This is a terrific time to bring such a high-caliber leader like ADI on as a shareholder."

UnitedSiC and ADI have been collaborating on SiC-based products and devices for more than two years. As wide-bandgap power devices, and SiC in particular, become more mainstream and cost effective, the inclusion of the devices should further strengthen ADI's analog power portfolio.

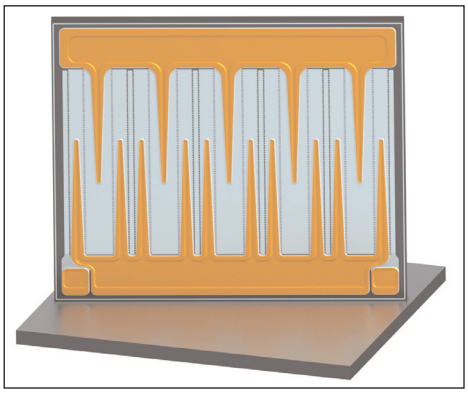
"For the last few years, we have been actively following the development and progress of silicon carbide technology and devices," notes Steve Pietkiewicz, senior VP of Power Products at ADI. "We found UnitedSiC's FET technology to be ideally suited for ADI's high-performance power platforms and our pursuit of additional high-voltage applications," he adds.

**www.analog.com**
**www.unitedsic.com**

# GaN Systems unveils highest-current GaN power transistors

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) has launched what it says are the industry's highest-current 650V GaN enhancement-mode high-electron-mobility transistors (E-HEMTs) with the addition of the GS-065-150-1-D (150A, 650V) and the GS-065-080-1-D (80A, 650V) to its line of GaN power transistors. In particular, the 150A, 650V transistor is claimed to be unmatched in both current (80A at 22mΩ) and resistance (50A at 18mΩ) compared with other GaN power transistors on the market.

The products are said to meet existing high-power system requirements to achieve higher operating currents, higher efficiency, and smaller size and weight. Developed specifically for automotive, industrial and renewable energy industries, the transistors feature the highest-current GaN in production. Applications include:



**GaN Systems' new GS-065-080-1-D 80A, 650V GaN E-HEMT power transistor.**

- traction inverters (75–150kW) and onboard chargers (6.6–22kW range) in electric vehicles;
- energy storage systems and solar/PV inverters up to 50kW+; and
- industrial motor drives and controllers up to 10kW+.

The products are sold in a die form factor, targeted at various power module topologies. Customers use the die in modules to create half-bridge, full-bridge and six-pack configurations to create optimized high-power designs with integrated gate drive circuits to differentiate their end-customer solutions.

"The increasing complexity and performance demands of power systems have created the need for higher-performance GaN solutions," says CEO Jim Witham. "Our family of innovative and unprecedented transistors are growing to meet the overwhelming requirements from our customers and partners for high-performance GaN-based technology," he adds. "Module companies can now offer the industry's best GaN E-HEMTs in high-power modules, allowing OEMs and tier-1 suppliers to focus on implementing highly efficient power electronics using GaN with ease and confidence."

GaN Systems displayed its family of GaN transistors at the Applied Power Electronics Conference (APEC 2019) in Anaheim, CA, USA (17–21 March).

**www.apec-conf.org**
**www.gansystems.com**

# GaN Systems makes available high-efficiency 50W wireless power amplifier evaluation kit

GaN Systems has announced the availability of its 50W wireless power amplifier, a small-size, low-cost and high efficiency evaluation board suitable for wireless power transfer and charging applications. It is targeted for lower-power applications in industrial and consumer markets for items such as power tools, Internet of Things (IoT) devices, handheld terminals, medical devices and household robots.

The evaluation kit adds to GaN Systems' solutions that include the 100W power amplifier and 300W power amplifier, which are designed to support, simplify and speed up the innovation of wireless power transfer systems. These kits combine GaN Systems' power transistors with high-frequency GaN E-HEMT drivers from pSemi Corp and are designed to be consistent with AirFuel standards.


**GaN Systems' new 50W wireless power amplifier evaluation kit.**

"Wireless power is growing, and technologies need to progress quickly to overcome the current technical challenges in the market," says Paul Wiener, VP strategic marketing. "In the area of wireless power transfer, designers are demanding solutions with spatial freedom, high power and high efficiency which, by definition, requires high-frequency GaN-based solutions."

The 50W evaluation kit addresses challenges associated with working at high frequency, which provides an easy-to-use baseline for engineers in their system designs, says the firm.

GaN Systems displayed its family of wireless power amplifiers and several wireless power implementations at the Applied Power Electronics Conference (APEC 2019) in Anaheim, CA, USA (17–21 March).

**www.gansystems.com/apec2019**

# Transphorm's Gen III GaN platform earns automotive qualification

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage (HV) power conversion applications — has announced that its third-generation, JEDEC-qualified high-voltage GaN platform has passed the Automotive Electronics Council's AEC-Q101 stress tests for automotive-grade discrete semiconductors. This marks the firm's second automotive-qualified product line, as well as its most reliable, given the Gen III GaN platform's ability to perform at 175°C during qualification testing.

The TP65H035WSQA Gen III AEC-Q101-qualified GaN FET has typical on-resistance of 35mΩ in an industry-standard TO-247 package. As with its predecessor — the 50mΩ Gen II TPH3205WSBQA — the devices target AC-to-DC on-board chargers (OBCs), DC-to-DC converters and DC-to-AC inverter systems for plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs).

Launched last June, Transphorm's Gen III devices came onto the market as what was claimed to be the highest-reliability, highest-quality (Q+R) GaN FETs available. They offered lower electromagnetic interference (EMI) along with increased noise immunity (threshold voltage at 4V) and gate robustness (at ±20V), producing quieter switching and higher performance at higher current levels with minimal external circuitry.

Transphorm says that commitment to Q+R influences its choice to conduct extended and accelerated standards testing, to include JEDEC and AEC-Q101. For this latest automotive qualification, the firm stressed the devices' thermal limits to 25°C more than those of the standard AEC-Q101-qualified high-voltage silicon MOSFET counterparts.

Beyond proving the GaN platform's robustness, the higher-temperature testing demonstrates that Transphorm's AEC-Q101 GaN FETs can give design engineers ample thermal headroom when developing any power system.

"Proving device quality and reliability is perhaps the most critical factor influencing customer confidence in high-voltage GaN FETs — particularly in the automotive and electric vehicle markets," says Philip Zuk, VP of worldwide technical marketing. "To that end, we ensure that our GaN maintains its performance and reliability even in real-world conditions that may be far harsher than what mission profiles call for," he adds. "As shown by the published reliability data, our JEDEC-qualified Gen III platform has a Field Failure FIT rate of 3, which is in line with that of silicon carbide (SiC). It's this high reliability level that allowed Transphorm to release a Gen III automotive FET at 175°C."

Transphorm reckons that its second AEC-Q101-qualified device further validates its Q+R, as was also demonstrated in the January release of what was claimed to be the industry's first Field Reliability data and first Early Life Failure rate calculations (the source of the FIT rate referenced above).

**www.transphormusa.com**

# US Navy awards Raytheon $402m contract for GaN-based SPY-6 radars

Raytheon Company of Waltham, MA, USA says that the Naval Sea Systems Command in Washington DC has awarded its Integrated Defense Systems (IDS) business of Tewksbury, MA a $402,658,015 fixed-price-incentive modification to the existing $327,146,998 contract N00024-14-C-5315 (awarded in May 2017, and itself a modification to prior contract N00024-14-C-5315) to exercise options for Air and Missile Defense Radar Program (AMDR) low-rate initial production (LRIP) for three SPY-6 radar units (to be deployed on DDG 51 Flight III-class ships).

AN/SPY-6(V) is the US Navy's next-generation integrated air and missile defense radar. Currently in production and on track for the DDG-51 Flight III destroyer, SPY-6 employs gallium nitride-based technology to enable 360° active electronically scanned array (AESA) capability, providing protection against air, surface and ballistic missile threats.

The radar comprises individual radar modular assemblies (RMAs) as building blocks — each a self-contained radar in a 2'x2'x2' box — that can stack together to form any size array to fit the mission requirements of any ship, making SPY-6 the Navy's first truly scalable radar.

Work will be performed by Raytheon IDS in Marlborough, MA, USA and is expected to be completed by March 2023.

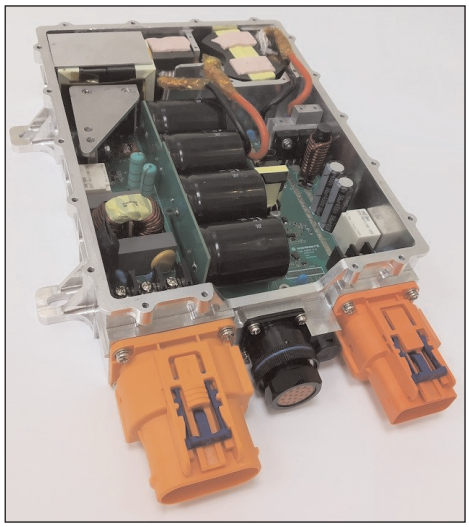
**www.raytheon.com/capabilities/products/amdr**

# VisIC offers smallest 6.7kW on-board charger reference design for EV market

VisIC Technologies Ltd of Nes Ziona, Israel — a fabless developer of power conversion devices based on GaN metal-insulator-semiconductor high-electron-mobility transistors (MISHEMTs) — has announced the availability of its on-board charger (OBC) reference design for the fast-growing electric vehicle (EV) market.

The 6.7kW OBC has a size and weight of only 2.3L and 4.5kg respectively, providing nearly 3kW/L power density (3x better than existing commercially available products). With efficiency above 96% across a wide load range, it helps automotive manufacturers to reduce power losses and enables faster charging for electric vehicle owners, says VisIC.

The 6.7kW OBC using VisIC's GaN power devices targets plug-in



hybrid vehicles/electric vehicles (PHEV/EV) applications. With a universal 110–220V/16–32A AC input and 200–430V DC output for charging the automotive battery by controlling voltage and current flow to the battery, the charger is designed to provide the interfaces to charging standards on the input power side and thus adapts to charging infrastructure.

The OBC design using VisIC's GaN technology, designed for AEC-Q101 automotive qualification requirements, demonstrates a reduction in power losses, size and weight, says the firm. The overall advantages include simplifying the cooling systems, reducing the charging time, and reducing the size and cost of the electric vehicle.

"This reference design proves the benefits and improvements VisIC's GaN technology can bring to the xEV users," says Ran Soffer, senior VP sales & marketing. "With VisIC's GaN technology, electrical cars will be more efficient, lighter in weight and more affordable."

**www.visic-tech.com**

# Gapwaves presents active 5G antenna using Qorvo's GaN power amplifiers

Following the release of a 28GHz active 5G antenna last August, Sweden's Gapwaves (founded in 2011 based on research at Chalmers University of Technology) has now presented a second release using the gallium nitride on silicon carbide (GaN-on-SiC) technology of Qorvo Inc of Greensboro, NC, USA.

As a development from the previous beam-forming antenna, this second release with a high-performing filter and a transition from PCB to Gapwaves' waveguide antenna technology uses integrated GaN monolithic microwave integrated circuits (MMICs) in a front-end module from Qorvo.

Integration of the dual-channel GaN front-end module together with the beam-forming chip-set yields a prototype based on standard components. Together with Gapwaves' waveguide technology, this provides telecom equipment suppliers with a platform to develop millimeter-wave products with exceptional coverage and performance, e.g. for 5G mobile access or fixed wireless access.

Measurements performed on the prototype are said to demonstrate good performance with low power consumption while maintaining good thermal handling (essential for the power amplifiers), as well as high antenna efficiency with low losses and high EIRP (equivalent isotropically radiated power). The solution is said to be one of the few meeting future performance needs of 5G mobile access and fixed wireless access networks.

"Built on standard components and Gapwaves waveguide technology, this product is one of few on the market that truly demonstrates a solution that meets the requirements of future 28GHz 5G-networks," claims Gapwaves' CEO Lars-Inge Sjöqvist. "Power consumption and large coverage are key elements when realizing the future's millimeter-wave mobile networks," he adds.

"Qorvo's innovative 5G products leverage decades of millimeter RF design, and have helped conduct dozens of 5G field trials," says Roger Hall, general manager, Qorvo High Performance Solutions. "Our differentiated GaN solutions are now addressing complex network requirements that are making 5G a reality."

The antenna prototype and measurement results were presented at Mobile World Congress (MWC19) in Barcelona, Spain (25–28 February).

Further releases of Gapwaves' 28GHz 5G-antenna will include features such as up- and down-conversion and digital beam forming.

**www.gapwaves.com**
**www.qorvo.com**

# USA's AFRL & Cornell opening ACCESS as Center of Excellence focusing on beta-gallium oxide

## AFRL–Cornell Center for Epitaxial Solutions focusing on synthesis and fundamental understanding of β-$Ga_2O_3$

The US Air Force Research Laboratory (AFRL) and Cornell University are announcing the opening of a new university-led Center of Excellence focusing on the synthesis and fundamental understanding of beta-gallium oxide (β-$Ga_2O_3$) — a material with the potential to challenge silicon and other materials currently used in high-voltage and high-power electronics such as electric vehicles (EVs) and solar cells.

The high-performance, wide-bandgap, oxide-based semiconductor has the potential to advance high-voltage electronics, but the fundamental understanding of this material remains extremely limited.

"The AFRL–Cornell Center for Epitaxial Solutions [ACCESS] will be a comprehensive Center of Excellence to grow, characterize and optimize this novel material," says Cornell lead principal investigator Dr Mike Thompson, an associate professor of Materials Science and Engineering (who for the past 28 years has focused on the behavior and processing of semiconductor materials under extreme conditions using pulsed and continuous-wave laser exposure).

Thompson and his team at Cornell were selected as the university partner by AFRL's Air Force Office of Scientific Research (AFOSR), Materials and Manufacturing directorate, and Sensors directorate. "ACCESS will be a unique collaboration between researchers at Cornell and counterparts at AFRL, enhanced by the exchange of students and researchers between these labs," says AFOSR program officer Dr Ali Sayir. Students and researchers at Cornell will have the opportunity to work closely with AFRL researchers at facilities at both Cornell's campus and Wright Patterson Air Force Base in Dayton, Ohio.


**The AFRL–Cornell Center for Epitaxial Solutions leadership team holds a plaque commemorating the opening of the center at Cornell. From left: associate professor Mike Thompson, associate professor Farhan Rana, professor Debdeep Jena, professor David Muller and professor Huili Grace Xing.**

This type of partnership has positive effects for both existing research and the future of the field, says Sayir. "We see the Center of Excellence program as a prime opportunity for academic engagement and as a pipeline for highly skilled researchers," he adds. "The hope is that student exposure to AFRL will enhance workforce development by making students aware and excited about career opportunities."

ACCESS has been made possible by a three-year, $3m grant awarded by the AFRL, with additional funds provided by Cornell and an option for a two-year extension. The center will be organized around two key thrust areas:

**The AFRL–Cornell Center for Epitaxial Solutions will be a comprehensive Center of Excellence to grow, characterize and optimize this novel material**

- understanding and developing the growth and processing methodologies to generate high-quality beta-gallium oxide; and
- developing the critical fundamental understanding of the material's properties and limits.

"Developing this comprehensive understanding will ultimately enable the intentional design and optimization of materials for future device applications," says Thompson. "Through close collaborations with AFRL, both this fundamental understanding, as well as the technical expertise to manage materials in these systems, will be effectively transferred."

ACCESS joins six other universities as AFRL partners through the Center of Excellence program. While each has its own very specific research objectives, all strive to enhance collaborations and generate excitement between AFRL and university researchers in fields important to the future success of the US Air Force.

**https://afresearchlab.com/partner-with-us/higher-education**
**www.mse.cornell.edu**

Fuji Electric
*Innovating Energy Technology*

# Fuji Electric Lambda Series
# Safety, Compact, Powerful

JIS EN

GB

Global Standard

## The New Generation of Low Voltage Earth Leakage Circuit Breakers

- Compact! Ground Fault Protection Built in One Unit for Space Saving Designs
- Same Footprint! MCCBs & ELCBs Interchangeable without Panel Modifications
- 18mm Per Pole Width(2P & 3P), IEC 35mm DIN Rail Mounting
- Higher Capacity SCCR ⇒ 18kA@ 240VAC UL489
- Lock Out Tag Out (LOTO) safety devices (fixed and removal types) are available as option.


**Fuji Electric Corp. of America** Distribution & Control Department

For sales, product & distributor information, please visit https://americas.fujielectric.com/products/distribution-control/

or contact us: x-fea-fuji-dc@fujielectric.com

# Keysight adds new analysis tool to PathWave Advanced Design System

Keysight Technologies Inc of Santa Rosa, CA, USA has announced Power Electronics Professional (PEPro) software, a new add-on to its PathWave Advanced Design System (ADS) that enables designers to visualize the effects of switched-mode power supply (SMPS) designs without the need to build and test time-consuming prototypes.

Demand for SMPS is driven by the need for greater efficiency, increased power density and lower cost. Due to their high performance and efficiency, semiconducting materials such as silicon carbide (SiC) and gallium nitride (GaN) will power future applications. However, high-performance materials result in new challenges, as the layout of a printed circuit board (PCB) becomes more difficult. Post-layout analysis of a 'virtual prototype' is suitable for managing this challenge, but until now it required expertise with a complicated, general-purpose electromagnetic (EM) field solver.

Keysight says that PEPro software makes post-layout analysis as easy as pre-layout analysis. It includes automatic setup that previously required an expert. In addition, it offers pre-built analyses of effects such as voltage spiking and electromagnetic interference (EMI).

"Keysight recognizes that next-generation wide-bandgap semiconductors represent a new paradigm for power electronics designers," says Dr Andrew Lemmon, assistant professor, Electrical and Computer Engineering, University of Alabama. "New tools are needed to help designers take full advantage of this technology by providing insight into subtle design trade-offs that can have major impact on application performance. These enhancements to Keysight's ADS represent an important step towards equipping power electronics designers to be in command of these important details," he adds.

"Keysight's PEPro enables power electronics designers to take another step toward end-to-end simulation and the complete power ecosystem," comments Steve Sandler, managing director of Picotest.

"Keysight understands that customers value application-specific post-layout analysis tools over more general-purpose ones," says Colin Warwick, product manager for power electronics EDA tools at Keysight. PEPro is "tailor-made for solving the challenges that SMPS designers face in this high-switching-speed era," he adds.

Pre-production PEPro is available to select customers under the Early Access program for ADS. The production version will be available on 1 July.

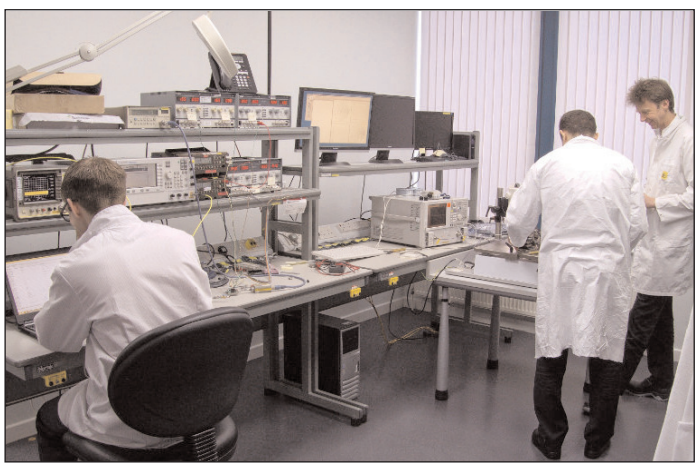
PEPro was on display in Keysight's booth at the IEEE Applied Power Electronics Conference (APEC 2019) in Anaheim, CA, USA (18–20 March).

**www.keysight.com/find/eesof-power-electronics**

# Plextek extends RF-on-wafer cleanroom facilities

Plextek RFI Ltd of Cambridge, UK (which designs RFICs, MMICs and microwave/millimeter-wave modules) has significantly extended the RF-on-wafer (RFOW) cleanroom facilities at its design center for the evaluation of both packaged and unpackaged semiconductor devices.

"Our new capability includes equipment suitable for the evaluation of ICs — either as bare die, on undiced wafers, or packaged — and modules, at frequencies up to 50GHz," says CEO Liam Devlin. "In addition to our RFOW probe station with vector network analyser and spectrum analyser for the characterization of ICs and modules, we also have a fully automated IP3 [third-order intercept point] measurement set-up," he adds.



**www.plextekrfi.com**

# EVG partners with NSI on first wafer-level heterogeneous integration of GaAs-on-Si for RF front-end modules

EV Group of St Florian, Austria — a supplier of wafer bonding and lithography equipment for semiconductor, micro-electro-mechanical systems (MEMS) and nanotechnology applications — has partnered with Chinese specialty foundry Ningbo Semiconductor International Corp (NSI) to develop what is said to be the first process technology platform for wafer-level heterogeneous integration of gallium arsenide (GaAs) on silicon for use in RF front-end module (FEM) manufacturing — reckoned to be a key milestone in developing next-generation, high-performance, ultra-compact RF front-end chipsets needed for 4G and 5G smartphones and other handsets.

As a joint venture subsidiary of Semiconductor Manufacturing International Corp (SMIC) with China IC Investment Fund, Ningbo Economic Development Zone Industrial Investment Company Ltd and other IC investment funds, NSI develops technology platforms for high-voltage analog, radio frequency and optoelectronics applications. Developments support customers in IC design and product development for applications in smart home, industrial and automotive electronics, new generations of radio communications, AR/VR/MR, and other specialty systems.

As part of the strategic collaborative effort, EVG provided NSI with its temporary bonding/debonding (TB/DB), permanent bonding, mask alignment lithography and related special metrology equipment and process expertise, which NSI leveraged together with its proprietary micro wafer-level system integration (μWLSI) technology platform to produce the RF FEM products for a "leading RF front-end devices and system solution provider".

"High-performance, ultra-compact RF front-end microsystem components are vital to the success of the 5G wireless terminal," says NSI's CEO Dr Herb Huang. "To support the customers and their RF front-end module products of the next generation of wireless terminals for meeting the stringent requirements of lower insertion loss, higher energy efficiency, ultra-miniaturization etc, it is necessary to provide more advanced wafer-level multi-chip heterogeneous integration process solutions for supporting and helping the customer meet the product standards and quickly ramp to volume production," he adds. "We are pleased to have access to EV Group's leading wafer bonding technology, lithography technology and expertise in heterogeneous integration."

**Wafer-level heterogeneous integration needed for 5G**

As RF FEMs include key components such as power amplifiers (PAs), antenna switches and filters, the high-density 3D heterogeneous integration of materials with different properties, such as GaAs and silicon, is effective in enabling improved gain, linearity and power performance. At the same time, however, the migration to 5G broadband wireless technology is driving the need for wider multi-band PAs and more RF filters in the FEM, which in turn can drive up cost and footprint of the overall chipset package. Enabling heterogeneous system integration at the wafer level provides a cost-effective approach for achieving greater chipset density with minimal footprint increase, says EVG.

"5G is offering huge opportunity to the RF front-end industry," comments Cédric Malaquin, technology and market analyst, RF Devices and Technology, at market research and strategy consulting company Yole Développement. "5G will completely redefine the interactions between the network and the modem. Indeed, new RF bands, sub-6GHz and mm-wave pose big challenges for the industry." The mobile handset RF front-end market, along with the WiFi connectivity sector, is projected to rise at a compound annual growth rate (CAGR) of 14% to $35.2bn in 2023, according to last year's report '5G's Impact on RF Front-End Module and Connectivity for Cell Phones' by Yole.

μWLSI is a middle-end-of-line technology platform for a unique wafer fabrication process developed by NSI for enabling heterogeneous multi-die-on-wafer system integration and wafer-level system testing while eliminating the need for bumping and flip-chip processes in typical system-in-package (SiP) practices. NSI developed the μWLSI technology platform specifically to address the surging need for high-density heterogeneous system integration of a variety of chipsets and microsystems through more wafer-level fabrication processing.

EVG says that its TB/DB systems play a key role in enabling the heterogeneous integration of compound semiconductors with silicon devices in a More-than-Moore approach. For example, TB/DB facilitates the reliable transfer and processing of very thin compound semiconductor, silicon and mold wafers, which can be integrated into higher-density vertical packages. Likewise, EVG's mask alignment systems support wafer-level heterogeneous integration by enabling lithography patterning of carrier-mounted and warped substrates (essential for the μWLSI process).

"NSI is at the forefront in the development of specialty semiconductors for next-generation wireless and telecommunications technologies, such as 5G," comments Swen Zhu, EVG's general manager, China. "NSI has entrusted us once again to work with them to support their advanced manufacturing efforts — this time on their ground-breaking development in RF FEM platforms," he adds. "The expertise that we have built up as a technology and market leader in wafer bonding and lithography process solutions will play an important role in our work with this leading foundry company."

**www.EVGroup.com**

# IQE's wireless wafer growth in 2018 outweighs VCSEL-driven drop in photonics

## Capacity investment establishes base for growth in 2019, driven by photonics and 5G wireless

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has reported full-year revenue growth of 1.1%, from £154.6m in 2017 to £156.3m in 2018. Despite being below the guidance of £160m given in mid-November, this has been achieved with a similar manufacturing capacity compared to 2017 and without any license income from sales to joint ventures (which was £1.9m in 2017). Wafer revenue specifically has hence grown by 2.4% from £152.7m.

Wireless wafer revenue grew by 6.6% (exceeding the initial guidance of 5%) from £91.7m to £97.8m (rising from 60% to 62.5% of total wafer revenue). Demand was strong throughout the year, especially for gallium nitride (GaN) products, including £5m from customer last-time buys prior to IQE closing its facility in New Jersey (as part of consolidating US-based GaN manufacturing capacity into the firm's existing Massachusetts facility). Also contributing to growth was additional manufacturing capacity made available to address gallium arsenide (GaAs) demand, including the replenishment of wireless inventory channels in first-half 2018 that were depleted following the conversion of wireless capacity in second-half 2017 to accommodate the aggressive ramp up of photonics capacity for vertical-cavity surface-emitting lasers (VCSELs) during a period of capacity constraint.

Photonics wafer revenue shrank by 8.1% (compared with the initial forecast for growth of 35–60%) from £47.7m to £43.8m (falling from 31.2% to 28% of total wafer revenue). Demand, especially for VCSEL products, was adversely impacted in first-half 2018 by a substantial inventory correction as excess inventory in the downstream supply chain took longer than expected to be consumed, and the sudden decline in short-term demand for VCSEL wafers in November 2018 also adversely impacted sales and volumes. Despite the decline in revenue year on year, IQE says it has made significant progress to strengthen its position in the VSCEL market, with more than 25 engagements with VCSEL chip companies at varying stages of product development, qualification and production.

Infrared wafer revenue grew by 9.5% (within the initial forecast of 5–15%) from £12m to £13.1m (rising from 7.8% to 8.4% of total wafer revenue). Demand, especially for defence applications, has remained strong, while progress continues to be made in broadening customer engagements into product development for mass-market consumer applications where continued growth opportunities exist.

Revenue from the CMOS++ segment (next-generation compound semiconductor-on-silicon technologies) rose from £1.38m to £1.62m (remaining about 1% of total wafer revenue).

Going forward, the three sectors of CMOS++, Power (power control and switching) and Solar (space PV, concentrated photovoltaics/CPV) — which are all in pre-production — will be combined under an 'emerging technologies' umbrella to provide a focus on next-generation applications, and to provide an efficient route to market, says IQE.

"Our disappointing 2018 financial performance was materially impacted by a very substantial VCSEL inventory correction in the first half of 2018 and the sudden disruption in a highly significant supply chain causing greatly reduced short-term demand for VCSEL wafers during the last two months of the year," notes chief executive Dr Drew Nelson. "Compounding this is the current well-heralded softness in the smartphone market," he adds.

Excluding license income (which has a 100% margin), the adjusted gross margin on wafer sales fell from 27.5% to 23.5%, reflecting the shift in product mix from higher-margin photonics sales to lower-margin wireless sales.

Adjusted selling, general and administrative (SG&A) rose from £17.3m to £20.7m, reflecting investment for growth alongside IQE's capital expansion program. This excludes adjusted measures such as charges before tax of £7.2m including:

- restructuring costs of £3.3m (£1.1m for severance payments and reactor decommissioning plus £2.2m in non-cash impairments) after closing the manufacturing plant in Somerset, New Jersey, and transferring the trade and assets to the plant in Taunton, Massachusetts (requiring process and customer re-qualifications), as part of IQE's consolidation and expansion of GaN capacity (yielding expected operating cost savings of about £3m per annum from Q2/2019);
- £1.3m for legal fees from an ongoing patent dispute defence (scheduled for an arbitration hearing this September); and
- a £4.4m onerous lease provision for unlet and unused space to the end of the lease on the Singapore manufacturing site in 2022.

Operating profit and operating margin were adversely affected by:

- the currency headwind;
- production inefficiencies resulting from lower VCSEL production volumes;
- a higher proportion of lower-margin wireless revenue;
- material investment in low- and zero-margin VCSEL qualifications for multiple new photonics customers;

● Newport foundry pre-production costs for recruitment, increased headcount and training.

Adjusted operating profit hence fell from £26.5m (or £24.6m for wafers alone, excluding the license income) in 2017 to £16m in 2018 (reducing operating margin to 10.2% of total revenue, from 2017's 17.1%, or 16.1% for wafers alone). By segment, Wireless margin fell from about 15% to 12%, partially reflecting costs associated with switching capacity from Photonics to Wireless in first-half 2018 and the competitive nature of the wireless market. Photonics margin fell from 38% to 26%, reflecting the decline in volume and the focus on lower-margin customer development work as IQE has sought to strengthen its position in the VCSEL market by engaging with all the major VCSEL chip firms. Infrared margin remained robust at about 26% (down only slightly from 2017's 27%) as the segment continues to grow.

Adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) has fallen from £37.2m to £26.4m, below both mid-November's guidance of £31m and late January's reduced guidance of £27.5m.

Cash generated from operations has fallen from £29.7m in 2017 to £17m in 2018. Operating cash conversion was 106% (down from 112%).

Cash invested rose from £28.2m in 2017 to £42.4m in 2018 as IQE continued with a significant two-year investment program (begun in 2017) across its global operations. Specifically, capital expenditure (CapEx) rose from £11.3m to £30.4m as IQE focused on capacity expansion with:

● construction of the firm's new flagship 30,000m$^2$ mega epi foundry in Newport, Wales (leased from the Cardiff Capital Region in September 2017 as an empty shell, and dedicated initially to photonics for sensor applications);

● the installation of additional wireless capacity in Hsinchu, Taiwan;

● the GaN capacity expansion in Taunton, Massachusetts; and gallium antimonide (GaSb) and indium antimonide (InSb) infrared production expansion in Milton Keynes, UK. These projects will greatly increase production capacity and operational efficiency, says IQE. In addition, the firm is continuing to invest in technology and intellectual property with cash expenditure totaling £12m.

Free cash outflow was hence £25.3m (compared with inflow of £40.9m in 2017). Net cash has therefore fallen during 2018 from £45.6m to £20.8m. After year-end 2018 (on 24 January 2019), IQE secured a three-year $35m multi-currency revolving credit facility with HSBC Bank.

"2018 represented a year of transformation, consolidation and preparation to position our business to maximise the opportunities ahead," says Nelson.

"During the last two years, great efforts have been made to consolidate our research, development and manufacturing activities, enabling the transfer of technologies and processes. This in turn has led to the closure of our activities in Bath, UK and Somerset, New Jersey, with activities being transferred to other IQE facilities whilst maintaining consistency of supply with our customer base," says Nelson.

**Our disappointing 2018 financial performance was materially impacted by a very substantial VCSEL inventory correction in the first half of 2018 and the sudden disruption in a highly significant supply chain causing greatly reduced short-term demand for VCSEL wafers during the last two months of the year**

"Whilst it is intended to maintain specialist manufacturing and development activities at some IQE sites, we have been implementing a long-term strategy to focus our high-volume manufacturing at four key 'production-optimized' facilities in Greensboro (North Carolina), Taunton (Massachusetts), Hsinchu (Taiwan) and our new flagship operation in Newport (Wales, UK)," he adds.

"We are also focussing on our three primary market sectors of wireless (connectivity, 5G), photonics (sensors, optical communications) and infrared (high-end imaging, healthcare technologies)."

Investment in product development in 2018 focused on materials directly addressing next-generation 5G wireless and advanced photonics applications including sensing:

● A milestone first production order of US$250,000 was received for edge-emitting distributed feedback (DFB) lasers employing the firm's nano imprint lithography (NIL) technology.

● The option to acquire the cREO (crystalline rare-earth oxide) technology and IP portfolio for $5m from Translucent Inc of Palo Alto, CA, USA was exercised in March 2018 and satisfied in September with a share issuance.

● A long-term supply contract with a tier-1 wireless customer was completed, securing an extended range of products and increased share of their epiwafer requirements.

● IQE completed the sublet of 25,000ft$^2$ of space in the new Newport Facility to the Compound Semiconductor Applications Catapult (underpinning IQE's continued contribution to creating a global center of excellence for compound semiconductors in South Wales).

"Revenue increases in 2019 will be driven by the return to strong growth of our photonics business and emerging opportunities in 5G and will be soundly based on operational improvements, rationalization and capacity expansions that have been in progress for the last two years and which will complete in first-half 2019," says Nelson.

The new mega foundry in Newport has opened, with 10 MOCVD systems ►

now installed (in a first-phase construction designed for up to 20 systems). Five systems have already been released for product qualification and the remaining five are in the process of final commissioning. Throughput, uniformity and yields are significantly better than originally expected at the outset of the project. Twelve customers are currently qualifying or have qualified the new facility. The first and largest has now completed all product testing and reliability, has conducted a detailed final audit and has released the site for mass production. Several others are in the final stages of production releases.

The expansion of the facility in Hsinchu, Taiwan (which will boost its wireless capacity by 40%) will complete in Q1/2019. Massachusetts (GaN) and Milton Keynes (infrared) capacity expansions will also both complete by the end of first-half 2019.

"We have also made considerable investment in engaging with more than 25 VCSEL chip companies, underscoring IQE's exceptional leadership position in the emerging VCSEL supply chains based on our technical excellence, proven ability to ramp and dedicated commitment to install capacity, with 12 companies already actively qualifying the new facility," says Nelson.

"Complementing this investment in physical infrastructure, we closed on the acquisition of the cREO technology and IP portfolio from Translucent Inc. We have also continued to invest in our own internal R&D projects including materials for high-performance HBTs, porous RF switches, and crystalline RF filters for 5G, next-generation VCSELs and diffusers for VCSELs, and infrared materials for high-volume consumer markets," Nelson adds.

With the New Jersey site closure, capacity expansion projects in Massachusetts and Taiwan and the start of production at the Newport epi foundry all completing in first-half 2019, IQE reckons that it has made significant progress in positioning itself for operational execution at scale.

Given the market opportunity and IQE's operational readiness, the outlook for 2019 and beyond remains strong.

**For 2019, IQE expects revenue growth (on a $US constant-currency basis) of 9%, including growth of more than 50% in Photonics and 15% in Infrared outweighing a 15% drop for Wireless**

Short-term headwinds are:
(1) the unwind of inventory levels in the VCSEL supply chain (given the sudden disruption experienced in Q4/2018) and
(2) general market softness in the semiconductor industry in general and the mobile handset market in particular. These will affect revenue and profitability in first-half 2019.
However, IQE believes that this is a temporary impact and there are strong signs that significant growth can be achieved in second-half 2019 and into 2020 in both the Photonics and Wireless business units.
Key drivers for this growth will be:
(1) broader adoption of 3D sensing VCSELs across multiple devices and multiple OEMs and
(2) anticipated 5G technology deployments into products and infrastructure.

For 2019, IQE expects revenue growth (on a $US constant-currency basis) of 9%, including growth of more than 50% in Photonics and 15% in Infrared outweighing a 15% drop for Wireless. For 2020, IQE expects Wireless to return to growth, continued Photonics growth, and consistent growth in Infrared. Over a 5-year period, the firm expects compound annual growth rates (CAGRs) of 0–20% for Wireless, 40% for Photonics and 5–15% for Infrared.

**The Newport facility will house up to 100 high-volume production tools... IQE previously operated about 100 legacy tools across its global facilities, so the expansion will create almost three times the manufacturing capacity**

During 2019, the H1:H2 split of revenue is expected to be ~40:60, influenced by the handset market softness in the first-half 2019, and expected completion of Photonics customer qualifications in first-half 2019 leading to higher production volumes in second-half 2019.

IQE expects adjusted operating margin of over 10% in 2019, with first-half in particular being affected by general market softness and high levels of customer qualification work associated with future revenue streams. Operating profits are expected to increase towards the end of 2019 and in 2020 and beyond due to the expanding revenue opportunity and IQE's ability to drive industry-leading production yield.

IQE says that, to fuel this growth, it continues to be committed to investing in capacity. For example, when fully occupied, the Newport facility will house up to 100 high-volume production tools comprising both MOCVD and MBE systems. IQE previously operated about 100 legacy tools across its global facilities, so the expansion will create almost three times the manufacturing capacity. To ensure that the growing revenue opportunities can be captured, capital expenditure will rise to about £40m in 2019 before dropping back to a more normal £15m in 2020.

"The investment we have made in site rationalization, increased production capacity and new products and the opportunity that this has created in the key sector areas of sensing, connectivity and energy will deliver margin expansion, growing profitability and increasing free cash flow in 2019 and beyond," concludes Nelson.

**www.iqep.com**

# IQE partners in DLINK wireless project for 5G infrastructure

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK is participating in a new £850,000 research project DLINK — funded with over £850,000 from the UK Engineering and Physical Sciences Research Council (EPSRC) — that aims to put the UK at the forefront of the next generation of millimeter-wave wireless communications technology for 5G infrastructure.

The project addresses the challenge of ubiquitous wireless connectivity for 5G, and is a collaboration between Lancaster University and Glasgow University along with major industrial partners including BT, Nokia Bell Labs, IQE, Filtronic, Optocap and Teledyne e2v. The advisory board includes Intel. The project aims to provide 'fiber-in-air' communication links with unprecedented data rates and transmission distance by exploiting a thus-far unused D-band (151–174.8GHz) portion of the wireless communications spectrum. The D-band is particularly relevant for 5G because, being very wide, it enables the wireless transmission of high data rates — of around 45Gb/s.

DLINK's goal is to enable data transmission over distances of 1km using a novel transmitter with excellent ability to withstand the high attenuation from rain and other atmospheric conditions that can be problematic at that portion of the spectrum.

There is an urgent need for new wireless communications technologies capable of delivering data at high speeds and low cost and without needing installations of fiber or large unsightly equipment to be fitted on the tops of many of the buildings in cities, says IQE. This is because wireless data demands are continuing to gather pace, with widespread proliferation of Internet-connected devices such as smartphones, tablet computers and laptops. What people choose to do with their devices is also increasingly demanding — about 74% of mobile data traffic is expected to come from video streaming within the next five years. All of these connected devices are placing huge strains on the existing wireless communications systems, and its limited data capacity.

IQE's role in DLINK is to provide the epitaxial needs for high-quality indium phosphide (InP)-based resonant tunneling diode (RTD) structures, building on the completion of a previous program (iBROW) in which IQE played a major role in supplying InP-based RTD structures grown on InP and silicon substrates using its proprietary germanium-on-silicon (Ge-on-Si) template process.

"The huge growth of mobile data and consumer demand for video streaming — along with the IoT, driverless vehicles, virtual reality and a multitude of other emerging technologies — are going to require fibre-quality data speeds but delivered wirelessly and ubiquitously," notes professor Claudio Paoloni, the Cockcroft Chair and head of Engineering at Lancaster University.

"5G networks will function across an unprecedented frequency range, from traditional cellular bands to millimeter wave," says IQE vice president Dr Wayne Johnson. "IQE offers a powerful array of materials solutions enabling 5G, including enhanced-efficiency gallium arsenide heterojunction bipolar transistor (HBT) PAs, novel RF filter products utilising IQE's proprietary cREO [crystalline rare-earth oxide] technology, and high-performance switches for mobile devices, gallium nitride high-electron-mobility transistors (HEMTs) for wireless infrastructure, InP products for high-speed oscillators and photodiodes, and many more," he adds. "This DLINK program is another example of how compound semiconductors produced by IQE will continue to fuel the connected world as it transitions to 5G platforms."

**http://wp.lancs.ac.uk/dlink**
**www.iqep.com**

# Aledia expands portfolio of Veeco equipment to develop and produce 3D micro-LEDs

Aledia S.A of Grenoble, France has expanded its portfolio of thin-film process equipment from Veeco Instruments Inc of Plainview, NY, USA to support the development and production of 3D micro-LEDs. Aledia cited Veeco's proven leadership in compound semiconductor applications, gallium nitride on silicon (GaN-on-Si) growth performance, and capability to grow a full range of high-quality epitaxial films as key factors influencing its decision.

"We have been impressed with the performance of Veeco's Propel GaN metal-organic chemical vapor deposition (MOCVD) platform for large-wafer 3D LED production," comments Aledia's co-founder & chief technology officer Philippe Gilet. "Veeco's solutions meet our rigorous material quality and system delivery requirements along with unmatched material flux stability and repeatability," he adds. "We are excited to take the next step with them in producing next-generation 3D micro-LEDs," says Gilet.

The firms say that the collaboration between them reflects the immense promise of micro-LEDs and other advanced LEDs for the future of displays. Micro-LEDs offer high efficiency, brightness and reliability benefits with shorter response time, enabling lighter, thinner and flexible displays with energy-saving advantages for applications such as wearables, smartphones, automotive, signage/large TVs, and augmented reality/virtual reality (AR/VR), it is said. According to a recent report by market analyst firm Yole Développement, nearly 1500 patents related to micro-LED displays have been filed collectively by 125 different companies, with the bulk of activity occurring after 2012.

"With the significant shift toward exploration of micro-LEDs for use in next-generation displays, leaders like Aledia are turning to Veeco," says Gerry Blumenstock, senior VP & general manager of Veeco's compound semiconductor business unit. "Veeco's proven materials engineering expertise puts us in a unique position to offer innovative thin-film deposition technologies for customers tackling tough compound semiconductor research, development and production challenges," he reckons.

**www.aledia.com**
**www.veeco.com**

## Veeco presenting at technical conferences in second-quarter 2019

Epitaxial deposition and process equipment maker Veeco Instruments Inc says that its technologists are scheduled to speak at seven technical events throughout second-quarter 2019. The firm says that the presentations, which follow several appearances in Q1/2019, highlight its expertise in working with customers to break through production-scale barriers that will ultimately lead to the wide adoption of game-changing trends in big-data, high-speed communications, artificial intelligence (AI), autonomous vehicles (AVs), high-resolution displays and more.

Through the papers, Veeco explains how it can solve materials engineering challenges with advances in its deposition, etch, lithography and wet processing technologies used in applications such as next-generation advanced packaging, photonics, sensors, MEMS, micro-LEDs, power electronics, high-bandwidth memory and related devices. Presentations in Q2/2019 include:

- **Critical Materials Council Conference** (25–26 April; Saratoga Springs, NY) — at the fourth annual forum for discussing actionable information related to semiconductor fab materials, VP of technology Drew Hanser will present 'Material Integration Challenges for GaN on Si for Power and RF Devices' on 25 April during Session II: Immediate Challenges of Materials & Manufacturing.
- **CS ManTech** (29 April – 2 May; Minneapolis, MN) — process development engineer Phillip Tyler will present 'Development of Advanced Lift Off Processes for 5G and VCSEL Applications'. Also, in booth #609, Veeco is exhibiting its latest innovations in compound semiconductor and wet processing technologies.
- **ECTC** (28–31 May; Las Vegas, NV) — chief technology officer Dr Ajit Paranjpe will co-author a presentation on 'High-Yield Precision Transfer and Assembly of Gallium Nitride (GaN) Micro-LEDs Using Laser Assisted Micro Transfer Printing' with experts from the University of California, Los Angeles (UCLA).
- **EUVL Workshop** (10–13 June; Berkeley, CA) — At this year's workshop focused on the fundamental science of EUV lithography and its continued extension to support Moore's Law, principal research scientist Sandeep Kohli will present 'Ion Beam Technology Roadmap for EUV Mask Deposition and Absorber Etch Processes'.

"Veeco builds production-scale fab solutions that solve tough materials engineering problems," says chief technology officer Ajit Paranjpe Ph.D. "Our technical contributions to these prestigious and peer-reviewed conferences demonstrate Veeco's commitment to remaining at the forefront of technological advances."

# CSconnected compound semiconductor cluster awarded £50,000 in seed funding

## Early-stage funding to allow development of full-stage bid for £10–50m

CSconnected is one of 24 projects (the only one based in Wales) to receive early-stage funding from the 'Strength in Places' Fund of UK Research and Innovation (UKRI) to develop full-stage bids that are intended to lead to significant economic growth in locations across the country.

Wales is home to IQE, SPTS Technologies, Newport Wafer Fab and Microsemi who, along with academic partners and the UK Government's £50m compound semiconductor applications Catapult, form CSconnected (which is reckoned to be the world's first compound semiconductor cluster).

Each of the shortlisted projects from the first wave of UK Research and Innovation's Strength in Places Fund has been awarded up to £50,000 in early-stage funding, which will allow applicants to develop full-stage bids. Teams behind the projects will then submit these bids to UKRI in late 2019, with four to eight of the strongest set to receive £10–50m each to conduct projects designed to drive substantial economic growth.

Operating across the UK with a budget of more than £7bn, UK Research and Innovation brings together the Arts and Humanities Research Council; Biotechnology and Biological Sciences Research Council; Engineering and Physical Sciences Research Council; Economic and Social Research Council; Innovate UK; Medical Research Council; Natural Environment Research Council; Research England; and Science and Technology Facilities Council.

Announced in the UK Government's Industrial Strategy in November 2017, the UKRI's Strength in Places Fund aims to benefit all nations and regions of the UK by enabling them to tap into research and innovation capabilities across the country. The fund brings together universities, research organisations, businesses, charities, local leadership and government on projects leading to significant economic impact, high-value job creation and regional growth.

**http://csconnected.com**

# Aixtron full-year revenue up 40% organically to €268.8m

## 2018 revenue, margins and operating profits exceed guidance

For fourth-quarter 2018, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €87.9m, up 39% on €63.4m last quarter and up 62.5% on €54.1m a year ago.

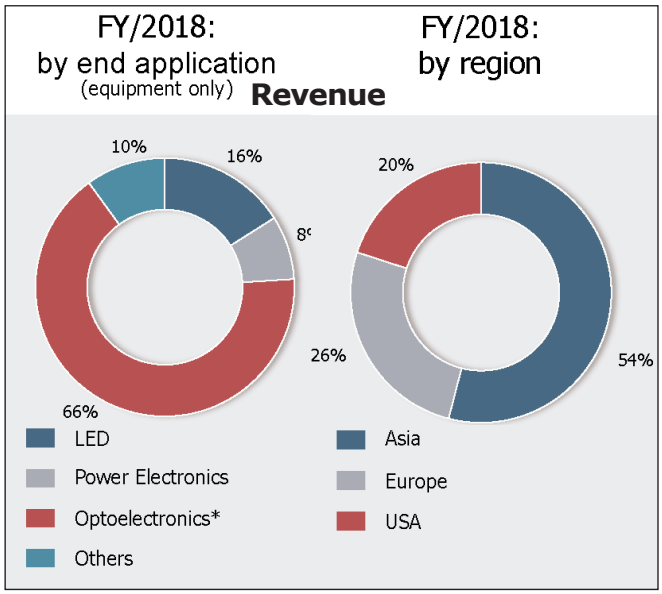
Full-year revenue was €268.8m in 2018 (exceeding the guidance of €260m). This is up 17% on €230.4m in 2017, or up 40% organically excluding the €38.8m from the atomic layer deposition/chemical vapor deposition (ALD/CVD) product line (for memory chip applications) that was divested at the end of 2017.

In particular, equipment revenue grew by 18% from €188m to €221.8m (remaining 82% of total revenue), while sales of spare parts & services rose by 11% from €42.4m to €47.1m (18% of total revenue).

Of equipment revenue, the proportion from metal-organic chemical vapor deposition (MOCVD) systems for manufacturing opto-electronic components (i.e. lasers and solar, excluding LEDs) rebounded from 25% to 66% (growing from €47.8m to €147m), driven by strong demand for vertical-cavity surface-emitting lasers (VCSELs). Despite continuing strong demand for red-orange-yellow (ROY) LEDs and specialty LEDs, systems for producing LEDs fell from 42% to just 16% (from €79.1m to €36m). Systems for manufacturing power electronics fell from 11% to 8% (from €20.4m to €18.2m).

Asian revenue has hence fallen back from 75% of total revenue in 2017 to 54% in 2018 (falling by 16% from €172.3m to €144.7m, including China falling from €89.8m to €72.6m and Korea from €44.3m to €11.9m, while Taiwan rose from €25.7m to €43.2m). Meanwhile, the Americas rebounded from 12% to 20% (rising by 89% from €28.9m to €54.4m) and Europe rose from 13% to 26% (up by 139% from €29.2m to €69.7m).

Aixtron's cost structure was further improved in 2018. Cost of sales developed at a lower rate than sales year-on-year, being cut by 3% from €156.4m in 2017 to €151.2m in 2018 (falling from 68% to 56% of revenue). As well as also being positively impacted by a stronger US dollar against the Euro in second-half 2018, this was due mainly to better capacity utilization in production and a more favorable product mix with higher margins.




Gross margin improved notably from 32% in 2017 to 44% in 2018 (above the guidance of 40%). Quarterly gross margin rose from 39% a year ago and 44% in Q3 to 45% in Q4/2018.

Operating expenses (OpEx) rose at a slower rate than sales growth, by 10% from €69.1m in 2017 to €76.2m in 2018. This is due mainly to R&D spending being cut by 24% from €68.8m to €52.2m (from 30% of revenue in 2017 to just 19% in 2018). Most recently, quarterly OpEx has been cut from €20.7m in Q3 to €18.6m in Q4/2018.

After operating losses of €26.7m in 2015 and €21.4m in 2016, the operating result (EBIT) has multiplied from a small profit of €4.9m (EBIT operating margin of 2% of revenue) in 2017 to €41.5m (15% margin) in 2018 (exceeding the €35–40m guidance). Quarterly EBIT has risen from €8.7m in Q3 to €20.8m in Q4/2018.

The financial development in 2018 was characterized by the profitable operating performance following the successful turn-around of the company. "2018 was an excellent year for Aixtron. We not only achieved the planned positive result from operating activities, but even slightly exceeded our forecast," notes president Dr Bernd Schulte.

Net profit has hence risen from €6.5m (3% of revenue) in 2017 to €45.9m (17% of revenue) in 2018 (higher than the operating result due to €9.5m in capitalization of deferred taxes). Most recently, quarterly net profit has risen from €11.7m in Q3 to €18.2m in Q4/2018.

Quarterly free cash flow has fallen from €11.2m in Q3 to €5.8m in Q4/2018. Full-year free cash flow was €4.4m in 2018 (down from €91.4m in 2017) due mainly to contractually agreed payments in Q1/2018 from the sale of the ALD/CVD product line. However, this is still a big improvement on free cash outflow of –€42.9m in 2016 and –€57.3m in 2015.

Total cash flow was €17.2m in 2018, down from €86.4m in 2017 but matching guidance. However, quarterly total cash flow has risen from €10.7m in Q3 to €18.3m in Q4/2018. Capital expenditure (CapEx) for 2018 totalled €9.2m (cut from €9.7m in 2017). Cash and cash equivalents including short-term financial investments hence grew during Q4/2018 from €246.5m to €263.7m.

Despite falling by 5% from €76m in Q3/2018, order intake of €72.2m in Q4 was up 10% on €65.7m a year ago. Full-year order intake hence rose to €302.5m (exceeding the guidance of €290m), up 15% on €263.6m in 2017 (despite the latter

including €35.6m from the since divested ALD/CVD unit). Equipment order backlog rose to €138.3m, down from €151.9m at the end of Q3/2018 but up 27% on €108.6m a year ago.

With the signing in late October of a joint venture agreement with South Korean organic light-emitting diode (OLED) supplier IRUJA Co Ltd (involving IRUJA contributing its automation & handling technology for display applications plus some cash, as well as acquiring up to 20% of Aixtron's OVPD-based OLED subsidiary APEVA over the next few years), Aixtron has completed the strategic adaptation of its structure that was initiated in 2017, which has led to sustainable profitability, says Schulte.

"With the entry of our joint venture partner IRUJA into our OLED subsidiary APEVA, we have successfully completed the realignment of Aixtron," says president Dr Felix Grawert. "After completion of the test phase for the Gen2 OLED system before the end of this year, we expect a first customer order for a large-scale production chamber," he adds.

For 2019, Aixtron expects only stable to slightly growing revenue compared with 2018. At the moment, customers are reluctant to make investment decisions in optoelectronics, and the further development for the second-half 2019 is difficult to anticipate, notes the firm. Both are also influenced by the currently prevailing critical view of the development of the global economy, in particular due to global trade conflicts and political uncertainties, it adds. However, management is optimistic about the long-term prospects regarding MOCVD system demand for the production of lasers for 3D sensing or optical data transmission as well as for LED applications. Regarding demand for systems for producing power components based on the wide-bandgap materials silicon carbide (SiC) and gallium nitride (GaN), management expects an increasing contribution to revenue in 2019 compared with 2018.

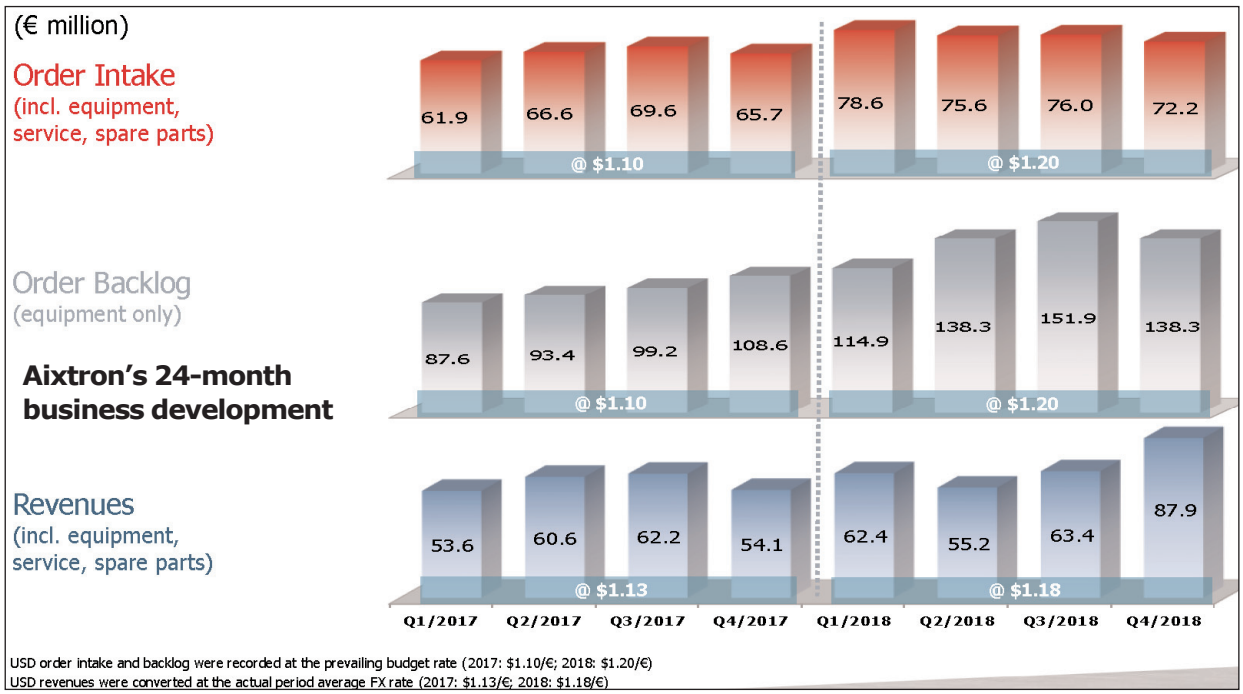
Based on the current corporate structure, an assessment of the order situation and the internal budgeted exchange rate of 1.20$/€, for full-year 2019 Aixtron expects order intake of €220–260m (taking into account both the uncertain development in second-half 2019 as well as the difficulty in quantifying the size of any possible OLED order).

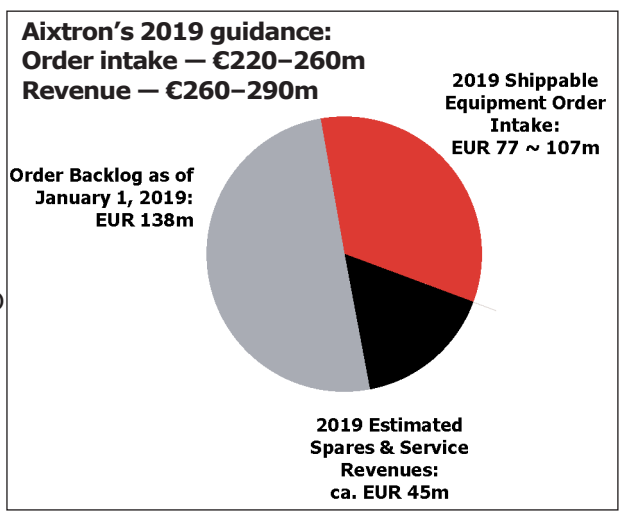
Based on the equipment order backlog of €138.3m on 1 January joined by an estimated €77–107m of order intake shippable in 2019 plus an estimated €45m of spares & services revenue, for 2019 Aixtron expects revenue of €260–290m.

Also, many of the MOCVD systems ordered in 2018 for ROY LED production will be delivered in 2019, leading to lower-margin revenue in 2019. Aixtron hence expects gross margin of 35–40% and EBIT operating margin of 8–13% of revenue (both down on 2018). Free cash flow should be €15–25m. "The sustainably profitable development shows that we have done our homework thoroughly in the realignment of the company," Schulte says. Expectations fully include the results of Aixtron's APEVA subsidiary, including all necessary investments to continue developing OLED activities.

"We are focusing on the sustainable development of the Aixtron Group, for example by tapping into the growth potential in power electronics," notes Grawert. "With a strong order intake and order backlog, we expect a clearly positive operating result for the current year."

**www.aixtron.com**



# Brooks Instrument promotes Pipal to general manager

Brooks Instrument of Hatfield, PA, USA (a provider of flow, pressure, vacuum and vapor delivery solutions) says that Eric Pipal has been promoted to VP & general manager.

With a bachelor's degree in mechanical engineering from Penn State University along with an MBA in finance from Saint Joseph's University, Pipal originally joined Brooks Instrument as an operations director in 2007. Since then, he's held positions of increasing responsibility within the operations department prior to taking a customer-facing role as manager of the industrial business unit in 2015.

**Eric Pipal.**

"Eric has a strong leadership record, and we are confident he will lead the Brooks Instrument team to continued positive results in the future," comments Sharon Szafranski, group president at ITW (which owns Brooks Instrument as part of its test & measurement business unit).

"I'm especially excited about several key products we're launching this year for biotech and semiconductor manufacturing, including new mass flow controllers equipped with EtherNet/IP and other features for bioprocessing, as well as new pressure-based mass flow controllers for semiconductor processing," says Pipal. "Besides our ongoing support for the industrial markets, the biotech and semiconductor segments are important product development areas for Brooks Instrument."

**www.brooksinstrument.com**

# Philips selects ClassOne's Solstice S4 for wafer cleaning

ClassOne Technology of Kalispell, MT, USA (which manufactures electroplating and wet-chemical process systems for ≤200mm wafers) has sold a Solstice S4 system to Philips Photonics GmbH of Ulm, Germany, a wholly owned business of Royal Philips of Eindhoven, The Netherlands that provides vertical-cavity surface-emitting laser (VCSEL) technology for datacom, consumer and industrial applications.

Established in 2000 as ULM Photonics GmbH and acquired by Philips in 2006, Philips Photonics produces VCSEL-based solutions for datacom, consumer and industrial applications — for security, surveillance, night vision and a range of sensing applications — and has enabled the introduction of laser-based PC mice, high-bit-rate active optical cables (AOCs), and introduced VCSEL-based laser Doppler technology to consumer applications. In November the firm announced its third production capacity expansion in the last three years (to be completed within the next 18 months). In mid-December it was announced that Philips Photonics is being acquired by TRUMPF GmbH of Ditzingen, near Stuttgart, Germany, but the transaction (which is expected to be completed in second-quarter 2019) should not impact the relationship between Philips Photonics and Class One.

"We will be using the new Solstice S4 for wafer cleaning applications. Its unique processing flexibility and high performance are especially useful to us, as well as its small footprint," comments Philips Photonics' general manager Hans Peter Ehweiner. "ClassOne's responsiveness and support for us in Germany are also significant factors in this purchase decision, thus we are looking forward to a fruitful and longstanding relationship," he adds.

"Solstice initially built its reputation on quality electroplating. But with its 'Plating-Plus' capabilities, Solstice is now recognized as a powerful multi-processing tool that can handle everything from plating to wafer cleaning, high-pressure metal lift-off, resist strip, UBM [under-bump metal] etch and more," says ClassOne Group's CEO Byron Exarcos. "Phillips Photonics is a perfect example of next-generation fabs that are using Solstice primarily for those additional wet processes," he adds. "Solstice is becoming the tool of choice for VCSEL manufacturers around the world."

**www.photonics.philips.com**

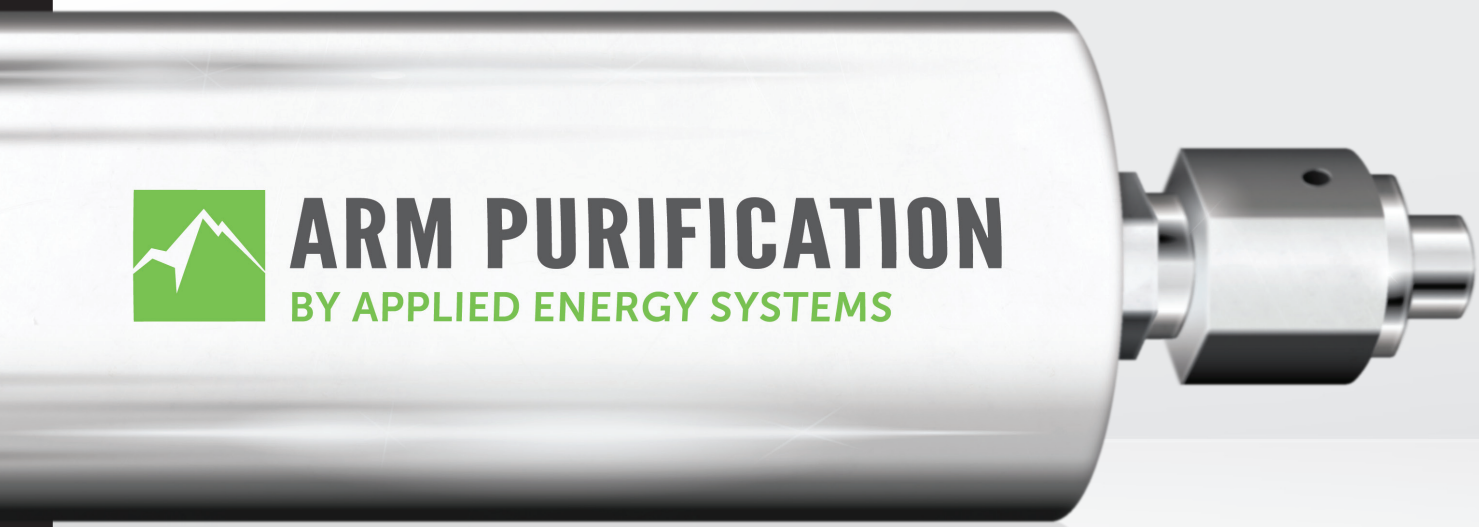
# Edwards iXH Mk2 dry pump for ultra-harsh processes

Edwards of Burgess Hill, UK has launched the iXH Mk2 Series — a high-efficiency, low-power, ultra-harsh-duty dry pump addressing existing semiconductor process requirements and future emerging application challenges in semiconductor, display, LED and solar PV manufacturing processes including high-k, low-k, sub-atmospheric chemical vapor deposition (SACVD), low-pressure chemical vapor deposition (LPCVD), atomic layer deposition (ALD), transparent conducting oxide (TCO), gallium nitride and epitaxy.

"The new iXH Mk2 dry pump provides an even longer service life than previous generations for the harshest of processes," says product manager Al Brightman senior. "It can also provide significant improvements in power efficiency," he adds. "The iXH reduces the environmental impact of some of the harshest processes used in semiconductor manufacturing."

**www.edwardsvacuum.com**

# SO MUCH MORE THAN A COMPONENT.



ARM PURIFICATION
BY APPLIED ENERGY SYSTEMS

## Your **gas purifiers** are crucial to upholding the integrity of your mission-critical processes.

**That's why when it comes to your gas purification needs, only the most capable partner will do.** For more than two decades, Advanced Research Manufacturing (ARM) has delivered the bulk and point-of-use purifiers innovators need to meet their most stringent purity requirements. Now, together with Applied Energy Systems (AES), we're delivering solutions that are more comprehensive and capable than ever.

ARM PURIFICATION
BY APPLIED ENERGY SYSTEMS

APPLIED ENERGY SYSTEMS

Learn how ARM and AES are together transforming gas purification at
**www.appliedenergysystems.com/pure**

# NIST boosts AlGaN/GaN nanowire UV LED electroluminescence fivefold at 365nm

## Aluminium added to shell layer confines electrons to core, reducing losses from electron overflow and light reabsorption

The US National Institute of Standards and Technology (NIST) has made ultraviolet light-emitting diodes (LEDs) that, due to a special type of shell, produce five times higher light intensity than comparable LEDs based on a simpler shell design (M.D. Brubaker, K.L. Genter, A. Roshko, P.T. Blanchard, B.T. Spann, T.E. Harvey and K. A. Bertness, 'UV LEDs Based on p-i-n Core-Shell AlGaN/GaN Nanowire Heterostructures Grown by N-polar Selective Area Epitaxy', Nanotechnology, vol30 (2019) 234001).

Ultraviolet LEDs are used in a growing number of applications such as polymer curing, water purification and medical disinfection. Micro-LEDs are also of interest for visual displays. NIST is experimenting with nanowire-based LEDs for scanning-probe tips intended for electronics and biology applications.

The new, brighter LEDs are an outcome of NIST's expertise in making high-quality gallium nitride (GaN) nanowires. Lately, researchers have been experimenting with nanowire cores made of silicon-doped GaN (which has extra electrons) surrounded by shells made of magnesium-doped GaN (which has a surplus of holes for missing electrons) to promote electron and hole recombination and hence the release of energy as light via electroluminescence.

**Model of nanowire-based LED showing that adding aluminium to the shell layer (black) directs all recombination of electrons and holes (spaces for electrons) into the nanowire core (multi-colored region), producing intense light. (Courtesy of NIST.)**

The NIST group previously demonstrated GaN LEDs that produced light attributed to electrons injected into the shell layer to recombine with holes. The new LEDs have a small amount of aluminium added to the shell layer, which reduces losses from electron overflow and light reabsorption.

The brighter LEDs are fabricated from nanowires with a p-i-n structure, a tri-layer design that injects electrons and holes into the nanowire. The addition of aluminium to the shell helps to confine electrons to the nanowire core, boosting the electroluminescence fivefold (at an emission wavelength of 365nm).

"The role of the aluminum is to introduce an asymmetry in the electrical current that prevents electrons from flowing into the shell layer, which would reduce efficiency, and instead confines electrons and holes to the nanowire core," says first author Matt Brubaker.

The nanowire test structures were about 440nm long with a shell thickness of about 40nm. The final LEDs, including the shells, were almost 10 times larger. Researchers found that the amount of aluminium incorporated into fabricated structures depends on nanowire diameter.

Group leader Kris Bertness says that at least two companies are developing micro-LEDs based on nanowires, and that NIST has a Cooperative Research and Development Agreement (CRADA) with one of them to develop dopant and structural characterization methods. The researchers have had preliminary discussions with scanning-probe companies about using NIST LEDs in their probe tips, and NIST plans to demonstrate prototype LED tools soon.

The NIST team holds US Patent 8,484,756 on an instrument that combines microwave scanning probe microscopy (SPM) with an LED for non-destructive, contactless testing of material quality for important semiconductor nanostructures such as transistor channels and individual grains in solar cells. The probe could also be used for biological research on protein unfolding and cell structure.

**https://iopscience.iop.org/article/10.1088/1361-6528/ab07ed**
**www.nist.gov**

# Plessey's new native green LEDs boosts output for micro-LED displays

## 530nm-wavelength emission orders of magnitude brighter than color-converted LED

Plessey Semiconductors Ltd of Plymouth, UK says that it has developed its proprietary two-dimensional (2D) planar gallium nitride on silicon (GaN-on-Si) process to emit green light without the need for color conversion techniques.

To produce green light, LED makers typically apply phosphors or quantum dot conversion materials to native blue LEDs. These materials then convert short-wavelength (typically 450nm) blue light to red or green wavelengths with typically 10–30% efficiency.

Plessey's native green LEDs are formed inherently using its proprietary GaN-on-Si epitaxial growth process, similarly to the native blue LEDs, with the principal difference being the amount of indium that is incorporated in the quantum well structures of the LED. With no color conversion losses, the native green emission is orders of magnitude

times brighter than the color-converted process for micro-LEDs, says the firm. With a dominant green wavelength of 530nm and a full width half maximum (FWHM) of 31nm, the green is suited to color displays, it adds. Also, the green emission exhibits outstanding wavelength stability versus current density, it is claimed.

**With no color conversion losses, the native green emission is orders of magnitude times brighter than the color-converted process for micro-LEDs**

"Plessey already provides powerful, efficient native blue micro-LEDs and, through this innovation in our growth technology, Plessey has produced world-leading high-performance native green micro-LEDs, which will provide for next-generation display and illuminator devices for our customers," says chief operating officer Mike Snaith.

**www.plesseysemiconductors.com/products/microleds**

# Jonathan Rich replaces Mark Adams as Lumileds CEO

Lumileds LLC of San Jose, CA, USA has appointed Dr Jonathan Rich as CEO. He succeeds Mark Adams, who is stepping down as CEO and from the board of directors but will remain in an advisory role to the company. "It has been a great experience leading Lumileds' transition to an independent company that is focused on delivering lighting solutions," comments Adams.

"Mark Adams has made significant contributions to Lumileds during his tenure, leading the transition to an independent company and cultivating a culture of innovation and customer focus," comments Rob Seminara, a senior partner at global alternative investment manager Apollo and chairman of the board of Lumileds. "Jon will be joining Lumileds to drive the next phase of innovation and growth."

"I am looking forward to building on the company's differentiated lighting technology foundation to increase the value we can deliver to customers across a broad set of industries," says Rich. "The opportunity for lighting innovation to make a positive impact on safety and sustainability is tremendous."

From 2010 to 2018, Rich was chairman & CEO of Berry Global Inc (a Fortune 500 specialty materials and consumer packaging firm).

Previously, Rich was president & CEO of specialty chemical company Momentive of Albany, NY, USA. Prior to that, he held positions with Goodyear Tire & Rubber Company, first as president of the Global Chemicals business and then as president of the North American Tire Division. Rich formative years were at General Electric, first as a research scientist at GE Global Research then in management roles with GE Plastics. He received a Bachelor of Science degree in chemistry from Iowa State University and a Ph.D. in chemistry from the University of Wisconsin-Madison. He has been a visiting lecturer at Cornell University Johnson School of Business since 2017.

**www.lumileds.com**

# Bridgelux appoints senior director of product marketing

Bridgelux Inc of Fremont, CA, USA (a vertically integrated manufacturer of solid-state light sources) has appointed Uwe Thomas as senior director of product marketing.

Thomas joins from Samsung, where he drove business development activities in smart lighting with the ARTIK IoT platform. Prior to Samsung, he held marketing positions at LED Engin and Philips Lumileds, and an engineering position at Hewlett-Packard (where he began his career).

Thomas has managed product lines including automotive lighting and camera flash products and led a team of technical support managers responsible for lighting design-in activities. He is now tasked at Bridgelux with managing the Vesta Series tunable white array and module product lines, as well as delivering the next generation of Vesta Series power and connectivity platform solutions to assist customers in developing the next generation of human-centric smart lighting products.

"We look forward to his leadership as we grow our Vesta Series portfolio," says CEO Tim Lester. "Uwe has over 25 years of experience in the lighting industry, with a diverse background," he adds.

Thomas has a Master of Science degree in Telecommunications Engineering from University of Applied Sciences, Darmstadt, Germany.

# Bridgelux launches Thrive white point options for full-spectrum, human-centric LEDs designed to mimic sunlight

Bridgelux has announced Thrive, a family of white point options for surface-mount devices (SMD), V Series, Vero Series and Vesta Series chip-on-board (COB) products designed to closely mimic the sun and provide a new class of full-spectrum, human-centric LED white point solutions.

Using proprietary chip, phosphor and manufacturing technologies, Thrive closely mimics the spectrum of the sun without violet light augmentation. It produces lower blue light intensity at shorter wavelengths and delivers a smoother spectrum over the visual wavelength range, enabling a close spectral match to sunlight. Thrive offers:

- full-spectrum 95 CRI (color rendering iindex) light quality with similar efficacy compared to 90-CRI light sources;
- excellent CRI and TM30 metrics with R1 to R15 greater than 92, Rf 96-98 and Rg 99-102;
- lower circadian action factor (CAF) and melanopic ratios (MR) in warm-white color points, and higher CAF and MR values in neutral and cool-white color points, which are optimized for human well-being; and
- 2700K, 3000K, 4000K, 5000K, 5700K, 6500K CCT options.

"Thrive white points may be effective in a variety of applications including hospitals, residential, offices, education, and museums," says Dr Brian Cumpston, VP of solutions. "So many of us spend a large portion of our time indoors without the benefit of natural light. Thrive improves our indoor experiences under artificial lighting with its vivid color rendering and close match to the natural light provided by the sun," he adds. "With the ongoing awareness and interest in human-centric lighting solutions, we believe Thrive will assist lighting manufacturers to incorporate circadian features into their products as the lighting market continues to evolve."

Thrive white points are now available for sampling on SMD 2835 1W 9V and V Series 10C LEDs. Additional Thrive SMD and COB product options will be available for sampling in second-quarter 2019.

**www.bridgelux.com/resources/rise-and-shine-bridgelux-thrive**

# Bridgelux appoints VP of sales to lead sales teams in Americas and EMEA

Bridgelux has appointed Mark van den Berg as VP of sales for North and South America, Europe, Middle East and Africa. van den Berg joins Bridgelux from Intematix. While at Intematix, he introduced new strategic customers to the company, and delivered year over year growth with many existing accounts. Prior to Intematix, van den Berg held sales and marketing positions at Philips Lumileds, and a business development position at Hewlett-Packard.

"We are excited to welcome Mark to the team, and look forward to his leadership and expertise as we continue to drive growth in our key accounts. Mark has over 22 years of experience in the lighting industry with insight and vision that make him the ideal candidate to deliver the Bridgelux promise of flexible, human-centric lighting solutions," says CEO Tim Lester.

During his career, van den Berg worked in both general illumination and brought LED lighting technology into specific markets including automotive and mobile phones. With his broad expertise, he is now tasked at Bridgelux with delivering a comprehensive go-to-market strategy and all related sales activities within his regions.

van den Berg is based in Europe, and received a bachelor's degree in business management.

**www.bridgelux.com**

# Cree selling Lighting Products business to Ideal Industries

## Cree sharpening its strategic focus on power semiconductors

Cree Inc of Durham, NC, USA has agreed to sell its Lighting Products business unit (Cree Lighting), which includes LED lighting fixtures, lamps and corporate lighting solutions business for commercial, industrial and consumer applications, to Ideal Industries Inc of Sycamore, IL, USA for about $310m before tax impacts (including up-front and contingent consideration and the assumption of certain liabilities). Cree expects to receive an initial cash payment of $225m (subject to purchase price adjustments) and has the potential to receive a targeted earn-out payment of about $85m based on an adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) metric for Cree Lighting over a 12-month period beginning two years after the transaction closes.

The agreement continues Cree's strategy, announced in February 2018, to create a more focused, power semiconductor company, providing growth capital for Wolfspeed, its core Power & RF business, and equips Cree with additional resources to expand its semiconductor operations. It is reckoned that the deal also enables Cree Lighting to gain additional global focus, channel support and investment as it becomes a growth engine for the Ideal team.

"Cree has made significant progress over the last 18 months in sharpening the focus of our business to become a semiconductor powerhouse in silicon carbide (SiC) and gallium nitride (GaN) technologies," says CEO Gregg Lowe. "Over that time frame, we have grown Wolfspeed by more than 100%, acquired the Infineon RF business, more than doubled our manufacturing capacity of silicon carbide materials, and signed multiple long-term supply agreements which, in aggregate, are in excess of $500m," he adds.

"With the addition of today's lighting divestiture news, Cree is well positioned as a more focused semiconductor leader," Lowe reckons. "Cree's technologies are at the forefront of the automotive industry's transition to zero-emission electric vehicles, the telecommunications industry's move to faster 5G networks and the continued ramp up of LEDs for specialty applications. Our leadership in silicon carbide and GaN position us well to capitalize on the tremendous advantages that these technologies offer," he adds. "This transaction provides significant resources to help accelerate Wolfspeed's growth while providing a terrific growth opportunity for the Lighting business and its employees through an expanded channel that strengthens its market position… This decision benefits the company and our employees, shareholders and customers as it unlocks value, increases management focus on the core business and supports our mission to accelerate silicon carbide adoption," he believes.

Ideal is a fourth-generation, family-owned global company in electric power control and management. Cree Lighting's portfolio and SmartCast Technology are complementary to Ideal's advanced control business and its channel of suppliers, distributors, agents and customer relationships.

**Over the last 18 months.. we have grown Wolfspeed by more than 100%, acquired the Infineon RF business, more than doubled our manufacturing capacity of SiC materials, and signed multiple long-term supply agreements**

"Our combined technology and expertise will continue to build on Cree Lighting's history of leadership and fits with the advanced systems Ideal has pioneered over the past 103 years," says the firm's chairman & CEO Jim James. "Together, we will create a powerful combination of innovation, channel strength and operational excellence," he reckons. "We're acquiring a very special business poised for sustained success, and we look forward to assisting Cree Lighting in realizing its potential."

The closing of the transaction is expected to occur in Cree's fiscal fourth-quarter 2019 (subject to receipt of required regulatory approvals and satisfaction of customary closing conditions).

Cree Lighting will be classified as discontinued operations as of fiscal third-quarter 2019 (ending 31 March). Cree is hence updating its guidance to reflect continuing operations only.

For fiscal Q3/2019 (for continuing operations, rather than prior guidance), Cree targets revenue of $271–277m ($139–141m from Wolfspeed and $132–136m from LED Products) rather than $385–405m, but gross margin of 36% rather than 32%, and net income of $14–18m ($0.14–0.18 per diluted share) rather than $13–19m ($0.13–0.19 per diluted share). This excludes $27m of expenses (net of tax) related to stock-based compensation expense, $4m in amortization or impairment of acquisition-related intangibles, $5m in interest accretion on convertible notes' issue costs and fair value adjustments, $1m in executive severance and expenses relating to the disposition. Cree also expects to incur a $8m GAAP impairment charge on the Cree Lighting intangible assets, which will be reflected in discontinued operations when Cree reports its fiscal Q3 results on 1 May.

**www.cree.com**
**www.idealindustries.com**

# Osram's quarterly revenue to fall 15% year-on-year; full year to decline 11–14%

## Opto Semiconductors hit by production capacity under-utilization

Osram of Munich, Germany says that its fiscal second-quarter 2019 (to end March) is expected to see a revenue decline of about 15% year-on-year (similar to last quarter's decline, to €828m), combined with an adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) margin in the mid to higher single-digit range (down from last quarter's 11.3%). Similar to fiscal first-quarter 2019, the Opto Semiconductors business unit has been particularly affected, impacted by under-utilization of its production capacities.

The firm has hence lowered its fiscal full-year 2019 forecast for continuing operations. Osram's previous guidance was conditional on order intake reviving meaningfully in fiscal second-half 2019, but this has not yet occurred and is it not expected for the rest of the fiscal year.

Among the reasons are the continued market weakness in the automotive industry, in general lighting and in mobile devices that has led to significant inventory build ups, particularly in China. In addition, business development is facing an ongoing impact from the general economic slowdown. Geopolitical uncertainties continue to negatively impact demand, the firm stresses.

For fiscal 2019 Osram hence now expects a revenue decline of 11–14% (compared with the prior forecast of 0–3% growth), an adjusted EBITDA margin of 8–10% (cut from 12–14%) and negative free cash flow of €50–150m (compared with the previously forecast positive free cash flow in the mid double-digit million range).

The managing board says that it has already proactively responded to the growing economic challenges in the past few months. As announced in January, Osram is honing its focus on photonics and optical technologies beyond lighting, as reflected by the new organizational structures initiated at the start of fiscal 2019. According to Bayerischer Rundfunk, this involves cutting 300 of the 2800 jobs in Regensburg by the end of September through voluntary redundancy. The firm also wants to cut up to 240 temporary workers. Through such initiatives the annual cost base is expected to be structurally reduced by more than €200m by fiscal year 2021.

Osram says that its strategy — with its focus on optical semiconductors, the automotive sector and digital applications — remains intact, irrespective of the current market weakness, believing that it will provide a sustainable and attractive return profile over the longer term. Transformation of the portfolio is progressing with the initiated sale of the European luminaires business and the sale of the US service business. New business areas such as facial recognition and professional farming are showing positive developments, the firm concludes.

**www.osram-group.com**

# Osram launches Duris S5 purple LED for horticulture lighting

To expand its portfolio of horticulture LEDs with various colors, voltage and beam-angle options, Osram Opto Semiconductors GmbH of Regensburg, Germany has launched the Duris S5 purple, which combines key wavelengths of red and blue into a single purple LED that can make horticulture applications more cost effective.

The options to select a specific color spectrum or wavelength, much lower power consumption and much longer lifespan — resulting in lower maintenance and operational costs — as well as more flexibility for design and control functions have created growing demand for LED-based horticulture lighting, for both professional as well as consumer applications, says Osram.

Designers of horticulture lighting systems for professional use often prefer multi-channel solutions with a combination of LEDs to be able to adapt and optimize the light output for different stages of the plant's life cycle, including seedlings, germination, vegetative growth and flowering. For consumer lighting systems cost and ease of implementation are key factors that system developers are focusing on when selecting their components.

Osram says, by combining two of the most important wavelengths (450nm & 660nm) for plant growth in a single package, the Duris S5 purple is particularly cost effective for cost-sensitive applications. The LED is available with output powers of 0.3W and 1.0W and is suitable for horticulture lighting systems in indoor consumer markets.

The new LED utilizes an innovative phosphor spectrum for high photosynthetic photon flux (PPF) professional-grade materials (such as a high-quality epoxy lead-frame), Osram's sapphire chip as well as robust silicone and has been qualified by extensive stress test. The Duris S5 purple can also be mixed with the Duris S5 lime to produce high-quality white light (good for harvesting and visual inspection).

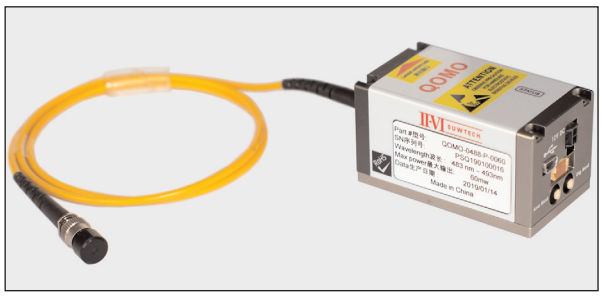
Osram also offers a new unique full-spectrum white Duris in various voltage options with a higher proportion of hyper red and far red compared with standard white LEDs.

**www.osram.com/os/applications/horticulture-lighting**

# II-VI introduces fiber-coupled visible lasers for biomedical instruments

As part of its QOMO series of visible lasers (deployed in biomedical applications such as flow cytometry, confocal microscopy and fluorescence spectroscopy), engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has introduced fiber-coupled visible lasers for biomedical instruments, available with emission wavelengths of 405, 488, 638 and 660nm, and 30, 50 or 100mW of output power.

II-VI says that its fiber-coupled lasers simplify the integration, manufacturing assembly and field serviceability of analytical instruments, eliminating the need for users to design, produce and assemble challenging beam




delivery systems. The visible lasers are coupled to a polarization-maintaining single-mode fiber that eliminates spatial-mode fluctuations, consistently delivering a near-perfect M-squared beam quality of less than 1.1, with what is claimed to be excellent pointing stability and very low noise.

"The fiber-coupled visible lasers afford our customers significant benefits in terms of shorter time to market, improved manufacturability and market-leading performance," claims Chris Koeppen, VP of II-VI's Industrial Laser Group. "The QOMO laser product series leverages II-VI's well-established hardware and software platform with decades of field-proven reliability in optical networks," Koeppen adds.

II-VI showcased its portfolio of products at the LASER World of PHOTONICS CHINA 2019 event in Shanghai (20-22 March).

**www.world-of-photonics-china.com**
**www.ii-vi.com/lasers-for-flow-cytometry/?SingleProduct=857**

# SemiNex making laser engines on new production line

## Assembly time reduced 10-fold and cost halved

SemiNex Corp of Peabody, MA, USA (which was founded in 2003 and designs and makes indium phosphide (InP)-based high-power infrared diode lasers for military, medical and industrial applications) has begun manufacturing its laser engines on a newly implemented assembly line.

This follows the acquisition of a suite adjoining the firm's headquarters, doubling production area and increasing office space for engineers and process technicians. The new cleanroom facilities have been designed to meet ISO Class 7 standards and ESD best practices, and are fully outfitted with upgraded test stations and equipment.

Over the past couple of years SemiNex engineers have optimized its trial production processes to reduce cost, improve performance and increase capacity. Now with production in full operation, SemiNex says it will continue to monitor and improve key performance metrics such as cycle time, on-time delivery, yield and throughput —


**SemiNex's headquarters building.**

steps that will be crucial to transferring the process to contract manufacturing (a technique that SemiNex typically uses to stay lean).

"The new production line uses custom fixtures to automate critical steps and requires minimal input from a technician," says mechanical engineer & project lead Matt Hamerstrom. "We've reduced assembly time 10-fold from the old design, and we were able to halve the cost while maintaining optimal performance."

While there has been considerable interest in home laser treatments, few companies have been able to produce laser devices at a price and safety standard that appeals to consumers, claims the firm. Every component of the new production line — from the custom fixtures to the software on the final test station — has been engineered to meet these requirements for the consumer beauty market, the firm adds.

"It's been invaluable to have the insider knowledge and experience SemiNex brings to the production process," comments Kayla Govoni, spokesperson for NIRA (a manufacturer of handheld home skincare laser devices). "We're expecting 2019 to be the year we really start seeing lasers for aesthetic use inside people's homes."

**www.seminex.com**

# EU Horizon 2020 project ULISSES to develop wearable on-chip optical air sensors

Senseair AB, AMO GmbH, KTH Royal Institute of Technology, Oxford Instruments Plasma Technology (OIPT), Graphenea Semiconductor SL, Universität der Bundeswehr München, Catalan Institute of Nanoscience and Nanotechnology, and SCIPROM Sàrl have launched the project ULISSES, which has received funding from the European Union's Horizon 2020 research and innovation program (under grant agreement no. 825272). The project aims to develop a new class of miniaturize on-chip optical gas sensors, enabling low-cost distributed sensing nodes for the Internet of Things (IoT).

Project partners will collaborate to combine silicon photonics with two-dimensional (2D) materials, to enable fully integrated optical gas sensing nodes for the IoT. These nodes should be able to be manufactured in large volumes at low cost and achieve performance improvements in terms of size and power consumption. The development would enable personal gas sensors embedded in wearable devices, as well as public infrastructure such as street lighting, buses and taxis, or even in small unmanned aerial vehicles (UAVs). The new technology aims to empower the general public to monitor and put demands on their air quality.

Gas sensors are already widely used in industry and agriculture, to ensure safety of personnel and to monitor and automate processes. However, rising general awareness of the importance of urban indoor and outdoor air quality is now driving demand for accurate, low-cost and mobile gas sensor technology. Optical gas sensors offer the highest sensitivity, stability and specificity in the market, but their current cost, power consumption and size hinder them from being widely employed by the general public. ULISSES technology should enable compact, low-cost and low-power gas sensor nodes to be networked for comprehensive and real-time monitoring of air quality in urban areas. This new approach will provide valuable information to city planners, employers and landlords to ensure a healthy indoor and outdoor environment.

**Oxford Instruments and partners launch EU Horizon 2020 project ULISSES:**

**ULISSES technology should enable compact, low-cost and low-power gas sensor nodes to be networked for comprehensive and real-time monitoring of air quality in urban areas**

By leveraging recent breakthroughs by ULISSES partners in waveguide-integrated 2D materials-based photodetectors, 1D nanowire mid-IR emitters and mid-IR waveguide-based gas sensing, ULISSES is targeting a three-order-of-magnitude reduction in sensor power consumption, permitting maintenance-free battery-powered operation for the first time. Furthermore, ULISSES will implement a new edge-computing self-calibration algorithm that leverages node-to-node communications to eliminate the main cost driver of low-cost gas sensor fabrication and maintenance.

Over the next four years, gas sensor supplier Senseair AB will coordinate the ULISSES project with the help of SCIPROM. Using systems developed by Oxford Instruments Plasma Technology, AMO will fabricate the silicon photonics chips with integrated silicon waveguides and 2D material-based photodetectors developed by KTH and AMO. The 2D materials will be provided by the Universität der Bundeswehr München and Graphenea. Senseair will lead the various application demonstrators and prepare the sensors for IoT applications together with KTH. ICN2 will provide modelling and simulation support, in order to optimize sensor design and efficiency.

**www.ulisses-project.eu**
**www.oxford-instruments.com/plasma**

# REDFINCH yields prototype portable photo-acoustic sensor for gas detection and analysis

## Leti-led project integrates quantum cascade lasers on silicon mid-infrared photonic integrated circuits

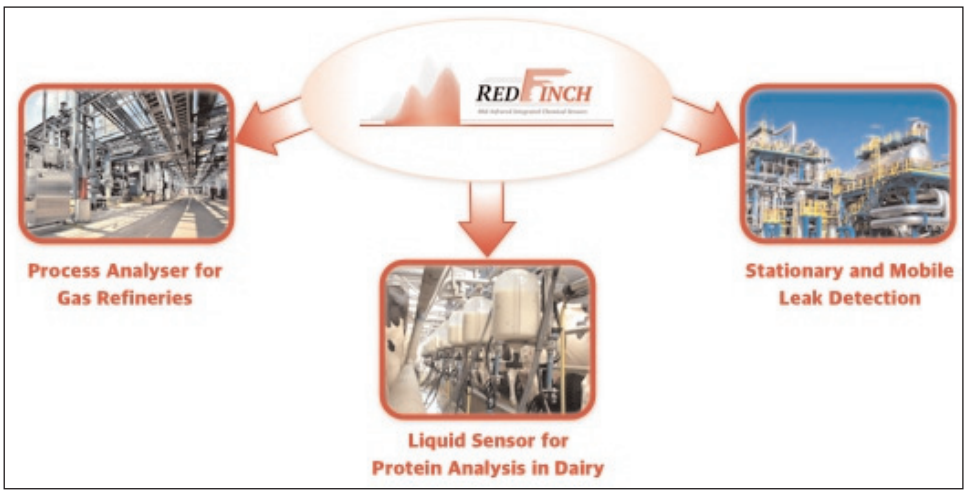
Grenoble-based micro- & nanotechnology R&D center CEA-Leti has announced the development of a prototype miniaturized, portable optical sensor for the chemical detection of gas — the subject of an invited paper 'Photo-acoustic cell on silicon for mid-infrared QCL-based spectroscopic analysis' (which won Best Paper Award at Photonics West 2019).

The next-generation centimeter-size photo-acoustic sensors are based on mid-infrared photonic integrated circuits (MIR PICs). The silicon PICs, created by integrating optical circuits onto millimeter-size silicon chips, comprise extremely robust miniature systems, in which discrete components are replaced by on-chip equivalents, making them easier to use and reducing their cost dramatically (by at least a factor of 10, it is expected).

Developed by the European Commission's REDFINCH project (headed by CEA-Leti), the prototype photo-acoustic sensors were fabricated on a CMOS line in a miniaturized silicon photo-acoustic cell, allowing extreme integration.

In demonstrations, the sensors match the performance of bulky commercial gas-sensing systems commonly available now. They are targeted at applications such as process gas analysis in refineries, gas leak detection in petrochemical plants and pipelines, and protein analysis in liquids for the dairy industry.

The sensors aims to consume less than 10W in continuous operation. They can be operated in a slow pulse-burst mode for infrastructure monitoring and, when leaks are detected, the pulse frequency of the sensor automatically increases. This keeps average power consumption very low, so the sensors can be battery-operated for more than a year or powered by an ambient energy harvester (e.g. a solar cell).




**The big picture is that the miniaturization of photo-acoustic spectroscopy based on quantum cascade lasers is entering the stage of mass production**

"The big picture is that the miniaturization of photo-acoustic spectroscopy based on quantum cascade lasers (QCLs) is entering the stage of mass production," says Jean-Guillaume Coutard, an instrumentation engineer at Leti who coordinate the project.

To develop the chemical sensors, the REDFINCH consortium overcame the challenge of implementing their capabilities in the important mid-infrared region, where many important chemical and biological species have strong absorption fingerprints.

"This allows both the detection and concentration measurement of a wide range of gases, liquids and biomolecules," says Coutard. "This is crucial for applications such as health monitoring and diagnosis, detection of biological compounds and monitoring of toxic gases," he adds.

"This project is a perfect fit for mirSense's development roadmap," says Mathieu Carras, CEO of mirSense, which participated in the project. "Our mission is to democratize QCL usage," he adds. "mirSense is ready to produce these state-of-the-art integrated QCL-based components and do a similar job on electronics and software to bring the value of this technology to the market."

The consortium members and contributions include:

- Cork Institute of Technology (Ireland) — PIC design & fabrication, hybrid integration;
- Université de Montpellier (France) — laser growth on silicon, photodetector growth;
- Technische Universität Wien (Austria) — liquid spectroscopy, assembly/test of sensors;
- mirSense (France) — MIR sensor products, laser module integration;
- Argotech a.s. (Czech Republic) — assembly/packaging of PICs;
- Fraunhofer IPM (Germany) — gas spectroscopy, instrument design/assembly;
- Endress+Hauser (Germany) — process gas analysis and expertise, testing validation.

**www.redfinch.eu**
**www.leti.fr**

# POET announces bridge financing exceeding needs till DenseLight sale

## Proceeds to advance development of optical interposer platform

POET Technologies Inc of Toronto, Canada and San Jose, CA, USA — a designer and manufacturer of optoelectronic devices, including light sources, passive waveguides and photonic integrated circuits (PICs) for the sensing and datacom markets — has arranged over C$10m of financing, representing the minimum funding needed to bridge the firm to the anticipated sale of its Singapore-based DenseLight subsidiary for C$34.2-39.5m (announced in February, and due for completion in September, subject to certain conditions including shareholder and other approvals).

Acquired by POET in May 2016 for US$10.5m in common stock, DenseLight has been engaged primarily in developing new sensing and datacom products, including active devices for POET's Optical Interposer platform.

The first component of the financing comprises the issue of up to C$14m of 12% convertible unsecured debentures, to be sold in multiple tranches over upcoming months (as needed) on a brokered private placement basis through financial advisors IBK Capital. Closing of the first tranche, for gross proceeds of about C$1.9m, occurred on 3 April (with IBK Capital paid a cash commission of 5% of the gross proceeds raised). Insiders of the firm (including all of its board of directors and senior management team) and IBK Capital subscribed for over 47% of the first tranche.

Further indications of interest amounting to C$1.6m from parties who could not participate in the first tranche are expected to be included in subsequent tranches over the next few months (each subject to approval by the TSX Venture Exchange).

The second component of the financing consists of a credit facility to be provided by Espresso Capital Ltd. POET has signed a term sheet for the bridge loan that (subject to execution of definitive loan documents and the approval of the TSX Venture Exchange) will give the firm access of up to C$6.6m (US$5m). The loan's initial advance of C$2.6m (US$2m) is expected soon.

"The significant investment made by management and the board clearly demonstrates our strong confidence in the long-term success of POET," says executive VP & chief financial officer Thomas Mika. "Additionally, as indicated when we announced the proposed sale of DenseLight, we upheld our commitment to finance the company without pursuing a highly dilutive equity raise," he adds. "The combination of the two forms of financing, when completed should comfortably exceed our needs over the next several months, giving us maximum flexibility. The continued offering of convertible debentures is intended to allow our stockholders and new prospective investors to participate in the future growth of POET Technologies."

The proceeds of the financing are expected to be used to advance the firm's Optical Interposer Platform and for working capital and general corporate purposes.

**www.poet-technologies.com**

## DenseLight digitally control integrated light module for wind LiDAR

POET and its subsidiary DenseLight say that samples of its new Integrated Light Module (ILM), designed for high-performance wind light detection & ranging (LiDAR) and other environmentally stressed applications, are now available to customers in limited quantities.

Because of expected high customer demand, the DL-BF9D will be on allocation beginning immediately. Company representatives took initial sample orders at the SPIE Photonics West 2019 exhibition in San Francisco in February, where DenseLight is exhibiting its suite of standard components for datacoms and sensing applications. In particular, for customers with an immediate requirement, the firm is offering quantities of its DL-DFB9C ILM, which offers the same enhanced performance but with analog control at a more affordable price.

The new DL-BF9D digital version has enhanced features and is a member of the Constellation series of ILMs, offering lower relative intensity noise (RIN) and phase-noise performance as well as improved linewidth stability performance compared with similar modules from other suppliers, it is claimed.

Key features include: tunable optical power; an operating temperature (chassis) of 0–50°C; RIN <–150dB/Hz (<–160dB/Hz 10–50MHz); low phase noise; linewidth, typical 10kHz; mode-hop-free operation over temperature; side-mode suppression ratio (SMSR) >45dB; and digital control interface via USB.

The DL-BF9D ILM is suitable for a wide range of communications and sensing applications where noise performance and linewidth stability are critical, such as wind LiDAR and other distributed acoustic sensing (DAS) applications.

**www.denselight.com**

# POET teams with MillView Photonics to establish collaborative design center in Ottawa

## POET named to 2019 TSX Venture 50 list of companies

POET Technologies Inc of Toronto, Canada and San Jose, CA, USA — a designer and manufacturer of optoelectronic devices, including light sources, passive waveguides and photonic integrated circuits (PICs) for the sensing and datacom markets — has entered into an agreement with MillView Photonics Inc to establish a collaborative design center in Ottawa, Ontario, Canada.

MillView was established two years ago by Dr Trevor J. Hall (professor in the School of Electrical Engineering & Computer Science and founding director of the Centre for Research in Photonics at the University of Ottawa). Along with his team, which includes senior passive component designer Peng Liu, senior active component designer Mihail Dumitrescu, and supported by doctoral and post-doctoral graduate engineers, MillView serves clients in photonics research, simulation, design and process development.

The agreement gathers in one lab the MillView team (including Hall), additional staff from MillView, and three PhD-level photonics engineers from POET. The team is also supported by POET's senior VP Dr William Ring and additional POET design engineering resources.

"MillView Photonics was founded along the same model as Cambridge Consultants where I worked on my return to Cambridge following PhD studies at University College London, UK," says Hall. "Cambridge Consultants tapped into a vast reservoir of talent to solve real-world design and engineering challenges utilizing academic/industry partnerships. MillView is similarly situated to bring in the specific talent needed to address and solve a broad range of engineering challenges in photonics… POET's unique Optical Interposer platform has tremendous market potential, and we are all committed as one team to its success," he adds.

"POET's partnership with MillView rapidly expands our effort with experienced photonics engineering talent and substantial simulation and design capacity," says POET's CEO Dr Suresh Venkatesan. "In line with our stated strategy, we have assembled a team in one place dedicated to one goal — the design and development of waveguides and filters for our Optical Interposer platform," he adds. "This places POET squarely in both a region and university where photonics design and development are vibrant and pervasive. The number of companies engaged in the photonics industry and the quality of the engineering talent available is extraordinary."

**2019 TSX Venture 50**

POET has been named to the 2019 TSX Venture 50 list, a ranking of the top performers on the TSX Venture Exchange over the past year. The list consists of ten companies from each of the five industry sectors represented on the TSX Venture Exchange. Companies are selected based on three equally weighted criteria: market capitalization growth, share price appreciation and trading volume.

"Last year was a transformational year for the company, highlighted by our first orders for our POET Optical Interposer-based solutions from leading global communications companies targeting data communications applications," says executive VP & chief financial officer Thomas Mika. "Additionally, we recently received an offer to purchase our DenseLight subsidiary as part of our plan to pursue a fab-light strategy with a less capital-intensive business model," he adds. "Today's announced collaboration agreement with MillView for combining design capabilities also furthers these efforts by leveraging key strategic partnerships to establish POET as a world-class organization with leading optical products," Mika reckons.

**Change to board**

POET also says that John O'Donnell has resigned from its board of directors (effective 31 December 2018) as part of his recent retirement from professional law practice. O'Donnell had served as the firm's chief legal counsel, corporate secretary and director since 2012.

**www.poet-technologies.com**
**www.denselight.com**
**www.tsxventure50.com**

# SiFotonics raises $30m in funding as it adds new production facility in China

## Chief operating officer hired to accelerate product development

SiFotonics Technologies Co Ltd of Woburn, MA, USA, which develops and manufactures germanium-on-silicon (Ge-on-Si) devices and silicon photonics integrated circuits (using its R&D centers in Beijing and Shanghai), has completed a new round of investment of over $30m, and will expand capacity with a new production facility in Nanjing, China.

"With new funding and a new manufacturing facility, SiFotonics is well positioned for market adoption of our leading-edge silicon photonics integrated circuit product solutions for global optical networking customers," reckons founder & CEO Dr Dong Pan.

Also, veteran technology executive Dr Rang-Chen Yu has joined SiFotonics as chief operating officer. "He has a wealth of industry experience and proven track record of turning new technologies into commercial success and turning young companies into large businesses, and we are looking forward to his leadership to grow the company to the next level," comments Pan.

Before joining SiFotonics, Yu was VP & general manager of the Optoelectronic Solutions business unit of Molex company Oplink Communications LLC. Previously, he was global VP at Source Photonics. He also served as senior executive and in management positions with Fiberxon (acquired by MRV), Agility Communications (acquired by JDSU) and SDL (also acquired by JDSU). He has a Ph.D. in Solid State Physics from University of Pennsylvania and a B.S. in Physics from Peking University.

"SiFotonics' team is one of the early pioneers in development of silicon photonics for optical networking applications and has developed one of industry's most advanced Ge-on-silicon capabilities, with complex photonics integrated circuit platforms," comments Yu. "With rapid increasing bandwidth for data centers networking connections and 5G wireless optical transports, SiFotonics' core technologies will provide differentiated and compelling solutions to address these challenges. In addition, SiFotonics has also developed silicon photonics platforms with a unique combination of commercial CMOS foundry and proprietary controlled Ge-on-Si processes and fabrication tools that enable rapid innovation with high efficiency," he adds. "I am looking forward to working with SiFotonics team to accelerate product solution development for global tier-1 customers with commercial success".

www.sifotonics.com

## SiFotonics showcases silicon photonics products at OFC

At the Optical Networking and Communication Conference & Exhibition (OFC 2019) in San Diego, CA, USA (3-7 March), SiFotonics showcased its portfolio of the following silicon photonics products:

- industrial-temperature, high-sensitivity 25Gbps avalanche photodiode (APD) receiver module for extended-reach 5G front-haul applications (now generally available and shipping in high volume);
- industrial-temperature, high-sensitivity 50Gbps PAM4 APD receiver module for long-reach 5G mid-haul optical networking applications (now available for sampling);
- commercial and industrial-temperature, high-sensitivity 100Gbps PAM4 APD receiver module for most economical data-center and 5G interconnect applications (now available for sampling);
- 4x25G PIN photodiode array for high-volume 100G data-center interconnect applications (now shipping in high volume);
- 4x25G APD receiver module for extended-reach 100G applications. This product is available for sampling;
- 32Gbaud micro integrated coherent receiver module for 100G and 200G metro and data-center interconnect (DCI) applications (available for sampling);
- 64GBaud integrated coherent receiver photonics integrated circuit chip for 400G metro and DCI applications (available for sampling).

"With the rapid increase of optical networking bandwidth required for large data centers and 5G wireless optical transport, advanced high-sensitivity receiver technologies are in high demand to address the challenge of physical limitation of reduced link budget with increase speed," says chief operating officer Dr Rang-Chen Yu. "SiFotonics unique capability of advanced germanium-on-silicon detection technology with complex photonic integrated circuits offers compelling solutions to global tier-1 customers," he adds.

"Our products are based on more than 10 years of development with industry-leading silicon photonics platforms with a unique combination of commercial CMOS foundry and proprietary controlled germanium-on-silicon processes and fabrication tools that enable rapid innovation with high efficiency," says founder & CEO Dr Dong Pan.

At OFC, Pan co-chaired a panel on 'PIC Foundry Commercial Access: Prospects and Challenges'. He also presided at a technical session 'Detectors'.

www.ofcconference.org

# Foundry CompoundTek partners with Southampton's Silicon Photonics Group to offer design services

## Combined design and foundry services to facilitate industry entrants

Singapore-based silicon photonic foundry services provider CompoundTek Pte Ltd has partnered with the Silicon Photonics Group at the University of Southampton's Optoelectronics Research Centre (ORC) — based in the Zepler Institute for Photonics and Nanoelectronics at the UK's University of Southampton — to offer silicon photonics design services.

Founded by professor Graham Reed at the University of Surrey in 1989 to support UK silicon photonics research, the Silicon Photonics Group has developed designs which have since become the industry standard in data centers, telecoms and high-performance computing applications, it is said.

This industry partnership aims to speed adoption of silicon photonics technology as a key enabler to transporting high levels of data, instrumental in enhancing operational efficiency and capacity within data centers. Silicon photonics technology is also paving the way for emerging applications such as data transfer, autonomous vehicles, telecoms, biomedical and artificial intelligence.

CompoundTek says that, as it continues to gain traction and progress with customer expansion globally, it can offer combined design and foundry services that are expected to accelerate new industry entrants. Led by Reed, the design partnership with the ORC aims to facilitate new entrants into the silicon photonics industry by giving them access to value-added design services backed by CompoundTek's foundry fabrication service.

"CompoundTek looks forward to providing the marketplace silicon photonics' design capabilities as a value-added service in addition to our existing foundry fabrication services," says CEO Raj Kumar. "This strategic partnership reflects CompoundTek's commitment to developing advanced solutions with real commercial benefits."

As one of the few global foundries or firms equipped to manufacture silicon photonics, CompoundTek's services includes end-to-end industry expertise from process technology to product co-design to manufacturing with strategic design partners.

**www.siliconphotonics.co.uk**
**https://compoundtek.com**
**www.orc.soton.ac.uk/silicon-photonics**

# CompoundTek and software provider Lumerical partner on enhanced silicon photonics PDK

## Photonics design automation accelerates prototyping silicon PIC designs with foundry services

CompoundTek has made available an enhanced process design kit (PDK) developed in collaboration with photonic simulation software provider Lumerical Inc of Vancouver, British Columbia, Canada. In combining Lumerical's photonics design automation for accelerated photonic integrated circuit (PIC) design prototyping with CompoundTek's proprietary foundry services, the SiPh PDK strengthens CompoundTek's efforts in driving customers' process efficiencies by accelerating their time-to-market.

The enhanced SiPh PDK will be offered through the implementation of a reliable compact model library (CML), which includes active and passive devices such as optical waveguide devices, fiber-to-waveguide couplers, high-speed waveguide germanium (Ge) photodetectors and high-speed modulator. It allows SiPh designers to leverage pre-developed blocks to design and verify their photonics products more quickly and efficiently before fabricating physical prototypes. These predictive capabilities enable photonics designers to validate designs prior to manufacturing.

"We are excited to partner with the industry's leading SiPh foundry service provider, CompoundTek, to provide a reliable CML for accurate time- and frequency-domain simulation using Lumerical's PIC simulator INTERCONNECT," comments Lumerical's chief technology officer Dr James Pond.

"This milestone partnership with Lumerical speaks to CompoundTek's commitment in supporting our existing and potential customers' endeavors to improve their productivity in SiPh design," says CompoundTek's chief operating officer K.S. Ang. "Together with our design partners, this photonics design automation solution, together with our open SiPh manufacturing process platform, will accelerate the adoption of SiPh solutions for various applications ranging from datacom transceivers, smart sensor, bio-medical, automotive LiDAR, quantum computing and artificial intelligence."

CompoundTek's operation include strategic partnerships with a fabrication service provider in Malaysia and global SiPh research institutes, offering solutions for SiPh players from start-ups to Fortune 500 firms.

**www.lumerical.com**

# MACOM & GlobalFoundries to scale silicon photonics to hyperscale cloud data-center & 5G network buildouts

MACOM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) and GlobalFoundries (GF) of Santa Clara, CA, USA (one of the world's largest semiconductor foundries, with operations in Singapore, Germany and the USA) have announced a strategic collaboration to ramp MACOM's laser photonic integrated circuit (L-PIC) platform using GF's 90WG current-generation silicon photonics offering to meet data-center and 5G telecom industry demands. The collaboration will leverage GF's 300mm silicon manufacturing process to deliver the requisite cost, scale and capacity that is expected to enable mainstream L-PIC deployment for hyperscale data-center interconnects and 5G network deployments at 100G, 400G and beyond.

Built on GF's 90nm SOI technology using 300mm wafer processing, 90WG enables low-cost integration of optical devices like modulators, multiplexers and detectors into a single silicon substrate. MACOM's L-PIC technology is said to solve the remaining key challenge of aligning lasers to the silicon PIC. Leveraging patented etched facet technology (EFT) lasers and a patented self-alignment EFT (SAEFT) process, MACOM's lasers are aligned and attached directly to the silicon photonics die with high speed and high coupling efficiency, accelerating the adoption of silicon photonics in industrial-scale applications.

The industry is entering a long upgrade cycle for high-speed optical connectivity within cloud data centers as well as 5G optical buildouts. Industry forecasts project 2019, 2020 and beyond to be strong growth years for coarse wavelength-division multiplexing (CWDM) and PAM-4, with the potential for overall unit demand in 2019, reaching volumes of 10 million units. With a track record of enabling 1.6 million ports in 2016, 4 million ports in 2017 and 6 million ports in 2018, MACOM will work with GF to scale L-PIC production, aimed at meeting this growing market demand.

"With the demand for bandwidth doubling inside data centers each year, cloud service providers are supply constrained in moving to 100G and beyond," says MACOM's president & CEO John Croteau. "On top of this, telecom carriers are now adopting the same CWDM and PAM-4 optical standards for their 5G network buildouts. The ability to efficiently scale transceiver capacity and manufacturing throughput is critical. By aligning capacity expansion between GF's silicon photonics technology and MACOM's EFT lasers, and moving to 300mm wafers, we believe that this very strategic collaboration will allow us to meet industry demand and position us to service the industry for years to come," he adds.

"We have built an incredible foundation as a leader in providing silicon photonic solutions and advanced packaging capabilities that enable our clients to build a new generation of high-performance optical interconnects," says GF's CEO Tom Caulfield. "With our deep manufacturing expertise, combined with MACOM's strong technology, we can deliver differentiated silicon photonic solutions at scale, accelerate time-to-market, and reduce costs for client applications in data-center and next-generation 5G optical networks," he reckons.

**www.macom.com/opto**
**www.globalfoundries.com**

## MACOM launches first 400G-FR4 L-PIC for cloud data-centers

MACOM's new MAOP-L564FP is a quad-channel silicon photonic integrated circuit with integrated lasers (L-PIC) for 400G-FR4 applications. It is expected to enable easy scaling from 100G to 400G while reducing cost due to the ease of assembly, calibration and test, while decreasing the production capital expenditures required.

Demand for data is pushing cloud data-center providers to continue to scale their solutions. Developing highly integrated, high-performance and cost-effective products from its patented L-PIC technology platform, MACOM is enabling the transition to 100G, 400G and beyond with its fully MSA-compliant solutions for CWDM4, FR4 and FR1/DR1.

The MAOP-L564FP for 400G-FR4 includes coarse wavelength-division multiplexing (CWDM) lasers, 4-level pulse amplitude modulation (PAM-4) modulators, a CWDM multiplexer and monolithic monitor photodiodes. The device features high bandwidth and low power dissipation, and is designed to operate up to 80°C.

"MACOM is continuing to leverage our L-PIC platform to enable the cloud data-center market with fully optimized solutions for scaling to 100G, 400G and beyond," says Vivek Rajgarhia, senior VP & general manager, Lightwave, at MACOM. "Leveraging our strong analog and photonic product and technology portfolio, our new 400G-FR4 device is expected to offer customers a high-performance, pre-engineered solution that reduces overall cost and investment while shortening time to market."

The MAOP-L564FP uses the same pin-out as the MAOP-L284CN L-PIC for CWDM4 applications (launched in March 2017), enabling easier scale from 100G to 400G.

**www.ofcconference.org**
**www.macom.com**

# Molex and Elenion extend investment to bring silicon photonic-based solutions to market

## Molex Optical Solutions Group expands collaboration with Elenion

Molex Ventures LLC, a subsidiary of Molex Electronic Technologies LLC of Lisle, IL, USA (which makes electronic components including connectors, cable assemblies, antennas, optical solutions, printed-circuit products, automation and lighting products), has announced a further investment between Molex Optical Solutions Group (OSG) and New York-based Elenion Technologies LLC (which designs silicon photonics-based system-on-chip solutions for high-bandwidth communication and networking applications), collaborating on the next generation of high-baud-rate coherent optical module solutions. The co-development efforts will focus on several new designs that will serve a variety of telecom and datacom applications.

Through the collaboration, Molex will combine its core capabilities of optical technology development, photonic integration, volume manufacturing and global supply chain with Elenion's next-generation coherent optical engines to deliver coherent optical solutions to the market. "High-speed silicon photonic-based technologies will enable the next generation of smaller form factors, with higher bandwidth and improved power efficiency," says Adit Narasimha, VP & general manager of the Molex Optoelectronics Segment. "This further investment will enable us to accelerate the introduction of next-generation coherent solutions, broadening the solutions we offer," he adds.

"With our SiPh technology platform, Elenion is able to rapidly innovate, meeting the future needs of our customers," says Elenion's CEO Larry Schwerin.

Elenion's existing optical engines are enabling CFP2-ACO and CFP-DCO coherent modules. With the introduction of its next-generation CSTAR system-on-chip solutions, Elenion enables new smaller-form-factor engines and pluggables tailored for telecom and hyperscale applications.

**www.elenion.com**
**www.molex.com/opticalsolutions**
**www.molex-ventures.com**

# Lumentum selling Oclaro Japan optical transceiver product lines to CIG

## CIG enters into long-term supply agreement for InP photonic chips

Lumentum Holdings Inc of Milpitas, CA, USA (which provides photonics products for optical networking and lasers for industrial and consumer markets) has entered into a strategic agreement and partnership for Shanghai-based Cambridge Industries Group (CIG, a ODM/JDM/EMS supplier for the ICT industry) to acquire certain optical transceiver product lines developed and manufactured by subsidiary Oclaro Japan Inc and to enter into a long-term strategic supply agreement for Lumentum's photonic chips.

"I am pleased to partner with CIG and leverage our respective strengths to better address the market opportunity created by the highly anticipated growth in high-speed datacom and telecom client-side transceiver volumes driven by data-center expansion and 5G wireless over the coming years," says Walter Jankovic, Lumentum's senior VP & general manager, Datacom. "This transaction enables Lumentum to become more commercially focused on its differentiated indium phosphide (InP) photonic chip capabilities and brings a new customer that is well positioned to compete in the datacom transceiver market," he adds.

"With this acquisition and ongoing partnership with Lumentum for supply of their industry-leading photonic chips, together with CIG's proven quality and volume JDM [joint design manufacturer] and ODM [original design manufacturer] capabilities, CIG expands its capabilities with industry-leading optical transceiver products and technology spanning the range of 10G, 25G to 400G serving many long-standing tier-1 customers," says CIG's president & CEO Gerald Wong. "With the combination of CIG's strengths in cost-effective high-volume manufacturing and Lumentum's optical transceiver team in Japan, with their decades of experience in high-performance datacom and telecom transmission, we are well positioned to address customer needs in the datacom and telecom client-side transceiver market," he believes.

The transaction is expected to close in second-quarter 2019 (subject to certain customary closing conditions). The sale is not expected to impact the guidance ranges provided on 5 February for Lumentum's third fiscal quarter (to end-March). Revenue attributable to the products to be sold in the proposed transaction is about $20m of the $50-55m of datacom revenues previously included in Lumentum's guidance for fiscal Q3/2019.

**www.cigtech.com/optical-sub-assemblies**
**www.lumentum.com**

# Rockley extends strategic partnership with Hengtong, expanding joint venture

## Hengtong investing $30m in Rockley's Series E funding round

Rockley Photonics of Pasadena, CA, USA (formed in 2013 to develop a silicon photonics platform for optical I/O in next-generation sensor systems and communications networks) has expanded its strategic relationship with Shanghai stock-exchange listed Hengtong Optic-Electric Co Ltd. The Suzhou-based joint venture with Hengtong addresses the burgeoning 400G DR4 transceiver market. As part of the deal, Hengtong will invest $30m in Rockley's Series E funding round.

Rockley-Hengtong is expanding its 2017 joint venture, increasing its portfolio to develop, manufacture and sell 400G DR4 transceivers utilizing Rockley's LightDriver Optical Engines. "This new funding provides us with significant capital to move to the next stage of our business plan," says Rockley's chief finance officer Mahesh Karanth. "We will accelerate volume manufacturing of Rockley's LightDriver Optical Engine and develop next-generation sensors and communications products," he adds. "Our technology will help to meet the

new connectivity requirements for data centers, supporting cloud computing, artificial intelligence (AI) and machine learning."

Emerging applications like AI, machine learning, AR/VR and 5G wireless are driving network traffic to unprecedented levels, notes Rockley. As bandwidth requirements increase, data centers are looking to deploy higher switching capacity. Rockley says that the architecture of its LightDriver facilitates the transition to in-package optics for 51T switches and drives a broad spectrum of connectivity products including 400G and 800G pluggables, which are required for the large-scale deployment of 12.8T and 25.6T switches, enabling data centers to adopt fiber-to-the-server and eliminate the need for costly, high-power electrical signaling.

"The LightDriver is the world's first 400G engine supporting 1310nm on a fully integrated, optimized waveguide platform," says chairman & CEO Andrew Rickman. "Its tight integration with electronics enabled by advanced 2.5D packaging is key to facilitating the high bandwidth and dense optical I/O required by increasing network traffic. The LightDriver technology in our chipsets is important for data centers wishing to improve performance while reducing power and costs," he adds.

"Combining Rockley's LightDriver Optical Engine and our fully integrated silicon photonics platform with Hengtong's world-leading manufacturing capability will deliver the lowest-power and most cost-effective transceiver in the market," Rickman continues. "It is a significant step towards furthering our mission to make photonics as pervasive as microelectronics."

**www.rockleyphotonics.com**

# Source Photonics launches transceivers for 5G ramp

Source Photonics Inc of West Hills, CA, USA has launched a comprehensive 5G portfolio (including 25G, 50G and 100G products transmitting between 300m and 40km) for front-haul, mid-haul and edge applications.

Bandwidth-hungry applications such as artificial intelligence (AI), virtual reality (VR) and augmented reality (AR), have increased front-haul requirements from 10Gb/s to 25Gb/s, notes the firm. The emergence of base-station pooling and eCPRI is driving mid-haul and back-haul bandwidth requirements beyond 50Gb/s while centralization and fiber constraints have increased the reliance on longer reach and WDM capabilities.

"Our broad portfolio of 25G/50G/100G optical transceivers supported by in-house high-volume manufacturing capability enable us to support the customers during their transition from 4G to 5G deployment," says Supriyo Dey, senior director of product line management. "We have started volume shipment to a number of customers."

The new 5G transceivers include:

- 25G SFP28 LR Lite supporting 25G CPRI/eCPRI and 25GE links up to 2km on duplex single-mode fiber;
- 25G SFP28 LR supporting 25G CPRI/eCPRI and 25GE links up to 10km on duplex single-mode fiber;
- 25G SFP28 20Km supporting 25G CPRI/eCPRI and 25GE links up to 20km on duplex single-mode fiber;
- 25G SFP28 BiDi supporting 25G CPRI/eCPRI and 25GE links up to 15km on simplex single-mode fiber;
- 25G SFP28 LAN-WDM 6 channels from 1287nm to 1309nm; supporting 25G CPRI/eCPRI and 25GE links up to 20km on duplex single-mode fiber;
- 50G QSFP28 LR supporting 50GE links up to 10km on duplex single-mode fiber;
- 50G QSFP28 ER supporting 50GE links up to 40km on duplex single-mode fiber; and
- 100G QSFP28 LR supporting 100GE links up to 10km on duplex single-mode fiber.

**www.sourcephotonics.com**

# Kaiam Europe's Scotland plant acquired by Chinese transceiver maker Broadex

After Kaiam Corp of Newark, CA, USA (which makes 100G optical transceivers for hyperscale data centers) on 22 December appointed KPMG as administrators for its subsidiaries Kaiam Europe Ltd and Kaiam UK Ltd then on 24 December made redundant 310 of the 338 workers at the manufacturing site in Livingston, Scotland (due to lack of orders and trading losses), Kaiam Europe's Planar Lightwave Circuits (PLC) division has been acquired by Broadex Technologies UK Ltd, a new subsidiary of Shanghai-based optical module maker Broadex Technologies Co Ltd (Planar Lightwave Circuits' biggest customer).

In May 2018, Kaiam signed a memorandum of understanding for Broadex to undertake volume production and to supply to the China market QSFP28 100G-CWDM4 transceivers based on Kaiam's LightScale2 platform. The deal allowed Broadex to make the transceivers in China and directly address Chinese customers that require local production. It was also intended to complement Kaiam's in-house manufacturing in Livingston, providing further capacity to address the high-volume data-center market. The MoU included details of mutual technology cooperation and manufacturing arrangements on timeline, cost roadmap, local sourcing and China market development.

Joint administrator Blair Nimmo (KPMG's global head of restructuring) said that the sale of the Kaiam Europe Livingston operation to Broadex preserves 20 jobs and knowledge within Scotland.

Kaiam acquired Gemfire, its strategic PLC supplier, in 2013, and ran an 8"-wafer silica-on-silicon line for fabricating integrated optical components in its large-scale manufacturing facility in Livingston, where it also operated 40Gb/s and 100Gb/s optical packaging lines.

"The new owners have expressed a keen desire to grow the PLC business, which could lead to new jobs being created," says Nimmo.

"This Livingston site has historically made significant contributions to the development of PLC technologies and we intend to make this place the center of technological innovations again by new investment and adaption to new market conditions," says Wei Zhu, CEO of Broadex. "We are committed to making this happen."

**www.kaiam.com**

# Source Photonics raises over $100m in funding to support growing data-center and 5G business

## Plans include new laser fab, upgraded production facilities and increased investment in R&D on next-generation technologies

To increase the scale of its operations in order to support its growing data-center and 5G business, Source Photonics Inc of West Hills, CA, USA (which provides optical connectivity products for data centers, metro and access networks) has closed more than $100m in equity funding from new financial and strategic investors that will be used for growth investments.

LightCounting reported that sales of optical components and modules to cloud companies grew by 63% in 2016 and 64% in 2017, and will average 20% annually through 2023. Higher growth rates in 2020–2022 will be driven by the first volume deployments of 400 Gigabit Ethernet (400GbE) as a result of the rise of 5G and the cloud, LightCounting adds.

Planned developments include the creation of a new laser fab, upgrades to existing production facilities and increased investment in the R&D of next-generation technologies.

"Exciting new applications such as the Internet of Things (IoT), virtual reality (VR) and cloud services are growing in popularity every day," notes CEO Doug Wright. "These applications all depend on the next standard of connectivity, and 5G depends on the backing of a world-class optical network… Our investors have shown this confidence in us and are confident that the investment will support our ongoing work to enable the next era of connectivity."

Upgrades to Source Photonics' fab in Taiwan have already been completed and production operations have begun for a new fab in Jintan, China, using the latest funding. The funding will also be used towards technology investments for advanced coating technologies to enable next-generation lasers and transceivers for the fast-growing 5G and data center markets.

Source Photonics' latest range of technology was exhibited at the Optical Networking and Communication Conference & Exhibition (OFC 2019) in San Diego, CA, USA (4–7 March). Products on display included its new 400G-LR8 and DR4 QSFP-DD solutions, which are the latest addition to its PAM4-based optical transceivers portfolio. Other products showcased included several QSFP28 solutions such as the 100G-DR/FR, 100G-SR4, 100G CWDM4, and 100G-LR4. The firm is also demonstrating some of its solutions for the 5G market, such as the 50G-ER QSFP28 and 25G LAN DWM SFP28.

**www.sourcephotonics.com**

# NeoPhotonics' revenue grows 11% in Q4 to $91.1m

## High Speed Products sales match record, driven by China despite tensions

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) has reported full-year revenue growth of 10.1%, from $292.9m in 2017 to $322.5m in 2018.

Fourth-quarter sales were $91.1m, up 11% on $81.7m in Q3/2018 and 19% on $76.9m a year ago, driven by strong demand from both Western customers and China.

Shipments to China comprised 59% of revenue (up from 56% in Q3). Of this, the firm's largest customer Huawei Technologies (including its affiliate HiSilicon Technologies) accounted for 44%. The next four collectively comprised 41%. The Americas fell from 27% to 20% of revenue, as certain customers shifted contract manufacturing locations.

"Within the Americas and rest of world, demand in shipments continued their sequential growth trend while within China we saw a larger increase as a result of continuing domestic deployments, especially in provincial network deployments from China Mobile as well as exports outside of China despite trade tensions," says chairman & CEO Tim Jenks. "Growth was consistent with normal seasonal demand patterns in China across our high-speed product lines."

High-Speed Products (for data rates of 100G-and-above) comprised 86% of total revenue (up from Q3's 84% and matching Q2's record). In particular, 400G-and-above products grew to over 10% of revenue. "We're increasingly ramping our 600G coherent solutions as well," notes Jenks.

"With continued strength in demand, combined with increasing volume growth across leading high-speed product lines, we again achieved solid gross margin expansion," says Jenks. Although non-GAAP full-year gross margin was down slightly from 22.5% in 2017 to 22.3% in 2018, quarterly gross margin has risen from 21.3% a year ago and 24% in Q3 to 28.6% in Q4. "From Q1 to Q4, our margins expanded steadily by approximately 14 percentage points [from 14.7%], significantly more than our normal annual improvement," Jenks notes. Specifically, product margin was 31.6%, down only slightly from 32% in Q3 as higher-than-expected volume and solid cost reductions partially offset the impact of the annual price reductions (which will have full impact in Q1/2019). The other cost of sales charges of 3 percentage points consisted of about 150 basis points of under-absorption charges in the firm's laser fabs and 150 basis points of other charges (mostly the impact of tariffs related to the US–China trade discussions).

Operating expenses (OpEx) were $22.3m, up slightly from $22.1m last quarter but cut from $24.1m a year ago (and down from 31.3% of revenue a year ago and 27.1% last quarter to 24.5%). This was slightly less than the expected $23m as some R&D spending was pushed out. Full-year OpEx has been cut from $103.2m (35.2% of revenue) in 2017 to $89.1m (27.6%) in 2018.

Net income was $2.4m ($0.05 per diluted share, better than the expected $0.00–0.04 on a lower tax provision). This improved on net losses of $2.1m ($0.05 per diluted share) last quarter and $11.7m ($0.27 per diluted share) a year ago. Full-year net loss has been halved from $40m ($0.92 per diluted share) in 2017 to $20.5m ($0.45 per diluted share) in 2018.

Cash generated from operations was $10.6m, down from $13.5m last quarter but an improvement from −$3.5m (of cash used in operations) a year ago. However, for full-year 2018, cash generated from operations was $19.6m, versus cash outflow of −$32.8m in 2017.

Free cash flow was $10m in Q4 (an improvement on −$12m in Q3). Cash & cash equivalents, short-term investments and restricted cash rose by $12m from $64.7m to $76.7m.

The above non-GAAP results exclude about $5.7m in charges, comprising a $2.2m payment to settle a lawsuit with Lestina International Ltd (pursuant to a purchase commitment for materials related to product assets sold by one of NeoPhotonics' foreign subsidiaries to APAT Optoelectronics Components Co Ltd in January 2017). They also exclude $3.5m in inventory and asset write-downs for discontinuing manufacturing and selling the end-of-life client transceiver modules after completing last-time production runs through May 2019 (also entailing accelerated depreciation of $3m, to be amortized over the final production across the first and second quarters of 2019).

Due to the strong customer demand, net inventory fell further during Q4/2018, from $57m to $52m (from 82 days of inventory on hand to just 69 days, although this should increase back toward the targeted 90 days in Q1/2019).

For first-quarter 2019, NeoPhotonics expects revenue to fall to $77–82m, impacted by the usual seasonal reductions related to Chinese New Year production shutdowns and the full impact of annual price declines. "Additionally, we are seeing some supply-related constraints for certain purchased sub-components potentially pushing out a few million dollars of revenue to Q2," says senior VP & chief financial officer Beth Eby.

Gross margin should fall to 23–27%. OpEx is expected to rise to $24–25m (including one-time payments on certain chips and components that the firm is designing, although this range of quarterly OpEx should be sustained for most of 2019). "We will increase R&D spending in 2019 as we invest in our next generation of coherent products," notes Eby. "Q1 includes early payment to support a number of new chips and components." EPS is expected to fall back to a net loss of $0.17–0.08.

**www.neophotonics.com**

# Finisar's quarterly revenue growth in WSS and VCSEL arrays for 3D applications offset by fall in sales of 10G-and-lower transceivers

## Favorable product mix and reduced manufacturing overheads drive increased margins

For its fiscal third-quarter 2019 (ended 27 January), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA has reported revenue of $327.6m, down 1.4% on $332.4m a year ago but up 0.7% on $325.4m last quarter, due to increased sales of wavelength-selective switches (WSS) and vertical-cavity surface-emitting laser (VCSEL) arrays for 3D applications, offset partially by a decline in sales of 10G-and-lower transceivers.

"Revenues again grew over the prior quarter and gross margins also improved over the prior quarter, primarily due to favorable product mix and continued focus on reducing manufacturing overhead," says CEO Michael Hurlston. On a non-GAAP basis, gross margin was 30.2%, up from 28.3% last quarter and 28.6% a year ago.

Operating expenses (OpEx) were level with last quarter (19.5% of revenue) but cut by $9m from a year ago (21.8% of revenue). This was despite facility start-up costs rising further, from just $0.6m a year ago and $11.4m last quarter to $15.1m, aided by R&D expenses being cut further, from $59.9m a year ago and $52.7m last quarter to $51.3m.

"The combination of the above resulted in significant improvement in operating margins and profitability," notes Hurlston.

Operating income rose further, from $22.7m (operating margin of 6.8% of revenue) a year ago and $28.6m (8.8% margin) last quarter to $35.2m (10.8% margin).

Likewise, net income has risen further, from $22.8m ($0.20 per diluted share) a year ago and $30.6m ($0.26 per diluted share) last quarter to $34.2m ($0.29 per diluted share).

During the quarter, the firm redeemed about $257.7m of convertible notes. Overall, cash, cash equivalents and short-term investments hence fell by $186.5m, from $1197.1m to $1010.6m.

Due to its proposed acquisition by engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA (announced on 9 November), Finisar has not provided forward guidance for fiscal fourth-quarter 2019.

## II-VI's acquisition of Finisar approved by both firms' shareholders

The acquisition of fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA by engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA (announced on 9 November) has been approved overwhelmingly at special meetings of the respective companies' shareholders: 97% of the shares of II-VI common stock voting at II-VI's special meeting voted to approve the proposal to issue II-VI shares pursuant to the merger agreement, and 99% of the shares of Finisar common stock voting at Finisar's special meeting voted to approve the proposal to adopt the merger agreement.

"Since the merger announcement, our shareholders have gained an appreciation of the long-term value creation that the unique breadth and depth of this combination will enable," says II-VI's president & CEO Dr Vincent D. Mattera Jr. "Meanwhile, the feedback from our major customers in the communications and consumer markets continues to be overwhelmingly positive, due to the high complementarity of our enabling technology, intellectual property, product portfolios and global footprint," he adds.

"While the two companies continue to operate independently, the integration teams are working together to ensure a seamless integration and transition," says Finisar's CEO Michael Hurlston. "We see the positive overlap between our cultures, the mutual appreciation for our companies' capabilities, the exceptional synergy potential, and the energizing outlook for our future."

The merger is expected to be completed in mid-2019. The filing is under review in China by the State Administration for Market Regulation (SAMR), in Mexico by the Federal Economic Competition Commission, and in Romania by the Romanian Competition Council.

II-VI and Finisar say that their combination will unite two firms with complementary capabilities and cultures to form a photonics and compound semiconductor company capable of serving the broad set of fast-growing markets of communications, consumer electronics, military, industrial processing lasers, automotive semiconductor equipment and life sciences. Together, they will employ more than 24,000 people in 70 locations worldwide.

# Micro-LED display market growing at 86.4% CAGR from $272m in 2018 to $21,129m in 2025

**Commercialization is still in the emerging phase, but growing demand for brighter, more energy-efficient displays will drive the market.**

The micro-LED display market was about $272m in 2018 and will rise at a compound annual growth rate (CAGR) of 86.4% from 2019 to $21,129m in 2025, forecasts Zion Market Research in its report 'Micro-LED Display Market, 2018–2025'.

As an emerging flat-panel display technology that provides what is reckoned to be unbeatable contrast and energy efficiency through microscopic LED arrays, micro-LED displays are based on gallium nitride (GaN) technology, providing 30 times more brightness as well as better efficiency than conventional organic light-emitting diode (OLED) displays, it is claimed. Other benefits include better contrast, compact display size, and a faster response time.

Global commercialization of micro-LED displays is still in the emerging phase, but growing demand for brighter and more energy-efficient displays is expected to drive the market over the forecast timeframe, notes the report. Demand for micro-LED displays that are compact in size with an excellent viewing angle is flourishing worldwide, it adds. The implementation of micro-LED displays is currently at its peak, as it provides a brighter picture with high pixel resolution and what is reckoned to be unbeatable energy efficiency. Display manufacturers are seen to be opting for micro-LED solutions to improve the overall consumer experience. Additionally, the high penetration rate of micro-LED displays is also due to their high pixel resolution and image quality. Furthermore, the continuous demand for reduction in display size will contribute notably to driving the micro-LED display market, the report adds. However, escalating demand for flexible and foldable display technology may constrain the micro-LED display market to some extent.

The micro-LED display market is segmented on the basis of panel size, application and vertical. Based on panel size, the micro-LED display market is segmented into small [<10.5"], medium [10.5"–65"] and large [>65]. By application, it is segmented into virtual reality (VR) headsets, augmented reality (AR) headsets, smartphones, smartwatches, tablets, TVs, laptops, head-up displays (HUDs) and digital signage. The micro-LED smartwatch segment is expected to see rapid market growth in the future, due to its growing commercialization. By vertical, the market includes automotive, consumer electronics, aerospace & defense and advertising. The consumer electronics segment is projected to hold a prominent market share in the years ahead, due to the flourishing demand for micro-LED display in smartwatches, smartphones, and tablets.

By region, North America held a prominent share of the micro-LED display market in 2018, due to the presence of leading micro-LED display manufacturers. The USA is projected to dominate this regional market as it is the corporate headquarter of numerous renowned market players such as Apple, Oculus VR, VerLASE Technologies, Lumiode, Uniqarta, etc, notes the report. Furthermore, the region is seeing many market-relevant business activities that are contributing significantly to overall market demand.

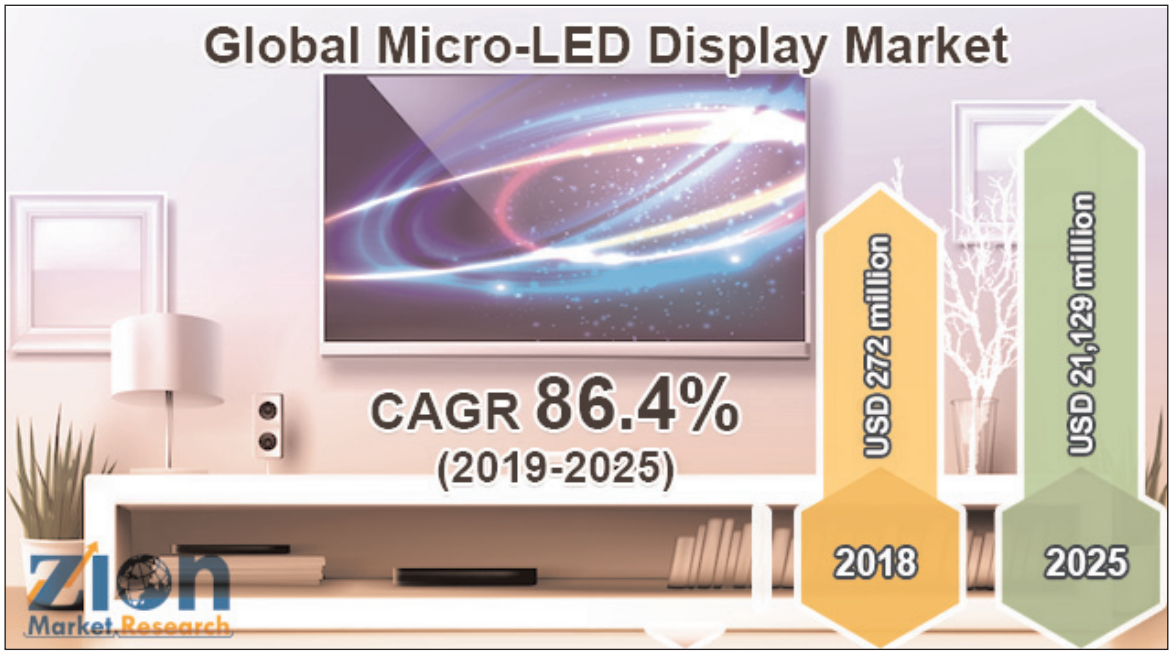
The rising automotive application of micro-LED displays is driving the market in European countries. Demand for micro-LEDs is trending in the automotive industry for various applications, such as rearview windows, in-car entertainment systems, dashboards and HUDs. Furthermore, the automotive sector plays a vital role in Europe's growth in gross domestic product (GDP), comprising nearly 4% of overall GDP in 2018. Many auto makers are involved in R&D activities to strengthen their overall competitiveness.

The Asia Pacific region is likely to see rapid market growth in the coming years due to the flourishing consumer electronics industry. In emerging economies such as India and China, conventional lighting is being replaced by LED lighting, which is contributing significantly toward the regional market. Moreover, awareness about the benefits offered by micro-LED displays has attracted many lighting manufacturers. Rising investment by LED lighting manufacturers for the technological enhancement of LED displays is expected to drive significant growth in the micro-LED display market in the future.

In Latin America, the rising number of technically advanced smartphones is playing a vital role in driving the micro-LED display market. This regional growth can be attributed to the compact size and high resolutions of micro-LED displays and the huge investments made

by numerous smartphone makers into integrating micro-LED displays. Also driving this regional market is growth in the total number of smartphone users in Latin America from 155.9 million in 2015 to an expected 245.6 million by 2019.

In the Middle East and Africa, the market demand for micro-LED displays is trending due to the growing use of smart wearable devices such as smartwatches. Nowadays, smartwatches are used for various purposes (i.e. from calling to GPS tracking). In 2018, the sales of smartwatches in the Middle East and Africa accounted for over 1.1 million.




The report cites key players in the micro-LED display market as Samsung Electronics, Sharp Electronics, LG Display, Sony, AU Optronics, VerLASE Technologies, Lumiode, Apple Inc, X-Celeprint, Rohinni, Oculus VR, Epistar, Lumens, Aledia, Cooledge Lighting, Nichia, JBD, Plessey Semiconductors, Ostendo Technologies, VueReal, ALLOS Semiconductors, Uniqarta, Mikro Mesa Technology, and PlayNitride. ■

**www.zionmarketresearch.com/report/micro-led-display-market**

# InP wafer market growing at 14% CAGR from $77m in 2018 to $172m in 2024

**Market dominated by fiber communications, with datacoms outgrowing telecoms.**

The indium phosphide (InP) wafer market is rising at a compound annual growth rate (CAGR) of 14% from $77m in 2018 to $172m in 2024, according to market research and strategy consulting firm Yole Développement in the report 'InP Wafer and Epiwafer Market - Photonic and RF Applications 2019'.

As an old but still gold-standard member of the compound semiconductor family, InP possesses the key advantage of being capable of light emission and detection at wavelengths above 1000nm. The InP wafer market is hence largely impacted by photonics applications and is dominated by the high-speed fiber-optic communication market for datacoms and telecoms, with each segment using InP as a substrate for both laser diodes and photodiodes in optical transceivers.

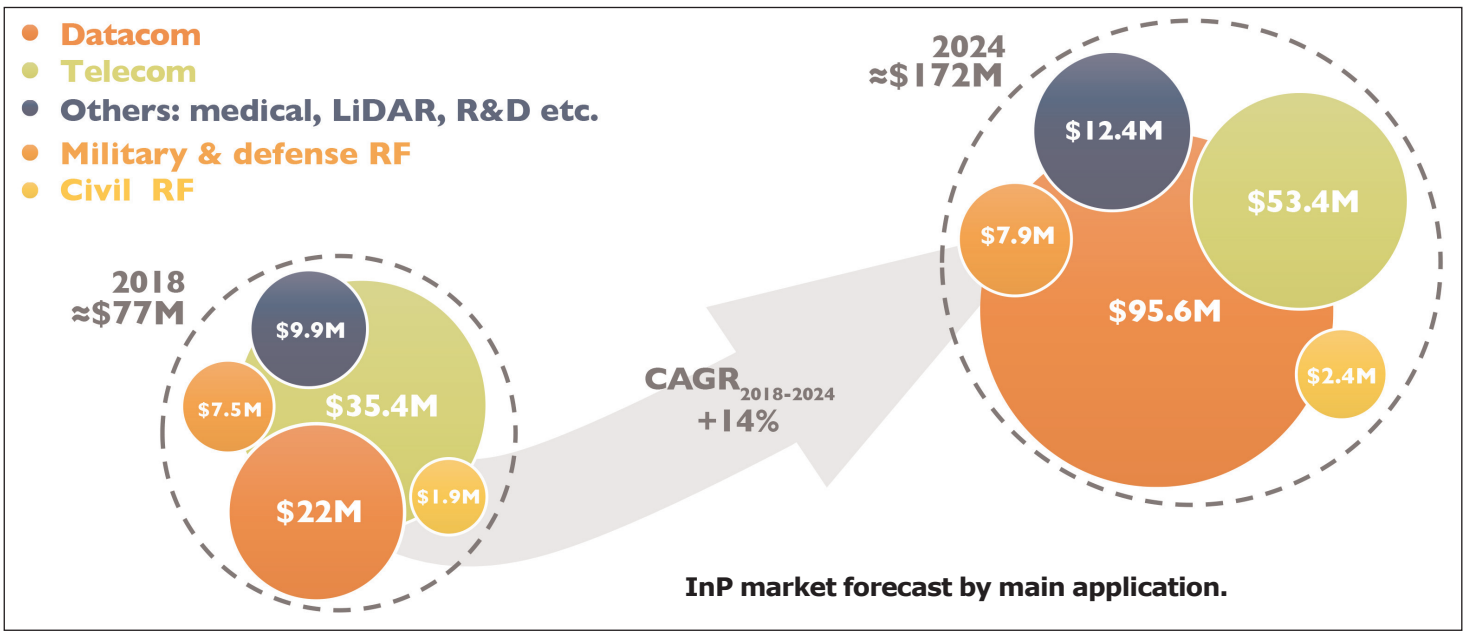
Most recently, driven by the arrival of 5G and the impressive growth in datacoms, the InP wafer and epiwafer market is showing strong growth.

In addition to the photonics domain, InP is also attractive for high-speed and low-noise performance in high-frequency RF applications. "Though it is often overshadowed by rivals like gallium arsenide (GaAs) and silicon germanium (SiGe) for mass-volume, cost-driven RF applications, InP remains a top choice for performance-driven niche markets like military communication, radar and radiometry as well as automatic test equipment," says Ezgi Dogmus PhD, technology & market analyst in Yole's Power & Wireless team. "Moreover, different industrial actors including Skyworks, GCS and IntelliEPI are monitoring InP technology for the upcoming 5G move," she adds.

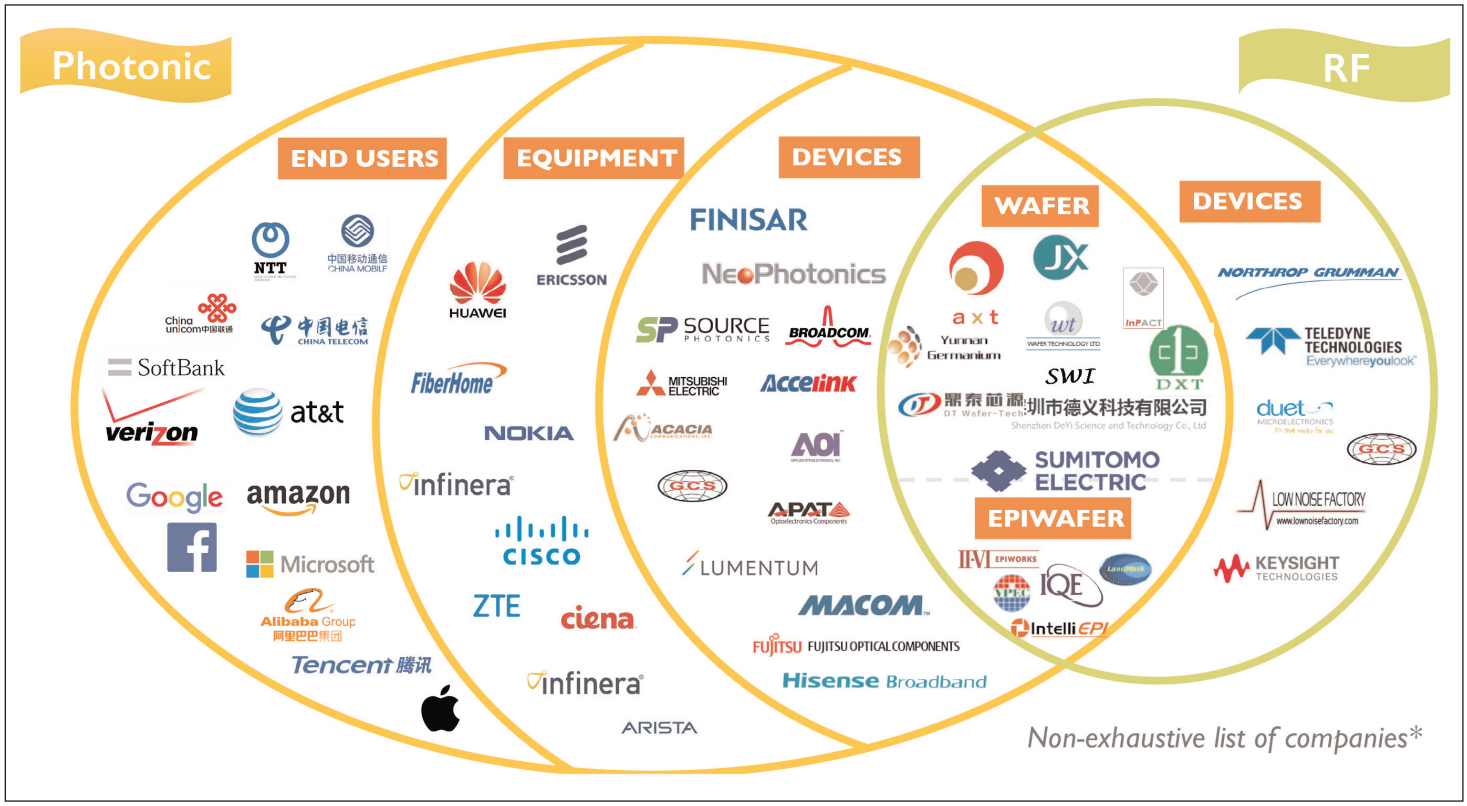
Currently, the real boost for the InP wafer market is expected in photonic applications. In optical communications, InP offers high performance in many functions including emission, photodetection, modulation and mixing, but it is often challenged by other semiconductor platforms because of its high cost. Nevertheless, InP is an indispensable building block for laser diodes in transceivers used for telecom and datacom applications.

With the requirement of more data transfer at higher speeds, transceiver technology is migrating to technology that offers higher rates (100GbE and 400GbE), for which InP is more favorable. The wafer market for datacoms applications is expected to explode, growing at a CAGR of 14% from $22m in 2018 to $95.6m in 2024.

Specific to the cyclical telecom market, which has recently slowed down, massive investment plans from




**InP market forecast by main application.**




**InP market supply chain overview.**

various operators (e.g. China Telecom) are expected with the advent of 5G networks. "In fact, the InP wafer market for telecom is projected to reach around $53.4m by 2024 [up from $35.4m in 2018]," says Hong Lin PhD, senior technology & market analyst. Also, significant investment in the datacom market is expected from different players, led by Internet giants Google, Amazon, Alibaba and more.

Yole expects growth in military & defense RF applications between 2018 and 2024 from $7.5m to $7.9m, and in civil RF applications from $1.9m to $2.4m.

Last but not least, other applications (e.g. LiDAR, R&D etc) are expected to grow from $9.9m in 2018 to $12.4m in 2024. Light detection & ranging (LiDAR) applications could be particularly promising for InP, i.e. enabling eye safety at higher wavelengths, which is currently in an early R&D phase.

## Many players at the device level, and high concentration at the epi & wafer levels

The InP industry has various business models and numerous players. It is worth noting that, from wafer to device manufacturing, the concentration of market players varies.

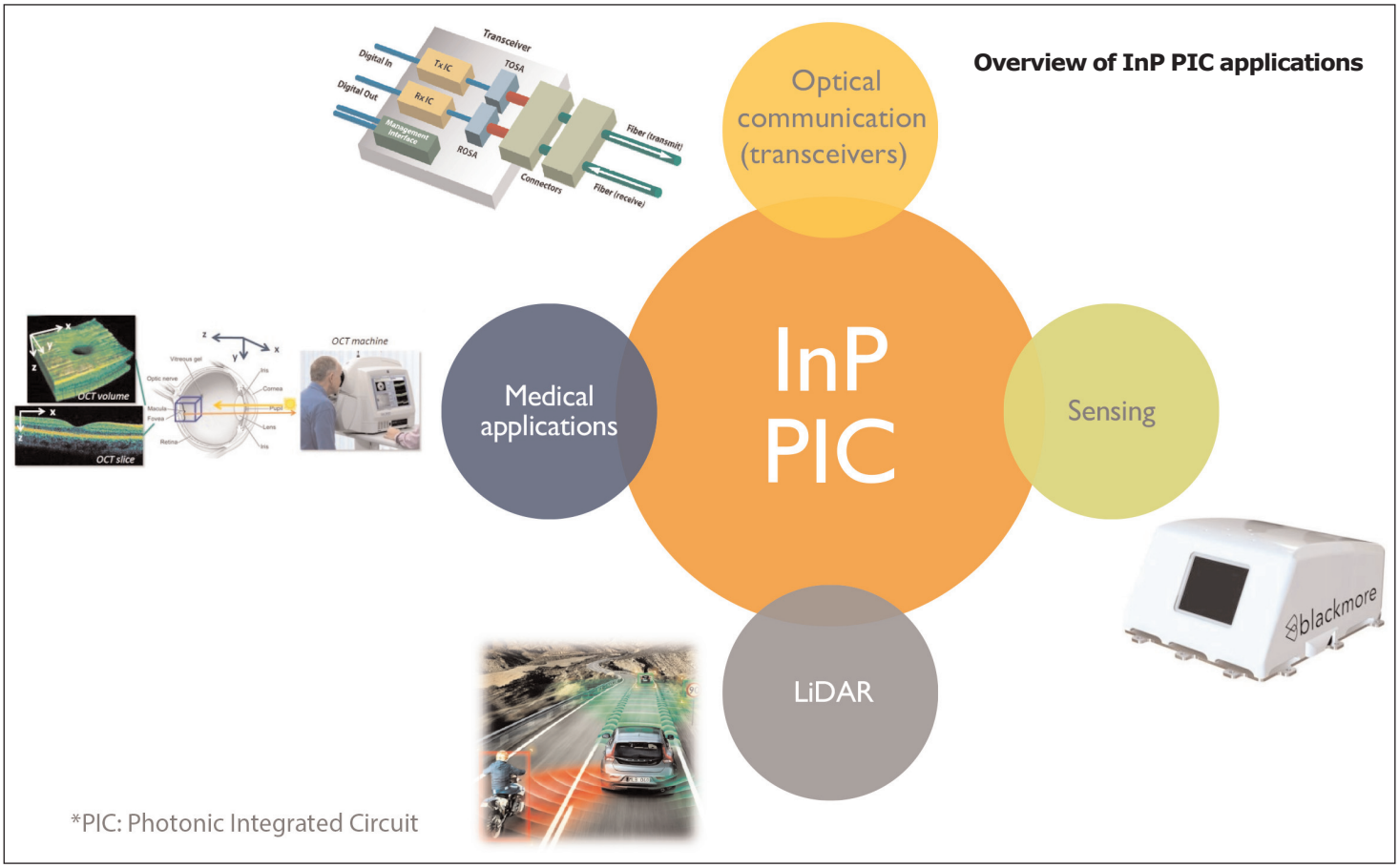
At the device level, Yole has identified more than 30 InP foundries and integrated fabs, most of which are currently focused on photonic chips. InP fabs are found globally, from the USA to Europe and Asia. Most players are integrated fabs manufacturing for their own products. These fabs have their own epiwafer production capacity or R&D capability, along with an outsourcing division for their epiwafers. There are also InP fabs that purchase epiwafers on the open market. Yole does not expect the outsourcing ratio to evolve quickly in the coming years.

In contrast to the device manufacturing arena, the epiwafer open market is highly concentrated. The leader is Landmark Optoelectronics, which is focused on photonic applications. Epiwafer foundry IQE also plays a key role, with products spanning photonics and RF applications.

The wafer-level segment mirrors the epiwafer market in terms of concentration. More than 80% of the market is held by two firms: Sumitomo Electric Industries (SEI) and AXT Inc. JX Nippon Group occupies third place in terms of wafer sales. Other players are either in pilot-line production and only delivering small wafer volumes or still in the R&D stages.

## Future for InP-based PICs if challenged by silicon photonics?

Since photonic integrated circuits (PICs) were first introduced in 1969, different platforms like InP, silicon photonics and polymer have been studied and developed. InP-based PICs have been widely studied, since they allow emission at wavelengths >1000nm, corresponding to several windows of optical fibers as well as being necessary for some other applications. In discussion with industry players about market data, Yole's analysts found that there are questions concerning the definition of monolithic InP PICs. In the extreme, electro-absorption modulated lasers (EMLs) are




already monolithic. In fact, it all depends on the level of integration. Although different building blocks (passive components, polarization components, phase modulator, laser, detector and others) have been demonstrated using InP, commercially available, fully integrated InP products are still limited.

In recent years, InP PICs have faced strong competition from silicon photonics, in which industrial players like Intel have invested heavily. Indeed, comparing silicon photonics and InP PICs, it is hard to dispute that — due to large, higher-quality silicon wafers — silicon photonics have a cost advantage for large-volume applications.

But, although InP has faced (and will continue to face) strong competition from other materials for photonic applications, its direct bandgap makes it unique for laser diode applications. Yole therefore believes that InP laser devices will prevail for a long time, at least for active optoelectronic devices. Moreover, InP PICs make sense for small-volume markets, reckons the firm, addressing diverse applications such as medical, high-end LiDAR and sensing, as well as optical communications. Players in these areas are likely to capitalize on the existing telecom/datacom supply chain for ramp-up, Yole concludes. ■

**www.yole.fr/InP_Wafer_Epiwafer_MarketStatus.aspx**

# High efficiency rates predicted for GaN devices by 2022

**Aafreen Shaikh of Market Research Future highlights growth in the GaN device sector, detailing opportunities in the market.**

Gallium nitride (GaN) has become synonymous with its use in the production of semiconductor power devices and their growing implementation in transistors. They have also been increasingly incorporated into RF components and light-emitting diodes (LEDs) over the past few decades. The demand for GaN semiconductor devices is expected to gather momentum, with revenue rising at a compound annual growth rate (CAGR) of 8% to $25bn in 2023, according to a report published by Market Research Future.
The incorporation of zinc and aluminum in the production of gallium nitride provides certain qualities such as the high-power-density abilities of GaN, together with the better thermal conductivity and low RF losses of silicon carbide (SiC). As gallium nitride is suitable for use in high-power devices that can operate at high temperature, global demand is seen to be on an upward growth curve.

## Application range for GaN devices

The price restriction for certain electronics applications has increased the reliance on GaN semiconductor devices. Although GaN is relatively new in semiconductor manufacturing, it is gaining popularity in applications that entail transmitting signals over long distances or at high power, such as satellite communications, radar and base transceiver stations [BTS], to name a few. The increasing use of GaN devices is also inspiring application in the renewable energy sector. Renewable energy sources are increasingly being harnessed due to the dearth of scalable solutions that can meet the growing energy needs globally.

The implementation of GaN power transistors in the renewable energy industry greatly helps in enabling the design of cheaper, less complex and more efficient energy storage systems that would not have been possible with the use of silicon as a material base. As GaN components are a feasible option to resolve some of the problems existing in renewable energy systems, demand for GaN devices is expected to rise. Moreover, the steady increase in the usage of vertical GaN structures is expected to broaden the applications of GaN devices and will also offer a robust basis for scaling production in the coming years.

## Production gains from GaN devices

The cost incurred in manufacturing GaN devices is inherently lower than the cost of manufacturing a silicon-based MOSFET device, since GaN devices can be made using standard silicon manufacturing techniques in the same fabrication plants that are presently producing traditional silicon-based devices, and the resulting devices have a better degree of functionality.

The transition in demand from silicon to GaN for semiconductor production is primarily due to new advanced all-GaN integrated circuits that are essential to the integration of passive devices. GaN's ability to conduct electrons more than 1000 times more efficiently than silicon, while being able to be mass produced at a lower cost than silicon, is a critical factor that is buoying the growth in GaN devices.

These qualities have increasingly contributed to their application in the military and space industries. The use of RF cell-phone base stations and military radars is expected to grow in the coming years due to the heightened possibility of conflict in different regions of the world. Even though GaN electronics is a quickly evolving area with active research globally, the market is growing at a relatively slow pace.

Conversely, the market for GaN semiconductor devices is expected to weather specific challenges on its growth path. The challenges identified with the use of GaN are that the material is difficult to fabricate and purify, and is a couple of years late in terms of its cost-effective production and the consequent reduction in the costs associated with its use in a range of devices. The popularity of GaN devices is lagging in terms of the quality that can be achieved from it. Nevertheless, the high breakdown field, which allows GaN devices to function at much higher voltages than other semiconductor devices, is a crucial factor that will lead to appealing innovations in the coming years, concludes the report. ■

**www.marketresearchfuture.com/reports/gan-semiconductor-devices-market-1174**

# IGaN's 200mm GaN-on-Si epi to optimize cost in power switching

**Commercialization in mid-2019 to advance next-generation high-speed, high-power devices.**

As gallium nitride (GaN) is a wide-bandgap semiconductor material that is suitable for the next generation of high-speed and high-efficiency power devices, Singapore-based IGSS GaN Pte Ltd (IGaN) has developed high-quality gallium nitride on 200mm silicon substrates for power electronics applications. In collaboration with its tool vendor, IGaN has developed the epitaxial wafers for a 200mm CMOS-friendly GaN fab process that they will make available by mid-2019.

"We believe that 200mm is the way to go to achieve mainstream adoption of GaN in new power electronics," says president George Wong. "With 200mm you potentially save two times of the cost of 150mm solutions, which is the prevalent platform today. It has first been demonstrated by Institute of Materials Research and Engineering (IMRE) Singapore in 2011, where we licensed the technology from," he adds.

"Today, we have achieved even better uniformity and demonstrated higher breakdown voltages. IGaN will be mass-production-ready with our fab partner in second-quarter 2019," says Wong. "We are looking for customers now to take first-mover advantage of our one-stop semiconductor hub solution for 200mm GaN epiwafer and GaN fab process."

The main challenge in manufacturing 200mm GaN-on-Si epiwafers is achieving high uniformity, good crystalline quality of GaN, low wafer warp and bow, low surface roughness, crack-free, and high breakdown voltage. This is mainly due to the thermal mismatch and lattice mismatch between the silicon and GaN. To overcome this, the epitaxial layer must have a buffer layer to mitigate the stress formed during GaN growth. IGaN has been able to optimize the buffer layer to achieve high breakdown voltages of greater than 650V without compromising the crystalline quality of the GaN. Figure 1 shows the typical IGaN GaN-on-Si epiwafer structure for power applications.

## Material quality

IGaN used a state-of-the art metal-organic chemical vapor deposition (MOCVD) tool with in-situ thickness measurement capability to grow the GaN on Si<111> substrates. The process used a thick film epitaxial growth technology to meet the >650V breakdown voltage requirements. The key was to optimize the gas flow rates, temperature and pressure at various stages to control the GaN crystal growth. IGaN demonstrated epiwafers that are crack-free, have low warpage of ≤±50μm (see Figure 2) and have low surface roughness of ≤0.3nm (see Figure 3). These characteristics meet the mass-production requirements of an 8-inch fab process for power devices.

## Low defect density

IGaN has optimized the process to achieve low dislocation density and high crystalline quality while achieving high breakdown voltage. To analyse the crystalline quality, high-resolution x-ray diffraction (HRXRD) measurements were performed. The XRD omega rocking curves measurement of GaN(002) and GaN(102) reflection are below 400 and 850 arc sec, respectively (see Figure 4).

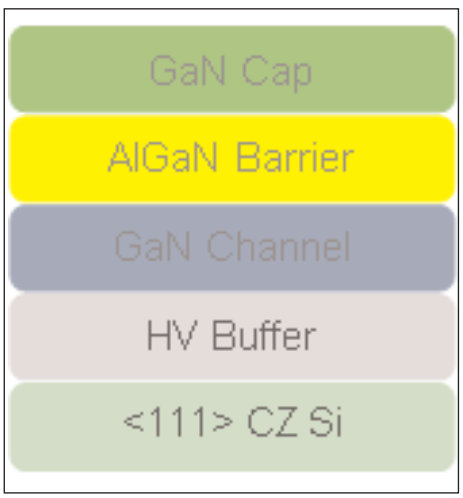



**Figure1: Epi structure of IGaN's GaN-on-Si epi for power applications.**

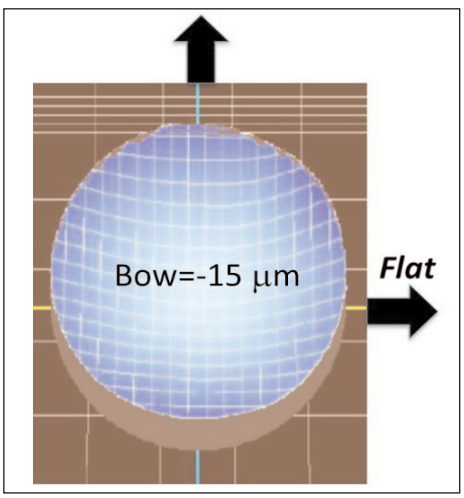



**Figure 2: Low wafer bow (<50μm) for 200mm GaN-on-Si epiwafer.**

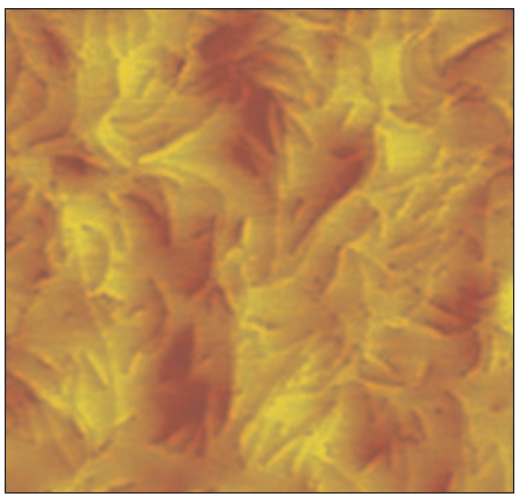


**Figure 3: Typical surface roughness of 200mm GaN-on Si epi 0.25nm.**

## Material uniformity

IGaN's epiwafers exhibit excellent material uniformity. The thickness and the aluminium composition distribution uniformity are typically better than 1% (see Figures 5 and 6), translating characteristics to high-yielding epiwafers during GaN device fabrication.

## High breakdown voltage

IGaN's GaN-on-Si epiwafers can withstand high breakdown voltage. Typical measurements exhibit a lateral breakdown voltage of greater than 800V at 1μA/mm with 15μm space (see Figure 7) and a vertical breakdown voltage of greater than 650V at 1μA/mm$^2$ (see Figure 8).

## Forward conduction characteristics

IGaN's epiwafers have good forward conduction characteristics. The two-dimensional electron gas (2DEG) concentration is more than 8x10$^{12}$cm$^{-2}$ and the 2DEG mobility is better than 1500cm$^2$/V·s. The resistance is less than 500Ω/sq.

## Conclusion

IGaN's 200mm GaN-on-Si epiwafers have achieved excellent performance and uniformity for GaN power devices fabrication. The firm aims to continue to innovate and contribute to driving the adoption of GaN by providing high-quality GaN-on-Si epiwafers and GaN fab processing.

IGaN also supplies GaN-on-silicon epiwafers in both 100mm and 150mm diameters. ■

www.igssgan.com

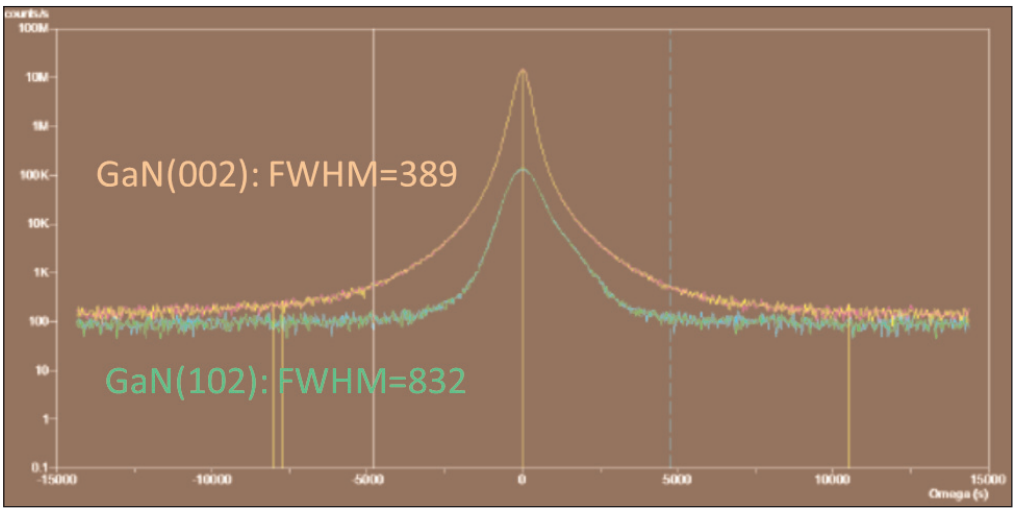



**Figure 4: XRD omega rocking curves of GaN (002) and GaN(102) reflection for IGaN's 200mm GaN-on-Si epiwafer giving a measure of tilt and twist in such a large area.**

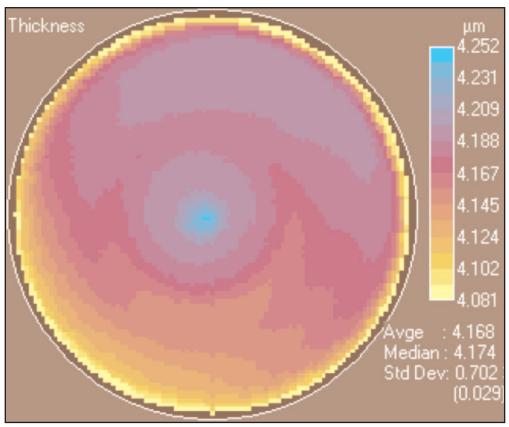



**Figure 5: Typical epitaxial thickness uniformity of IGaN's 200mm GaN-on-Si epiwafer.**

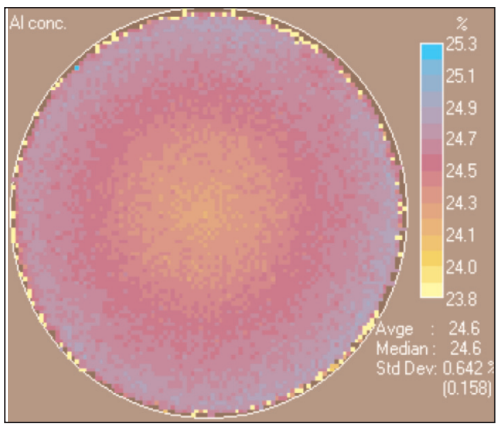



**Figure 6: Al composition distribution of AlGaN barrier layer of IGaN's 200mm GaN epiwafer.**

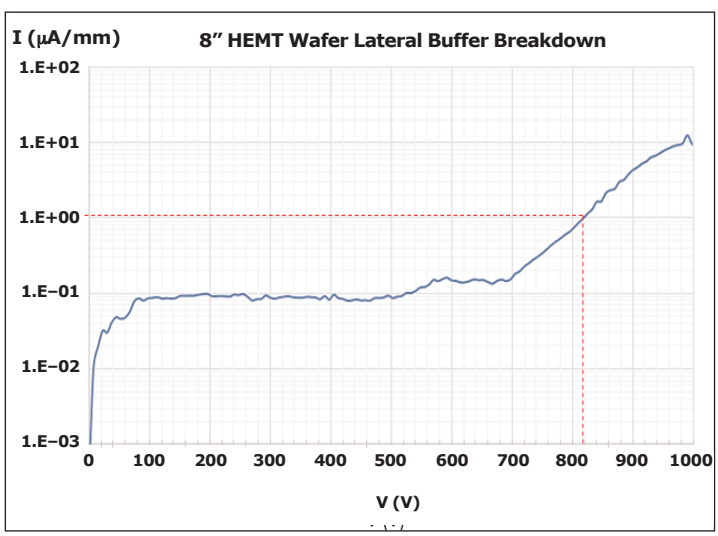



**Figure 7: Lateral breakdown voltage characteristics of IGaN's 200mm GaN-on-Si epiwafers with 15μm space.**

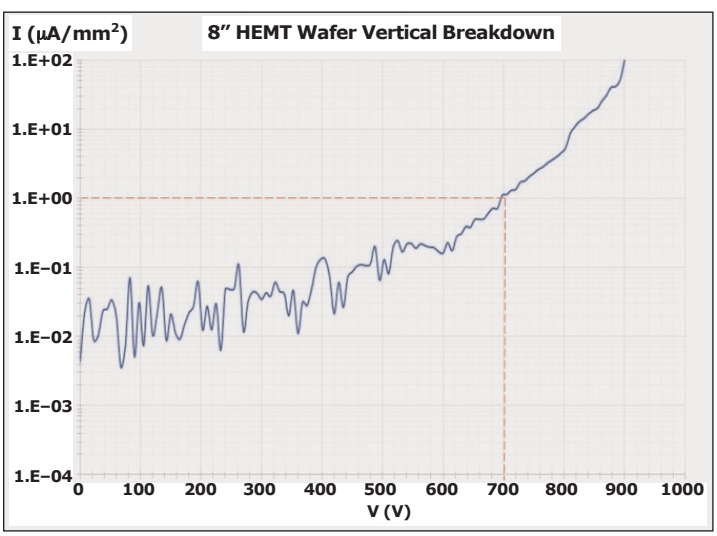



**Figure 8: Vertical breakdown voltage characteristics of IGaN's 200mm GaN-on-Si epiwafers.**

# Vertical integration of gallium nitride nanowire transistor and light-emitter

**Smaller pixels could lead to compact, efficient virtual-reality and augmented-reality systems.**

Matthew Hartensveld and Jing Zhang of Rochester Institute of Technology in the USA claim the first vertical integration of nanowire gallium nitride (GaN) field-effect transistors (FETs) and indium gallium nitride (InGaN) light-emitting diodes (LEDs) [IEEE Electron Device Letters, published online 29 January 2019]. The integration enables voltage control of the light output from the device. Vertical integration allows for compact structures with easier fabrication than alternatives such as high-electron-mobility transistor (HEMT) combinations with LEDs.

Hartensveld and Zhang see potential for displays that need smaller pixels and higher efficiency than can be easily constructed using present-day thin-film transistor and liquid-crystal combinations. Conventional LEDs also have scaling and other difficulties.

Compact, efficient light emission is desired in virtual-reality and augmented-reality systems, and micro-LED and nano-LED structures would seem a perfect fit. The problem is in the driving and control of such devices, preferably in an integrated monolithic format.

Hartensveld and Zhang's devices (Figure 1) consisted of 45 vertical nanowires each, on average. Heterostructured epitaxial material (Figure 2) was dry etched to create the wires — the so-called 'top-down' approach. The mask material for the chlorine reactive ion etch consisted of 3μm-diameter silica nanospheres spin-coated in deionized water onto the epitaxial wafer. Buffered oxide etch reduced the nanosphere diameters to 1.6μm. Dry etch damage was removed with a potassium hydroxide wet etch. The final nanowires were 5.5μm high and 1μm diameter.

Device contact fabrication built up layers of dielectric and metal. Transparent polydimethylsiloxane (PDMS) was spin coated, planarized and etched back to provide the dielectric spacing material for the various levels.

The titanium/aluminium (Ti/Al) source and drain contacts were applied in the same evaporation step to the bases and tops of the nanowires. Annealing (600ºC 10m, 900ºC 20s) was performed to form TiN, leaving behind nitrogen vacancies in the adjoining GaN. Such vacancies act as donors, releasing electrons for n-type conduction

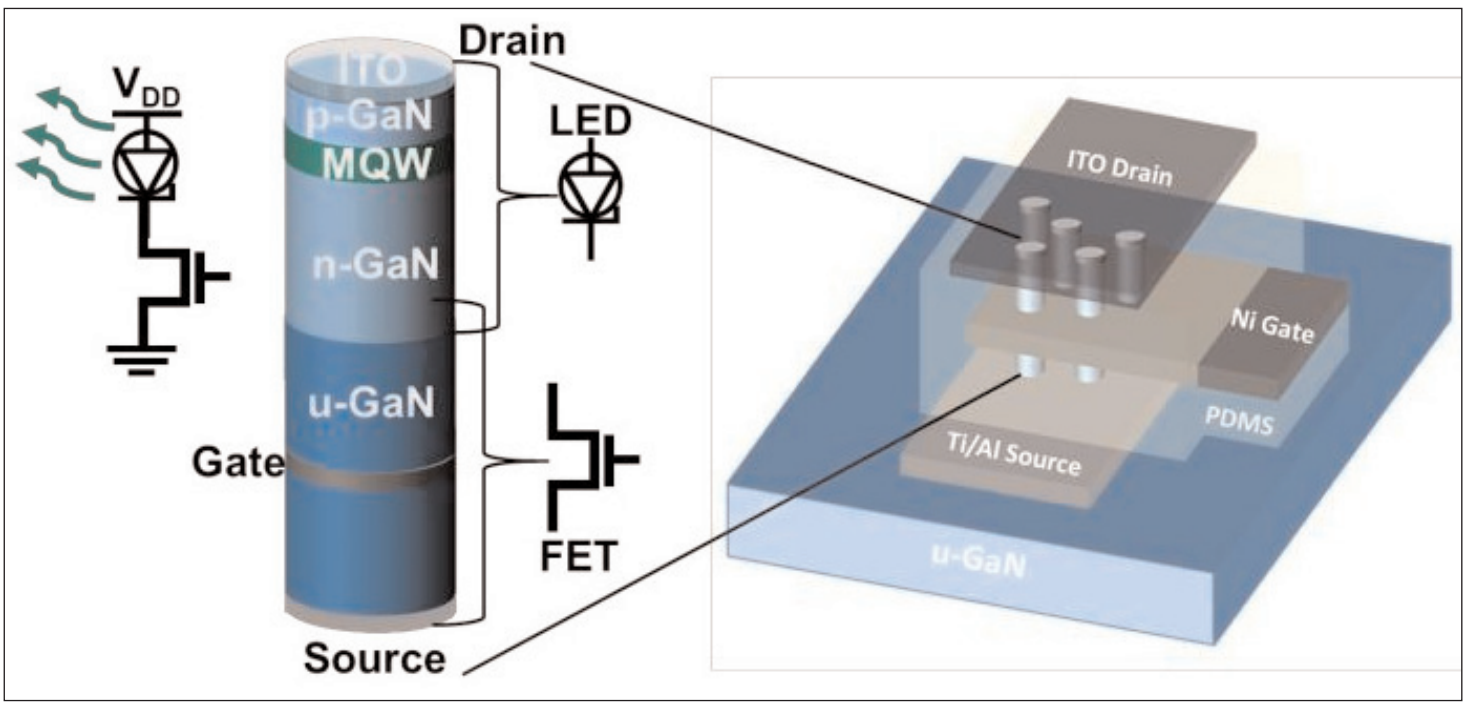



**Figure 1. Schematic of vertical GaN nanowire LEDs with nanowire FETs. Inset: single wire and series connection.**

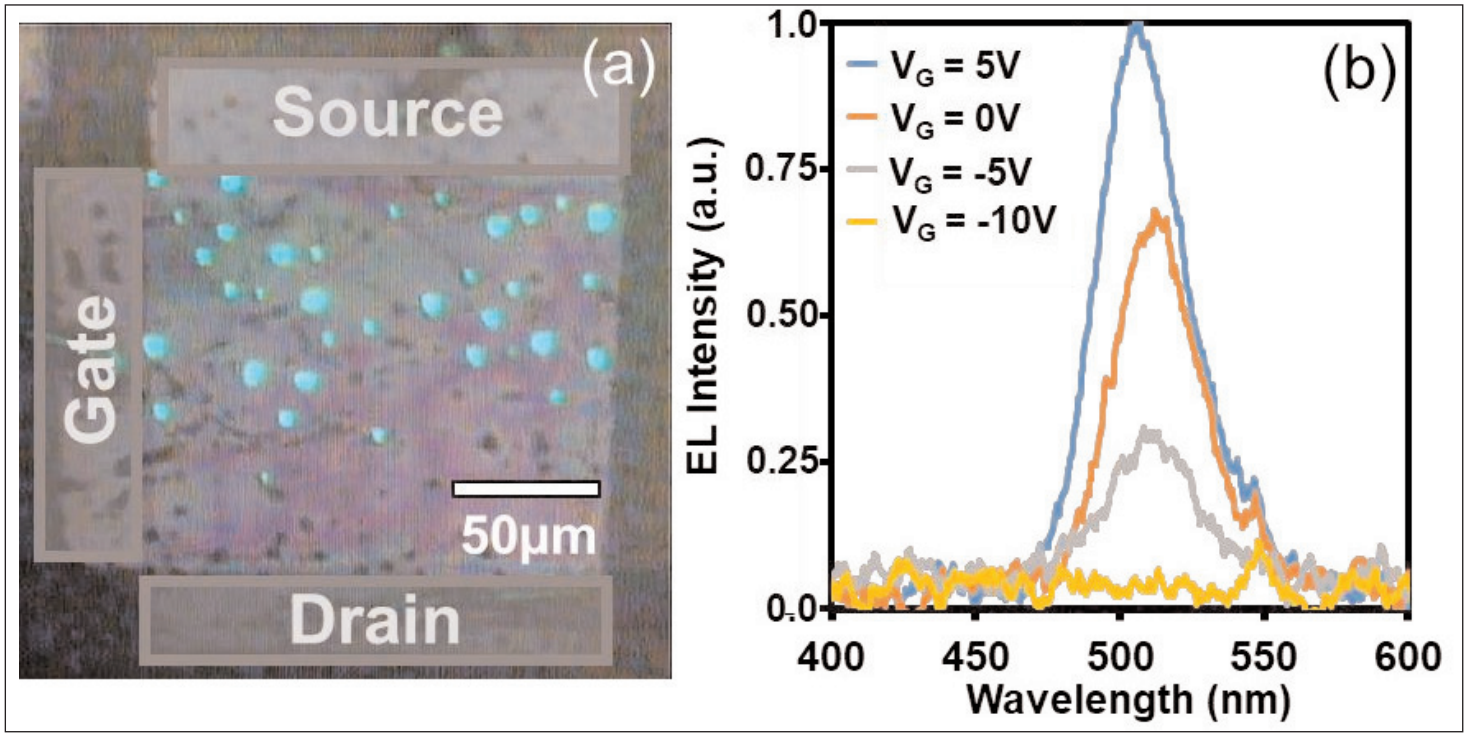



**Figure 2. (a) Nanowire LEDs with FETs lighting up, and (b) electroluminescence spectra with gate modulation.**

and giving an n-intrinsic-n (n-i-n) FET structure.

The all-around gate was formed from 40nm nickel evaporated about half-way up the undoped/intrinsic u-GaN region. The researchers see the use of this previously unused layer to give a 'static induction transistor' as a novel feature of their work.

The final fabrication steps include more spin-coated PDMS, etching and then evaporation of transparent indium tin oxide (ITO) conductor joining together the drain contacts of the individual nanowires, and etching to reveal buried device gate and source contacts.

The 1μm diameter of the nanowires was insufficient to fully deplete or pinch off the material under the Schottky gate at zero bias — therefore the transistor was not normally-off — a property desired for lower power consumption. It is hoped that narrower wires will lead to normally-off operation.

The switch-off of the 'depletion-mode' transistor came at −2.2V gate potential with the drain at 5V. The on/off current ratio was $2.9 \times 10^4$, a 2.4x improvement over a 2014 GaN HEMT-LED report from Hong Kong University of Science and Technology (HKUST). There was some stepping in the current output of the Rochester device with increasing gate voltage, indicating the presence of unwanted trap states.

Due to the random distribution of the wires, the light intensity varied (Figure 2). It was found that clusters of wires shone more brightly than sparsely distributed ones. "Spin coating a close packed array or use of photolithography would allow high densities of ordered wires," the researchers comment. The brightness was controlled by the gate potential — with 24V drain bias, the device was off with −10V on the gate, but as the potential increased the light emission increased. ■

https://doi.org/10.1109/LED.2019.2895846

*Author: Mike Cooke*

# First demonstration of fully vertical gallium nitride transistors on silicon

**Devices achieved 2.8x-better current density and 3x-lower on-resistance, compared with previous quasi-vertical structures on silicon.**

Switzerland's École Polytechnique Fédérale de Lausanne (EPFL) has claimed the first demonstration of fully vertical gallium nitride (GaN) metal-oxide-semiconductor field-effect transistors (MOSFETs) on silicon (Si) [Riyaz Abdul Khadar et al, IEEE Electron Device Letters, vol40, issue 3 (March 2019), p443–446].

Vertical devices are desired to take advantage of the large critical electric field, high electron mobility and saturation velocity, and high-temperature capability of GaN. Compared with lateral devices, vertical structures are more compact and the peak electric field tends to occur inside the bulk of the semiconductor rather than at surfaces.

Unfortunately, the vertical format has generally used prohibitively expensive bulk or free-standing GaN substrates to avoid leakage paths through threading dislocations. Use of silicon significantly reduces material costs, while the larger-diameter substrates should also lead to processing savings in mass production.

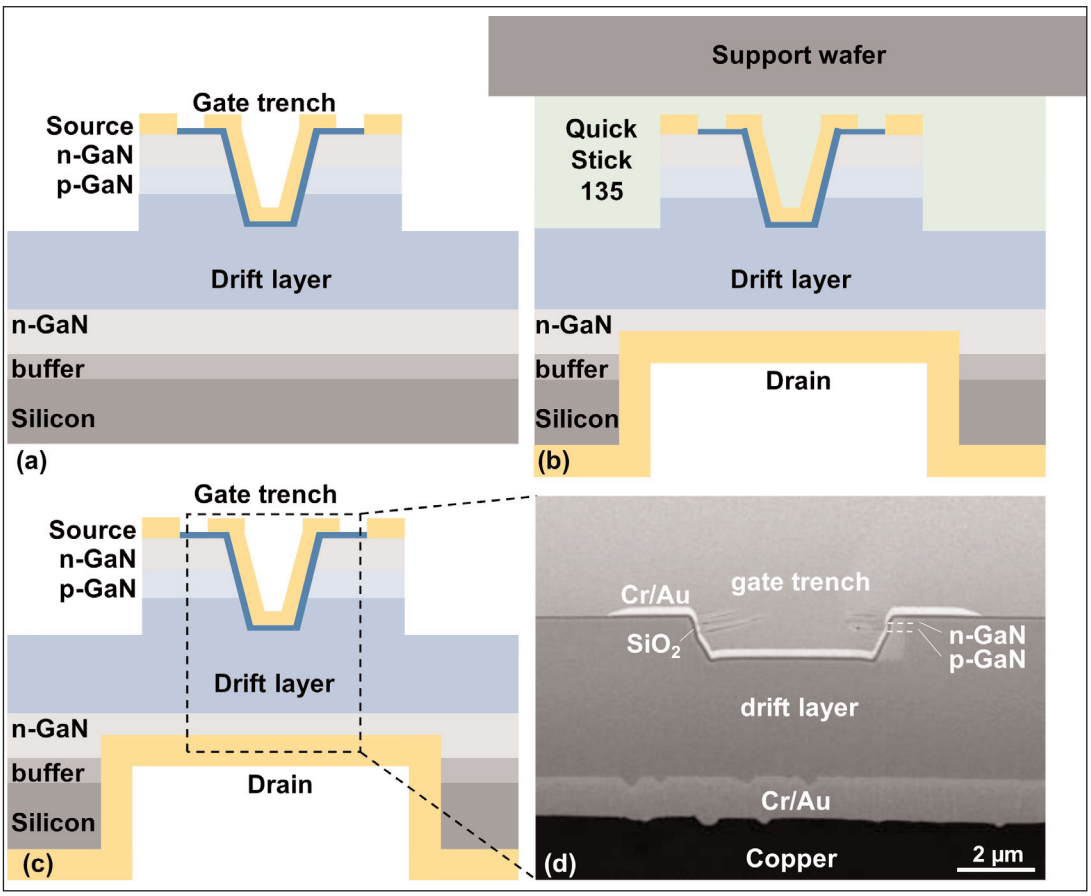



**Figure 1. (a) Schematic of device structure after definition of source and gate pads. (b) Drain contact defined at back-side via support wafer attached using QuickStick 135 wax. (c) Schematic of completed device after removing support wafer. (d) Cross-sectional scanning electron microscope image of fabricated fully vertical GaN-on-Si MOSFET.**

Some quasi-vertical devices have been produced on silicon with contacts arranged on the front-side of the wafer, similar to the way GaN LEDs on sapphire or silicon are powered. This leads to current crowding effects, increasing on-resistance.

GaN layers for the EPFL device (Figure 1) were grown by metal-organic chemical vapor deposition (MOCVD) on 6-inch (111) silicon: 1.07µm buffer, 1µm n-GaN, 4µm i-GaN intrinsic drift layer, 350nm p-GaN, 180nm n-GaN, and 20nm $n^+$-GaN. Enkris Semiconductor collaborated with EPFL in the wafer growth processing.

The resulting n–p–i–n structure was fabricated with 1.27µm gate trench dry etch and tetra-metal ammonium hydroxide wet treatment to remove etch damage. Rapid thermal annealing activated the p-GaN doping. Mesa etching to a depth of 1.35µm electrically isolated the devices. The gate oxide consisted of 100nm of atomic layer deposition (ALD) silicon dioxide. Dry etch of the silicon dioxide opened windows for

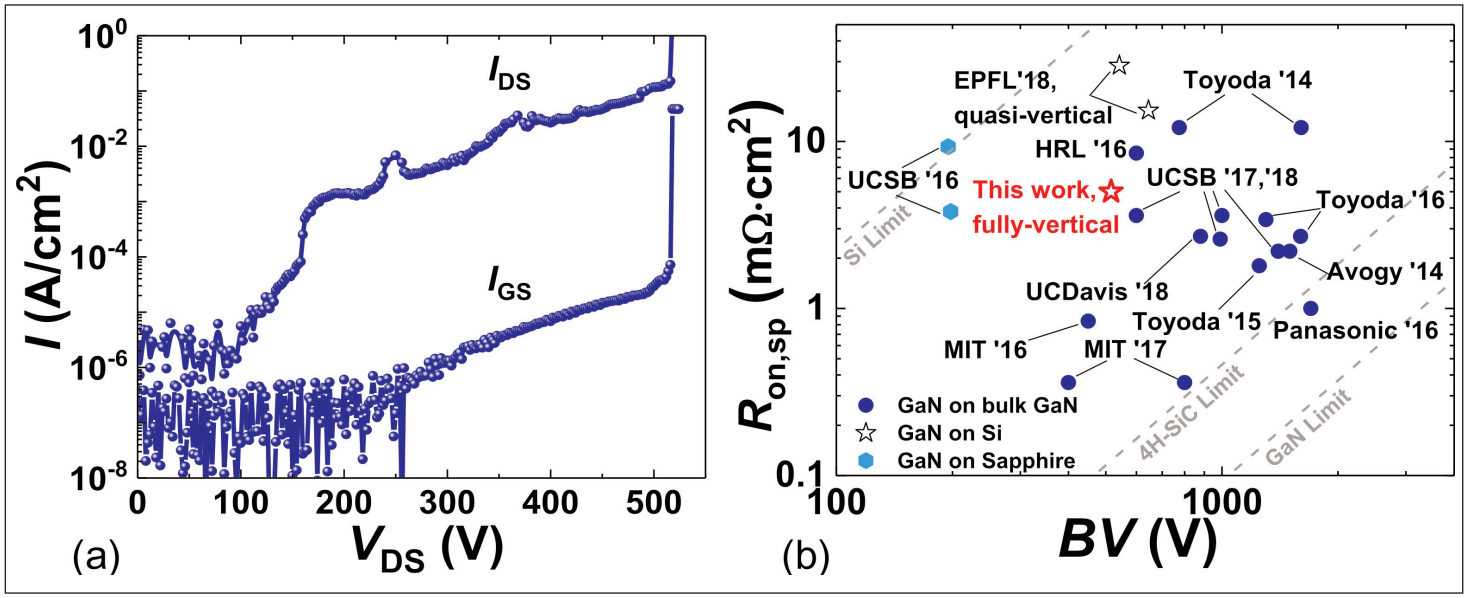



**Figure 2. (a) Off-state blocking performance of metal mask vertical MOSFET measured at 0V gate potential. (b) $R_{on,sp}$ versus BV benchmarking against other reported GaN vertical transistors on bulk GaN and Si substrates.**

chromium/gold source and gate contacts.

Back-side processing began with grinding the 1000μm-thick substrate down to 500μm. The wafer was then mounted on a silicon wafer with wax. Deep reactive ion etch (Bosch process) removed the silicon under the device, followed by dry etch of the resistive GaN buffer layer. An ohmic chromium/gold deposition made contact with the n-GaN drain. Electroplated copper in a 35μm-thick layer provided mechanically stable support for the GaN membrane. Acetone was used to release the device wafer from the mounting wax.

The researchers found the orientation and material of the etch mask for the gate-trench etch affected performance. Alignment along the m-plane, rather than a-plane, of the GaN crystal structure increased the current by up to 3x. "Such a significant enhancement is due to the much smoother m-plane sidewall after TMAH treatment compared to the a-plane," the team comments. Using a nickel mask, rather than silicon dioxide, gave a further 1.6x boost to the drain current.

The nickel mask also increased effective channel mobility to 41cm$^2$/V-s, compared with 21cm$^2$/V-s for the oxide. The researchers comment that the 41cm$^2$/V-s figure was "To the best of our knowledge,... the highest mobility reported on GaN trench gate MOSFETs grown on foreign substrates."

One difference between the gate-trench etch results was the sidewall angle — 67° for the oxide mask, compared with 84° near-vertical for nickel. The team points out the 67° angle for the oxide mask puts the surface close to the non-charge-neutral $\{10\bar{1}1\}$ GaN crystal plane.

The nickel-mask device achieved a drain current density of 1.6kA/cm$^2$ and specific on-resistance ($R_{on,sp}$) of 5mΩ-cm$^2$, both normalized to the active gate-trench area of the MOSFET (10μmx36μm), and accounting for a lateral 2μm current spreading from all sides of the trench. Compared with the EPFL's previous work with quasi-vertical MOSFETs on a similar GaN epitaxial structure on Si substrate, the researchers report: "These devices exhibited 2.8x-better current density and 3x-lower $R_{on,sp}$."

The p-GaN inversion channel is thought to be the major factor limiting performance, since other sources adding to the on-resistance are small.

The threshold voltage at 10V drain bias was 7.9V from linear extrapolation, and 6.4V according to the defined drain current density of 20A/cm$^2$. The threshold is described as "relatively low", "mainly due to donor-type N-vacancies present in the trench sidewall as a result of defects from the dry-etching process." The MOSFET also suffered from a negative hysteresis of ~2V at 0.2kA/cm$^2$ current density, "likely due to bulk oxide traps". The team suggests that improving the oxide gate insulation and post-deposition annealing could reduce the hysteresis. The peak transconductance was 300S/cm$^2$.

The off-state breakdown voltage (BV) was 520V (Figure 2). This is considered "excellent" by the researchers, who point out that the device did not use field reduction techniques such as field plates or edge termination structures. Breakdown was traced to the gate edge. The leakage current in the off state was less than $10^{-1}$A/cm$^2$, normalized to the 110μmx197μm mesa area.

The researchers comment: "Compared to other GaN-on-Si transistors, our device presented a much lower $R_{on,sp}$ of 5mΩ-cm$^2$ and BV similar to previous reports on GaN-on-Si MOSFETs with a similar epitaxial structure and without field plates." ■

**https://doi.org/10.1109/LED.2019.2894177**

*Author: Mike Cooke*

# Fin structures for aluminium gallium nitride high-power electronics

**Mike Cooke reports on recent research on multi-channel and vertical-current-flow devices.**

Tri-gate transistors using fin nanostructures in silicon were rolled out in mass production in 2011 by Intel and other companies after many years of development. Such structures were needed to improve electrostatic control of current flow by wrapping gates around transistor conduction channels.

In recent years, researchers have applied similar fin structures to overcome problems in high-mobility III–V compound semiconductors. One application has been for high-speed transistors using materials like indium gallium arsenide or antimonide, as potential replacements for silicon-based channels.

Another direction (the topic here) has been the potential for improving the performance of high-power and high-current-flow devices, for switching applications, using gallium nitride (GaN) and aluminium gallium nitride (AlGaN) materials. These semiconductors have a wide bandgap and relatively high mobility. Such features allow for higher electric fields and hence voltages to be supported, while maintaining low on-resistance.

A problem that could be helped by wrap-around gates is converting the normally-on 'depletion-mode' performance to the more useful normally-off 'enhancement-mode'. In depletion mode, the transistor conducts when the gate is at zero potential. By contrast, enhancement-mode transistors resist current flow under a 0V gate. Normally-off behavior reduces system power consumption and also shuts off current flow when the surrounding system fails, making for safer operation in high-voltage situations.

## High-mobility multi-channels on silicon

Researchers based in Switzerland and China have fabricated tri-gate metal-oxide-semiconductor high-electron-mobility transistors (HEMTs) with five III-nitride semiconductor channel levels, boosting electrostatic control and drive current [Jun Ma et al, Appl. Phys. Lett., vol113, p242102, 2018]. Fin structures were used here to enable electrical access to the deeper channels. The same team also report a Schottky barrier diode (SBD) based on similar structures [Jun Ma et al, IEEE Electron Device Letters, vol40, p275, 2019].

The team from École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland and Enkris Semiconductor Inc in China sees many possible applications for lateral devices with low on-resistance and high voltage blocking enabled by tri-gate structures.

It is expected that thinner fins will allow more effective depletion under gate structures — as suggested by recent theoretical and experimental studies with Schottky gates by National Taiwan University (NTU) [Li-Cheng Chang et al, J. Appl. Phys., vol125, p094502, 2019]. Full depletion across a fin should turn a transistor off when the gate potential is zero.

The EPFL/Enkris researchers used a material structure consisting of five parallel layers of a 10nm AlGaN barrier, a 1nm AlN spacer, and a 10nm GaN channel (Figure 1). The barrier was silicon doped at a partial level of $5x10^{18}cm^3$ to enhance conductivity.

Hall measurements on the five parallel thin two-dimensional electron gas (2DEG) channels gave the sheet resistance as 230Ω/square with $1.5x10^{13}/cm^2$ carrier density and $1820cm^2$/V-s mobility ($\mu$). The effective resistivity ($\rho_{eff}$) was 2.4mΩ-cm but with small total thickness ($t_{tot}$). The team comments: "Small $\rho_{eff}$ and high $\mu$ are crucial to reduce $R_{ON}$, and a thin $t_{tot}$ facilitates electrostatic gate control and device fabrication (the etching of high-aspect-ratio fins and the formation of electrodes around them can be challenging)."

The tri-gate structure was achieved with patterned inductively coupled etching to a depth of 200nm. The ohmic source/drain contacts consisted of annealed titanium/aluminium/titanium/nickel/gold. The gate stack was 25nm atomic layer deposition (ALD) silicon dioxide insulator and nickel/gold electrode.

One device had a gate length of 51μm: 50μm fin length and two 0.5μm extensions towards source and drain. Control of the channel current was affected by the fin width. In particular, with wide fins, control of the deeper channels was sluggish. This was shown by the transconductance exhibiting five peaks, one for each channel, when the width was greater than 200nm. (Consistent with the NTU study on Schottky gates that found an "early pinch-off effect" for

narrower fins.) The peaks merged at 40nm width. The 40nm device demonstrated a small negative threshold of –0.08V, improved subthreshold swing of 101mV/decade, and 29.5mS/mm peak transconductance.

Of course, reducing fin widths tends to reduce drain current in the on-state. The multiple channels compensate for this somewhat. The maximum current decreased steadily as the fin width was reduced in single-channel devices, while for 5-channels the impact was only apparent for widths less than 200nm. With 100nm-wide fins, the single-channel current was reduced by 41% relative to a planar gate; the 5-channel reduction was only 12%.

The researchers explain that "the multi-channel structure mitigates greatly the electron–electron and sidewall scatterings in tri-gate (MOS)HEMTs." The electrons in single-channel devices are tightly packed, increasing the rate of electron–electron collisions and hence resistance. Further resistance comes from more electrons hitting the fin sidewalls. Multi-channel structures reduce electron crowding in the separate channels.

A high-voltage MOSHEMT was produced with 10μm gate–drain spacing, and 700nm-long, 100nm-wide fins. The spacing between the fins was 100nm, giving a fill factor of 50%. The gate metal extended 0.5μm towards the source and 1.3μm in the drain direction, giving a total length of 2.5μm.

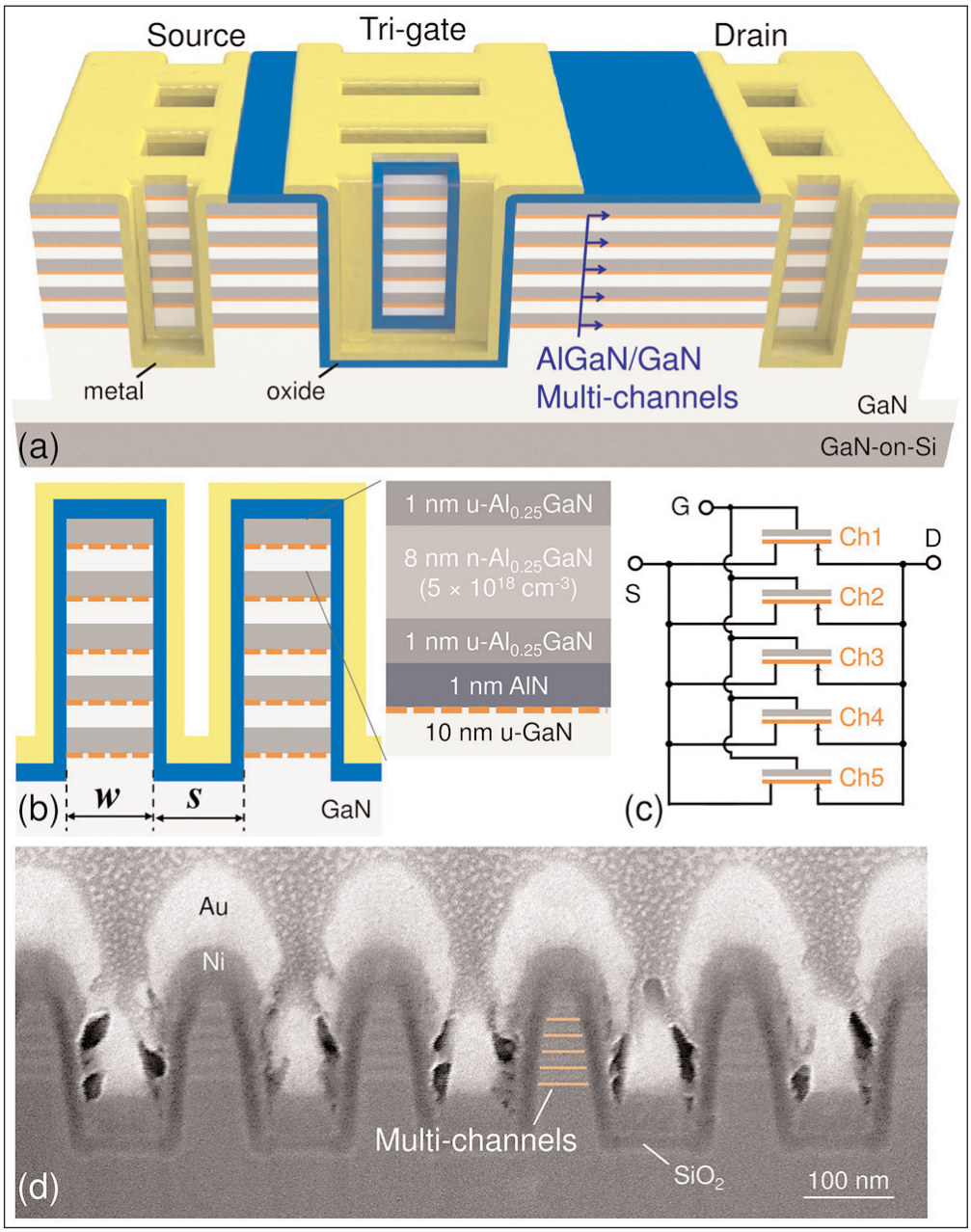



**Figure 1. (a) Schematic of multi-channel tri-gate AlGaN/GaN MOSHEMT. (b) Cross-sectional schematic of tri-gate region. Inset shows multi-channel heterostructure. (c) Equivalent circuit. (d) Cross-sectional scanning electron microscope image of tri-gate region, tilted by 52°.**

Two single-channel reference devices were fabricated with similar dimensions: one with planar- and the other with tri-gate structures. The barrier layer in these reference devices was a typical 20nm of $Al_{0.25}Ga_{0.75}N$ on GaN channel.

The multi-channel tri-gate devices showed reduced on-resistance (Figure 2). Compared with the single-channel tri-gate reference, the on-resistance was almost half, and the maximum drain current increased more than three-fold. Normalized by the device width, the on-resistance was 6.0Ω-mm for the multi-channel MOSHEMT, compared with 11.2Ω-mm for the single-channel device. The multi- and single-channel maximum drain currents were 797mA/mm and 252mA/mm, respectively.

The team comments: "These results are remarkable since they indicate that the multi-channel tri-gate technology can lower the conduction losses of the transistor for a given device footprint or, equivalently, deliver a given current rating in a smaller device footprint, both of which are highly beneficial for efficient power transistors."

Compared with the planar reference, the multi-channel MOSHEMT had 38% reduced on-resistance and 41% increased maximum drain current. This was despite the 50% fill factor of the fin structure, compared with the 100% of the planar setup.

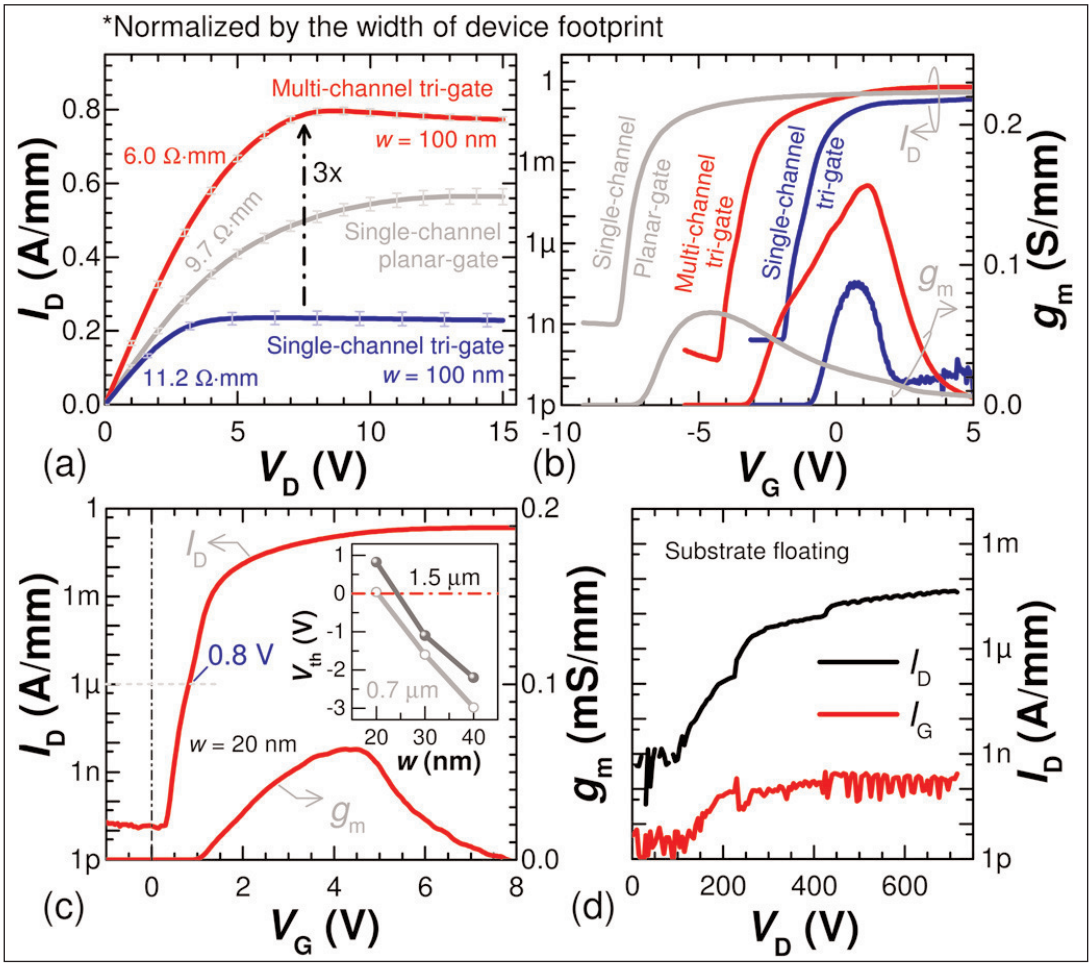



**Figure 2. (a) Output characteristics at 5V gate potential ($V_G$) and (b) transfer characteristics at 5V drain bias ($V_D$), normalized by width of device footprint. (c) Transfer characteristics of multi-channel tri-gate transistors with 20nm fin width and 10% fill factor at 5V $V_D$. Inset threshold voltage ($V_{TH}$, for 1µA/mm current) versus fin width (w) for two fin lengths (l).(d) Typical OFF-state breakdown characteristics of multi-channel tri-gate transistors measured with floating substrate.**

The threshold voltage was made more positive by moving from the planar reference to the multi-channel fin MOSHEMT, going from −7.6V to −3.6V, respectively. The peak transconductance also increased 2.4-fold in the multi-channel device — 156.6mS/mm, compared with 66.1mS/mm. The on/off current ratio of the multi-channel MOSHEMT was ~$10^{10}$.

Using a 20nm fin width (700nm length), the researchers achieved a positive threshold voltage of 0.82V a 1µA/mm. The off-current at 0V gate potential was 12pA/mm. Positive thresholds are desired for normally-off, enhancement-mode operation. The researchers attribute the positive threshold to the sidewall depletion effect. For longer 1.5µm fins, the sidewall depletion fin width was slightly increased to 24nm, likely due to increased strain relaxation relative to shorter fins.

Hard off-state breakdown came at 715V, while the gate leakage was still of order 0.2nA/mm at 700V drain bias.

## Reducing Schottky on-resistance

The EPFL/Enkris lateral Schottky barrier diodes (SBDs) also used tri-gate multi-channel AlGaN heterostructures on silicon. The team comments: "This unique design significantly enhanced the device performance, leading to state-of-the-art lateral GaN-on-Si power SBDs, and unveiled a novel platform to drastically improve the efficiency, increase the current rating, and reduce the size of GaN-based power devices."

The multi-channel material consisted again of 5 layers of 10nm/1nm/10nm AlGaN/AlN/GaN grown on silicon with a 4.3µm buffer layer (Figure 3). The electrical performance was identical in terms of sheet resistance, carrier density and mobility — presumably the same epitaxial material was used in both experiments.

Fin structures were etched to enable access to the multi-channels. The nickel/gold (Ni/Au) Schottky anode comprised 200nm-high and 50nm-wide fins with 1.2µm oxide-insulated tri-gate and 4µm tri-anode regions. The tri-gate region served as a field plate to reduce peak fields and enhance breakdown performance. The gate structure also extended into the planar region, operating as a second field plate. The gate insulator was 25nm atomic layer deposition (ALD) silicon dioxide. The cathode-anode spacing was 15µm. The fins in the cathode region were 500nm wide with 500nm spacing.

A single-channel reference device was produced based on material with 1x$10^{13}$/$cm^2$ carrier density and 2000$cm^2$/V-s mobility. The multi-channel device had ~50% reduced on-resistance ($R_{ON}$), compared with the single-channel performance. Also, the forward voltage for 0.1mA/mm current was reduced from 2.21V to 1.57V for the single- and multi-channel SBDs, respectively. The turn-on voltage of both devices was around 0.67V.

The reverse current of the multi-channel device (0.89nA/mm at −100V) was around six times smaller than for the single-channel structure. At 150ºC, the

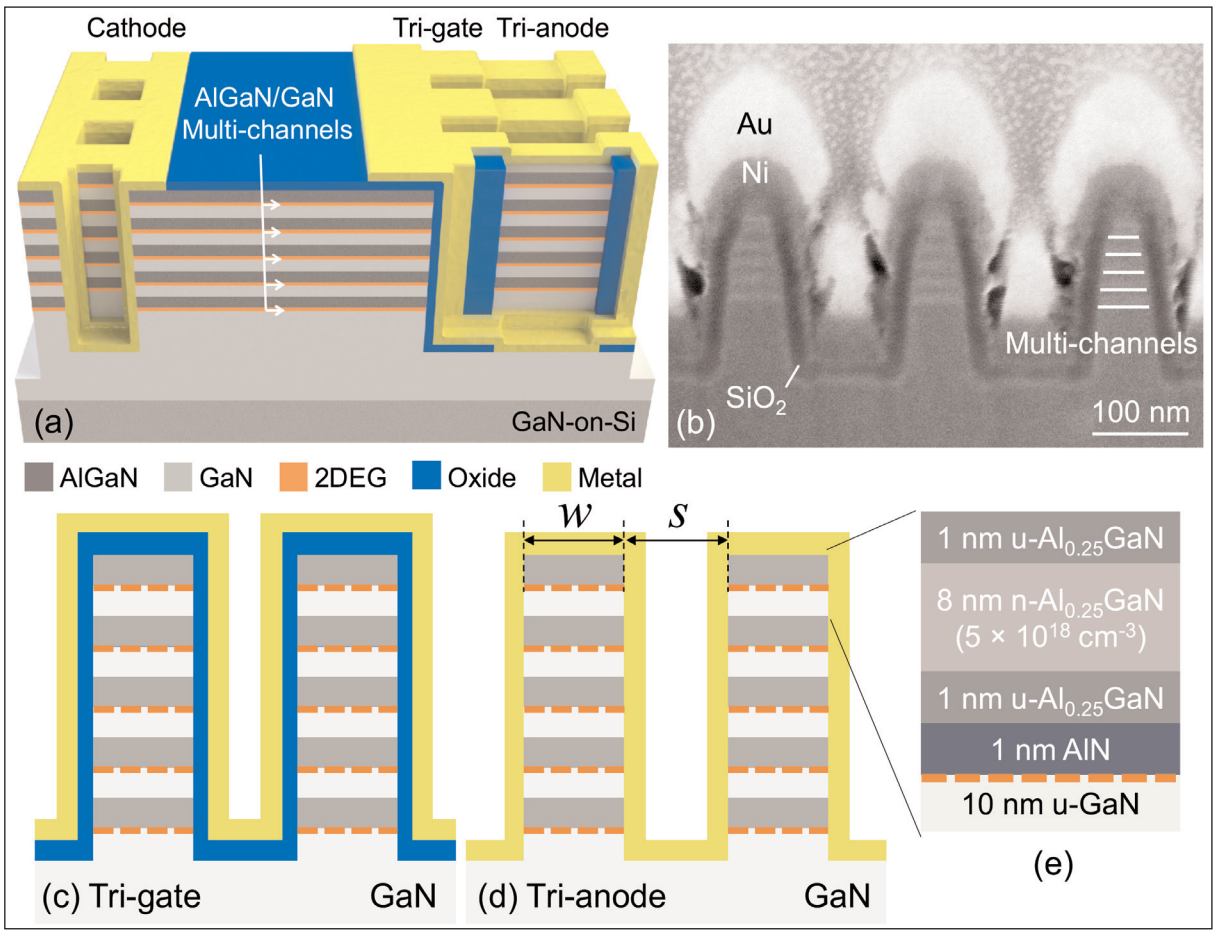



**Figure 3. (a) Schematic of multi-channel tri-gate SBD. (b) Cross-sectional scanning electron microscope image of tri-gate region, tilted by 52°. Cross-sectional schematics of (c) tri-gate and (d) tri-anode regions. (e) Schematic of heterostructure composing each channel.**

reverse current at −100V was 86nA/mm for the multi-channel SBD.

With grounded substrate, the multi-channel SBD had a 1μA/mm break-

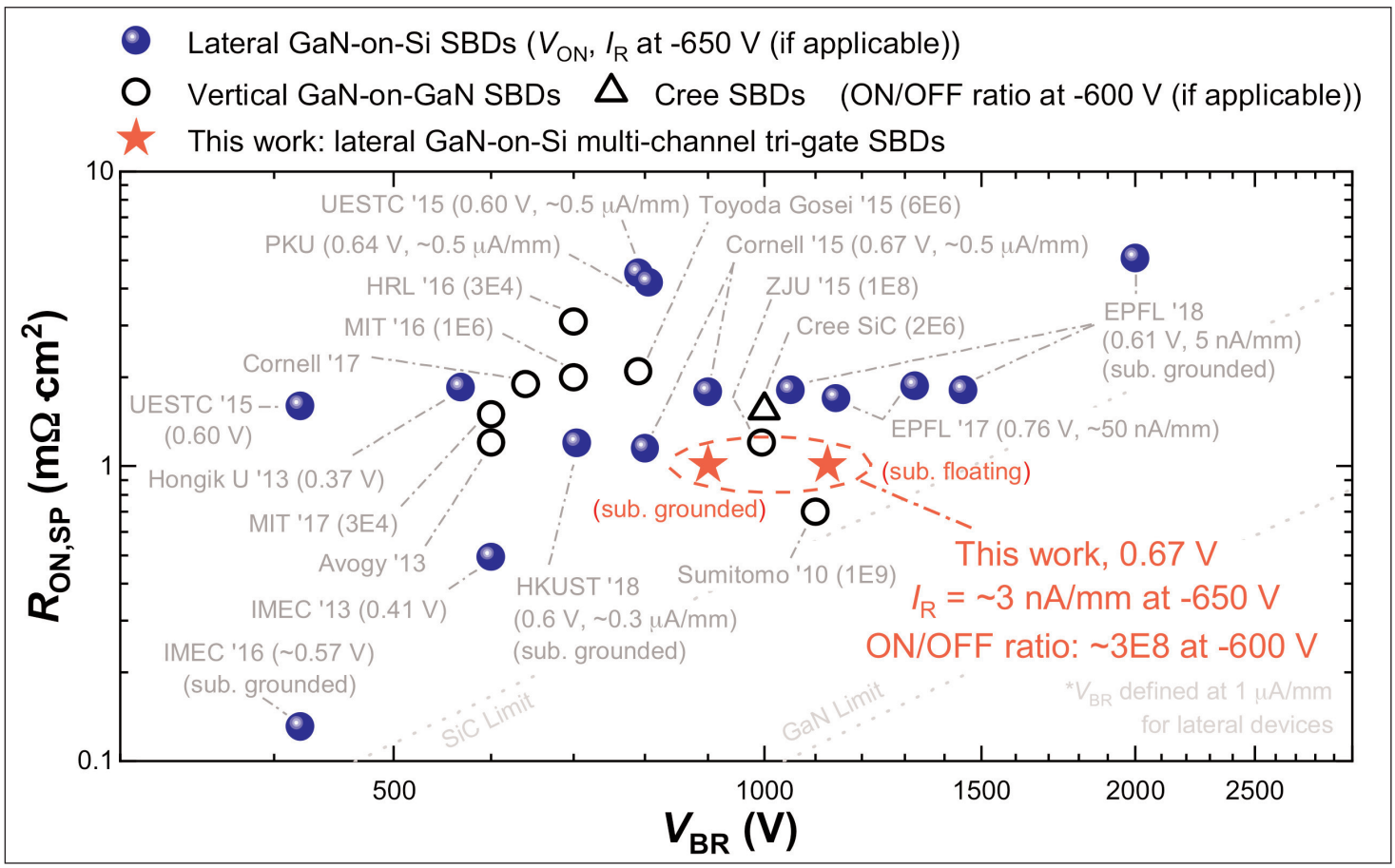



**Figure 4. Specific on-resistance ($R_{ON,SP}$) versus $V_{BR}$ benchmark of multi-channel tri-gate SBDs against state-of-the-art lateral GaN SBDs. Some values were recalculated for fair comparison.**

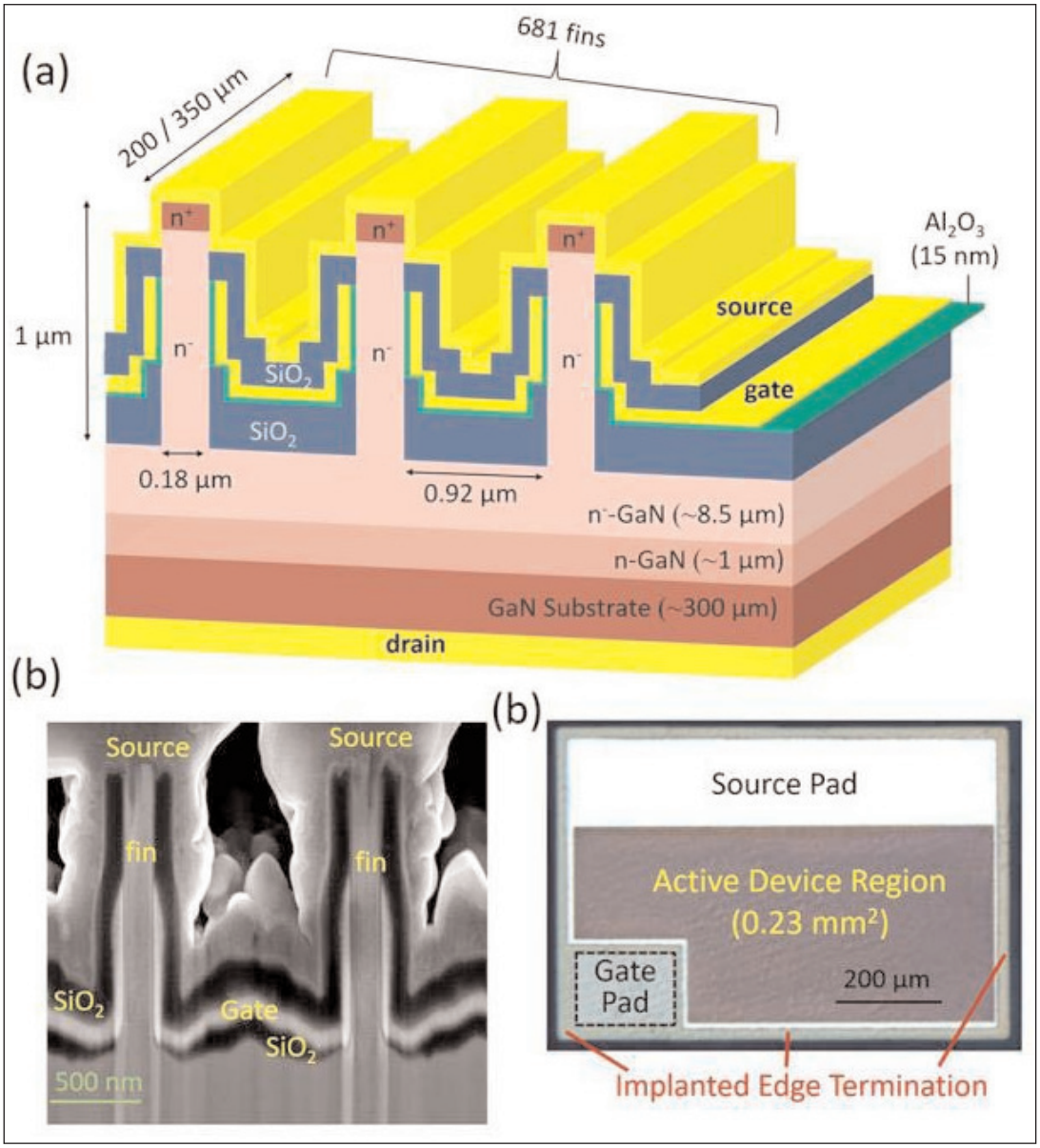



**Figure 5. (a) Three-dimensional schematics of GaN vertical power FinFETs with multiple fin channels. (b) Cross-sectional scanning electron microscope (SEM) image of fin area, taken in focused ion beam system. (c) Optical microscope image.**

down voltage ($V_{BR}$) of 900V. At –650V reverse bias, the leakage current ($I_R$) was ~3nA/mm. "Such high voltage-blocking performance indicate the potential of these devices for 650V applications, providing a small $I_R$ at the rated voltage and a safety margin of ~50% from the rated voltage to the hard breakdown," the researchers comment.

The $V_{BR}^2/R_{ON}$ power figure of merit was 1.25GW/cm$^2$. The team says that this is comparable to state-of-the-art GaN-on-GaN vertical SBDs and GaN-on-silicon transistors (Figure 4).

The recovery times at 1MHz were 13.8ns and 8.2ns in the forward and reverse directions, respectively. These values were stable between 10kHz and 10MHz. However, a phase shift between voltage and current became apparent above 5MHz.

## Boosting switching frequency in vertical transistors

Fins have also been used in vertical device structures. Researchers based in USA and Singapore claim a record switching figure of merit for large-area 1.2kV GaN vertical power fin field-effect transistors (FETs) [Yuhao Zhang et al, IEEE Electron Device Letters, vol40, p75, 2019]. The team from Massachusetts Institute of Technology in the USA, the Singapore–MIT Alliance for Research and Technology in Singapore, and IQE RF LLC and Columbia University in the USA writes that this was "the first experimental study on capacitances, charges and power-switching figure of merits (FOM) for a large-area vertical GaN power transistor."

Vertical GaN structures should enable higher breakdown voltages in smaller dimensions with easier thermal management. The team reported on their design over a year ago at the International Electron Devices Meeting 2017 [Mike Cooke, Semiconductor Today, vol12, issue 10, p98, Dec 2017/Jan 2018]. The device uses only n-type material, making for easier epitaxial growth and reducing charge-storage problems. Normally-off performance is enabled by the fin structure in combination with the gate-metal work function producing full depletion of the channel at zero gate potential. Normally-off operation reduces power consumption and further allows for easy shut-off after failure.

The latest development of this device structure incorporated argon-implant edge termination under the gate pad edges "for the first time in vertical GaN FinFETs".

The researchers used metal-organic chemical vapor deposition (MOCVD) on 2-inch heavily n-doped GaN substrates. The lightly doped $n^-$-GaN drift layer was ~9.5µm. The heavily doped $n^+$-GaN cap was 300nm.

The epitaxial material was fabricated into devices (Figure 5) with 489 350µm-long fins and 183 200µm-

long fins (the gate pad region). The active device area was 0.23mm$^2$. Adding pads and so on, increased the area to 0.45mm$^2$.

The process sequence was fin etch and corner rounding, argon-implantation edge termination, spacer oxide deposition, and formation of gate, source and drain contacts.

The resulting device had a threshold voltage of +1.3V at 2mA drain current. The researchers report that there was almost no hysteresis in the threshold with up and down sweeps. The drain current was able to reach 5A and the on-resistance was 0.9Ω, giving an active-area specific value of 2.1mΩ-cm$^2$.

The reverse turn-on voltage was 0.8V, lower than usual for silicon carbide or GaN devices (2–3V). The team attributes this to the absence of pn junctions in the epitaxial material. The low turn-on implies lower power losses, and in some cases this could "eliminate the need for paralleling a freewheeling diode in many switching applications". Destructive breakdown occurred above 1.2kV. Just before breakdown the leakage current was at the micro-Amp level.

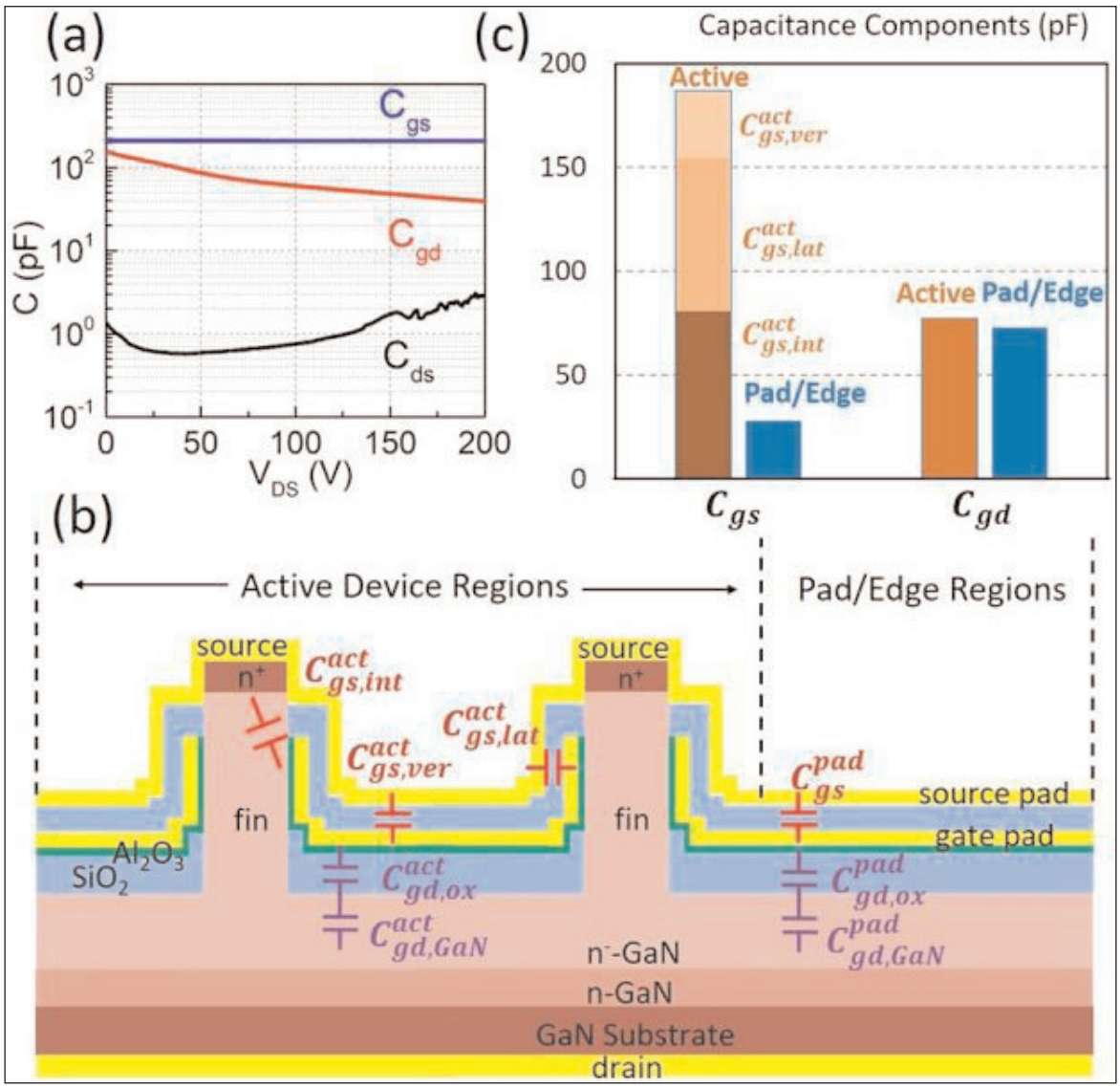



**Figure 6. (a) Device junction capacitances $C_{ds}$, $C_{gs}$ and $C_{gd}$ measured by using Agilent B1505A power device analyzer and custom-built RC circuit. (b) Schematics of different $C_{gs}$ and $C_{gd}$ components in active and pad/edge regions. (c) Calculated components break-out for measured $C_{gs}$ and $C_{gd}$.**

The researchers estimate that switching speeds for their device could reach ~3.5MHz on the basis of the on-resistance and charge-storage performance. The greater the charge stored in parasitic capacitors (Figure 6), the more difficult it is to switch states. A figure of merit (FOM) based on the product of the on-resistance and gate and gate–drain charge was calculated at 3.3nΩ-C. The researchers believe this could be reduced to around 2nΩ-C if the contact pads were optimized. A low value should enable higher switching speeds.

The team also reports the FOM for other devices: 7.68nΩ-C for Cree's CPM2-1200-0160B silicon carbide MOSFET, 5.4nΩ-C for United SiC's UJN1208Z JFET, 54.5nΩ-C for ON Semi's NGTB15N120FLWG insulated-gate bipolar transistor, and 48nΩ-C for Infineon's IPD90R1K2C3 silicon CoolMOS device. These devices also have significant reverse-recovery charge storage ($Q_{rr}$) problems due to the presence of p-type regions. Including this charge increases the FOMs to 24.48nΩ-C, 14.85nΩ-C, 429.5nΩ-C, and 4488nΩ-C, respectively. By contrast, since there is no p-type material in the team's FinFET, the reverse-recovery charge is effectively zero.

The researchers comment: "As shown, our device exhibited the best power switching FOMs among all 0.9–1.2kV power transistors. This is attributable to the combination of the superior physical properties of GaN and the merits of our vertical FinFET (small capacitances, low $V_G$ [gate potential] and no $Q_{rr}$)." ■

*Author: Mike Cooke*

# Gallium oxide could have low cost in future, reckons NREL technoeconomic analysis

**The cost of manufacturing a six-inch $Ga_2O_3$ wafer in USA is less than a third of that for a silicon carbide wafer, halving the cost of power electronics.**

The potential use of gallium oxide as a power electronic technology of the future is borne out by a new technoeconomic analysis by the US National Renewable Energy Laboratory (NREL). The findings reveal that gallium oxide wafers could be three to five times cheaper to manufacture than related silicon carbide technology, according to the paper 'How Much Will Gallium Oxide Power Electronics Cost?' (to be published in the April edition of Joule at https://doi.org/10.1016/j.joule.2019.01.011).

The proportion of electricity that flows through power electronics is forecast to rise from an estimated 30% currently to 80% in the next decade, making it critical to optimize efficiency of power electronics for use in the generation, transmission, storage and use of that energy.

"If you look at the grid of the future, you'll see more power electronics for renewables and electric vehicle charging," says Johney Green, associate lab director for Mechanical and Thermal Engineering Sciences at NREL. "As we get more and more of these power electronics-based devices on the grid, it changes the physics of the grid. We really need to understand how these devices will impact the grid and how to control them." Green, who championed the analysis, is a co-author of the paper along with Samantha Reese, Timothy Remo, and Andriy Zakutayev. The four authors come from three different research directorates at NREL.

The analysis into the cost of gallium oxide dovetails with ongoing research at NREL into the use of wide-bandgap semiconductors for power electronics. Power electronic devices made of silicon, with its narrow bandgap, produce too much heat when confined in a small space. Wide-bandgap semiconductors, such as gallium oxide, silicon carbide (SiC) and gallium nitride (GaN), can potentially operate more efficiently in a tight space, so components utilizing a wide-bandgap semiconductor can be more compact and hence lighter.

Both gallium oxide and silicon carbide are being considered as replacements for silicon in power electronic devices. Silicon carbide is already in use, but wide-spread adoption has been hampered by its relatively high cost. Gallium oxide semiconductors are not being used commercially, but several companies are working on device prototypes, says Zakutayev, a materials scientist whose work involves the development of new materials for use in renewable energy technologies. While there have been published papers indicating that the low cost of gallium oxide could be a future advantage, the NREL research is the first to provide a quantitative analysis, it is reckoned.

**NREL researchers Timothy Remo (left), Samantha Reese, Andriy Zakutayev and Johney Green used technoeconomic analysis to determine 'How Much Will Gallium Oxide Power Electronics Cost?', a paper published in Joule. (Photo by Dennis Schroeder/NREL)**

The new analysis could prompt further materials and device research into the use of gallium oxide, which has been relatively overlooked compared with silicon carbide and gallium nitride devices. Reese (a senior analyst/engineer in NREL's Strategic Energy Analysis Center) and Remo, along with other analysts at NREL, published a cost analysis in 2017 for the use of silicon carbide in medium-voltage motor drives. "It's hard to get the funding for the technical research if you don't have a cost motivation, given that silicon carbide's already in the market," says Reese. "But it's hard to get money to do the analysis of the

cost if you don't have technical results demonstrating the capabilities."

For the gallium oxide analysis, a bottoms-up cost model created around the manufacturing process considered such factors as crystal growth and ingot machining to approximate the fabrication of crystal wafers ready for use in a device. The assumptions used in the model included an ingot 1m long, a wafer 6 inches in diameter, and a manufacturing volume of 5000 wafers a month.

The NREL analysis determined that it would cost $283 to manufacture a 6-inch gallium oxide wafer in the USA (less than a third of the $919 it would cost to make a silicon carbide wafer). The significantly lower wafer cost enables the gallium oxide-containing power electronics (which also consist of many other components and packaging) to be twice as cheap. The techno-economic modeling relies on manufacturing scenarios that are not currently commercialized, but it's projected to hold true once R&D advances move gallium oxide into mainstream applications.

The potential exists to reduce the cost of gallium oxide wafers even further. More than half of the cost of a gallium oxide wafer comes from the use of iridium as the crucible in which the crystal ingot is grown. Using an alternative material, such as molybdenum or tungsten, could bring the price of gallium oxide semiconductors down further.

Unlike gallium oxide, gallium nitride semiconductors are already in widespread use in applications other than power electronics, because they form the basis of light-emitting diodes and solid-state lighting. "The biggest difference is that gallium oxide crystal wafers should be easier to scale up in size, and decrease in cost, compared to gallium nitride," Zakutayev says.

In addition to the new analysis, NREL is a part of the five-year-old Next Generation Power Electronics National Manufacturing Innovation Institute (PowerAmerica), whose mission is to make wide-bandgap semiconductors cost-competitive with their silicon-based counterparts. ■

**www.sciencedirect.com/science/article/pii/S2542435119300406**

**www.nrel.gov/docs/fy17osti/67694.pdf**

# suppliers' directory

# Index



**To have your company listed in this directory, e-mail details (including categories) to mark@semiconductor-today.com**
**Note: advertisers receive a free listing. For all other companies, a charge is applicable.**

## 1 Bulk crystal source materials

**Mining & Chemical Products Ltd (part of 5N Plus, Inc)**
1-4, Nielson Road,
Finedon Road Industrial Estate,
Wellingborough,
Northants NN8 4PE,
UK
Tel: +44 1933 220626
Fax: +44 1933 227814
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.thinfilmproducts.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

## 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

## 3 Substrates

**AXT Inc**
4281 Technology Drive,
Fremont,
CA 94538,
USA
Tel: +1 510 438 4700
Fax: +1 510 683 5901
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, $B_2O_3$.

**CrystAl-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
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

**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

**Kyma Technologies Inc**
8829 Midway West Road,
Raleigh, NC, USA
Tel: +1 919 789 8880
Fax: +1 919 789 8881
www.kymatech.com

**MARUWA CO LTD**
3-83, Minamihonjigahara-cho,
Owariasahi, Aichi 488-0044,
Japan
Tel: +81 572 52 2317
**www.maruwa-g.com/e/products/ceramic**

**sp3 Diamond Technologies**
2220 Martin Avenue,
Santa Clara, CA 95050,
USA
Tel: +1 877 773 9940
Fax: +1 408 492 0633
**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**

**III/V-Reclaim**
Wald 10,
84568 Pleiskirchen,
Germany
Tel: +49 8728 911 093
Fax: +49 8728 911 156
**www.35reclaim.de**
III/V-Reclaim offers reclaim (recycling) of GaAs and InP wafers, removing all kinds of layers and structures from customers' wafers. All formats and sizes can be handled. The firm offers single-side and double-side-polishing and ready-to-use surface treatment.

**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**

**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
**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**

**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**

**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**

**IQE**
Cypress Drive,
St Mellons, Cardiff
CF3 0EG,
UK
Tel: +44 29 2083 9400
Fax: +44 29 2083 9401
**www.iqep.com**
IQE is a leading global supplier of advanced epiwafers, with products covering a diverse range of applications within the wireless, optoelectronic, photovoltaic and electronic markets.

**OMMIC**
2, Chemin du Moulin B.P. 11,
Limeil-Brevannes, 94453,
France
Tel: +33 1 45 10 67 31
Fax: +33 1 45 10 69 53
**www.ommic.fr**

**Soitec**
Place Marcel Rebuffat, Parc de Villejust, 91971 Courtabouef,
France
Tel: +33 (0)1 69 31 61 30
Fax: +33 (0)1 69 31 61 79
**www.picogiga.com**

## 5 Deposition materials

**Akzo Nobel High Purity Metalorganics**
**www.akzonobel.com/hpmo**
***Asia Pacific:***
Akzo Nobel (Asia) Co Ltd,
Shanghai,
China
Tel. +86 21 2216 3600
Fax: +86 21 3360 7739
metalorganicsAP@akzonobel.com
***Americas:***
AkzoNobel Functional Chemicals,
Chicago,
USA
Tel. +31 800 828 7929 (US only)
Tel: +1 312 544 7000
Fax: +1 312 544 7188
metalorganicsNA@akzonobel.com
***Europe, Middle East and Africa:***
AkzoNobel Functional Chemicals,
Amersfoort,
The Netherlands
Tel. +31 33 467 6656
Fax: +31 33 467 6101
metalorganicsEU@akzonobel.com

**Cambridge Chemical Company 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**

**Dow Electronic Materials**
60 Willow Street,
North Andover, MA 01845,
USA
Tel: +1 978 557 1700
Fax: +1 978 557 1701
**www.metalorganics.com**

**Matheson Tri-Gas**
6775 Central Avenue,
Newark, CA 94560,
USA
Tel: +1 510 793 2559
Fax: +1 510 790 6241
**www.mathesontrigas.com**

**Mining & Chemical Products Ltd**
**(see section 1 for full contact details)**

**Praxair Electronics**
542 Route 303, Orangeburg,
NY 10962,
USA
Tel: +1 845 398 8242
Fax: +1 845 398 8304
**www.praxair.com/electronics**

**SAFC Hitech**
Power Road, Bromborough,
Wirral, Merseyside CH62 3QF,
UK
Tel: +44 151 334 2774
Fax: +44 151 334 6422
**www.safchitech.com**

**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**

## 6 Deposition equipment

**AIXTRON SE**
Dornkaulstr. 2,
52134 Herzogenrath,
Germany
Tel: +49 2407 9030 0
Fax: +49 2407 9030 40
**www.aixtron.com**

AIXTRON

AIXTRON is a leading provider of deposition equipment to the semiconductor industry. The company's technology solutions are used by a diverse range of customers worldwide to build advanced components for electronic and optoelectronic applications (photonic) based on compound, silicon, or organic semiconductor materials and, more recently, carbon nanotubes (CNT), graphene and other nanomaterials.

**Evatec AG**
Hauptstrasse 1a,
CH-9477 Trübbach, Switzerland
Tel: +41 81 403 8000
Fax: +41 81 403 8001
**www.evatecnet.com**

**Ferrotec-Temescal**
4569-C Las Positas Rd,
Livermore,
CA 94551,
USA
Tel: +1 925 245 5817
Fax: +1 925 449-4096
**www.temescal.net**

Temescal, the expert in metallization systems for the processing of compound semiconductor-based substrates, provides the finest evaporation systems available. Multi-layer coatings of materials such as Ti, Pt, Au, Pd, Ag, NiCr, Al, Cr, Cu, Mo, Nb, $SiO_2$, with high uniformity are guaranteed. Today the world's most sophisticated handsets, optical, wireless and telecom systems rely on millions of devices that are made using Temescal deposition systems and components.

**Plasma-Therm LLC**
10050 16th Street North,
St. Petersburg, FL 33716,
USA
Tel: +1 727 577 4999
Fax: +1 727 577 7035
**www.plasmatherm.com**

**Riber**
31 rue Casimir Périer, BP 70083,
95873 Bezons Cedex,
France
Tel: +33 (0) 1 39 96 65 00
Fax: +33 (0) 1 39 47 45 62
**www.riber.com**

**SVT Associates Inc**
7620 Executive Drive,
Eden Prairie, MN 55344,
USA
Tel: +1 952 934 2100
Fax: +1 952 934 2737
**www.svta.com**

**Veeco Instruments Inc**
100 Sunnyside Blvd.,
Woodbury, NY 11797,
USA
Tel: +1 516 677 0200
Fax: +1 516 714 1231
**www.veeco.com**

Veeco Solutions for a nanoscale world.™

Veeco is a world-leading supplier of compound semiconductor equipment, and the only company offering both MOCVD and MBE solutions. With complementary AFM technology and the industry's most advanced Process Integration Center, Veeco tools help grow and measure nanoscale devices in worldwide LED/wireless, data storage, semiconductor and scientific research markets—offering important choices, delivering ideal solutions.

## 7 Wafer processing materials

**Air Products and Chemicals Inc**
7201 Hamilton Blvd.,
Allentown, PA 18195, USA
Tel: +1 610 481 4911
**www.airproducts.com/compound**

**MicroChem Corp**
1254 Chestnut St. Newton,
MA 02464, USA
Tel: +1 617 965 5511
Fax: +1 617 965 5818
**www.microchem.com**

**Praxair Electronics**
**(see section 5 for full contact details)**

## 8 Wafer processing equipment

**EV Group**
DI Erich Thallner Strasse 1,
St. Florian/Inn, 4782,
Austria
Tel: +43 7712 5311 0
Fax: +43 7712 5311 4600
**www.EVGroup.com**

**Logitech Ltd**
Erskine Ferry Road,
Old Kilpatrick,
near Glasgow G60 5EU,
Scotland, UK
Tel: +44 (0) 1389 875 444
Fax: +44 (0) 1389 879 042
**www.logitech.uk.com**

**Plasma-Therm LLC**
**(see section 6 for full contact details)**

**SAMCO International Inc**
532 Weddell Drive,
Sunnyvale, CA,
USA
Tel: +1 408 734 0459
Fax: +1 408 734 0961
**www.samcointl.com**

**SPTS Technology Ltd**
Ringland Way, Newport NP18 2TA,
UK
Tel: +44 (0)1633 414000
Fax: +44 (0)1633 414141
**www.spts.com**

**SUSS MicroTec AG**
Schleißheimer Strasse 90,
85748 Garching,
Germany
Tel: +49 89 32007 0
Fax: +49 89 32007 162
**www.suss.com**

**Veeco Instruments Inc**
**(see section 6 for full contact details)**

## 9 Materials & metals

**Goodfellow Cambridge Ltd**
Ermine Business Park,
Huntingdon,
Cambridgeshire PE29 6WR,
UK
Tel: +44 (0) 1480 424800
Fax: +44 (0) 1480 424900
**www.goodfellow.com**

Goodfellow supplies small quantities of metals and materials for research, development, prototyping and specialised manufacturing operations.

## 10 Gas and liquid handling equipment

**Air Products and Chemicals Inc**
**(see section 7 for full contact details)**

**Cambridge Fluid Systems**
12 Trafalgar Way, Bar Hill,
Cambridge CB3 8SQ,
UK
Tel: +44 (0)1954 786800
Fax: +44 (0)1954 786818
**www.cambridge-fluid.com**

**CS CLEAN SOLUTIONS AG**
Fraunhoferstrasse 4,
Ismaning, 85737,
Germany
Tel: +49 89 96 24000
Fax: +49 89 96 2400122
**www.csclean.com**

**SAES Pure Gas Inc**
4175 Santa Fe Road,
San Luis Obispo,
CA 93401,
USA
Tel: +1 805 541 9299
Fax: +1 805 541 9399
**www.saesgetters.com**

## 11 Process monitoring and control

**Conax Technologies**
2300 Walden Avenue,
Buffalo, NY 14225,
USA
Tel: +1 800 223 2389
Tel: +1 716 684 4500
E-mail: conax@conaxtechnologies.com

Ideas. Solutions. Success.
**www.conaxtechnologies.com**
Conax Technologies is a designer and manufacturer of standard and custom-engineered temperature sensors, compression seal fittings and feedthroughs, probes, wires, electrodes and fiber-optic cables. The company is headquartered in Buffalo, New York, with locations on the US West Coast, Canada, Europe and Asia.

**k-Space Associates Inc**
2182 Bishop Circle
East, Dexter, MI 48130,
USA
Tel: +1 734 426 7977
Fax: +1 734 426 7955
**www.k-space.com**

**KLA-Tencor**
One Technology Dr,
1-2221I, Milpitas,
CA 95035,
USA
Tel: +1 408 875 3000
Fax: +1 408 875 4144
**www.kla-tencor.com**

**LayTec AG**
Seesener Str. 10–13,
10709 Berlin,
Germany
Tel: +49 30 89 00 55 0
Fax: +49 30 89 00 180
**www.laytec.de**
LayTec develops and manufactures optical in-situ and in-line metrology systems for thin-film processes with particular focus on compound semiconductor and photovoltaic applications. Its know-how is based on optical techniques: reflectometry, emissivity corrected pyrometry, curvature measurements and reflectance anisotropy spectroscopy.

**WEP (Ingenieurbüro Wolff für Elektronik- und Programmentwicklungen)**
Bregstrasse 90,
D-78120 Furtwangen im Schwarzwald,
Germany
Tel: +49 7723 9197 0
Fax: +49 7723 9197 22
**www.wepcontrol.com**

## 12 Inspection equipment

**Bruker AXS GmbH**
Oestliche Rheinbrueckenstrasse 49,
Karlsruhe, 76187,
Germany
Tel: +49 (0)721 595 2888
Fax: +49 (0)721 595 4587
**www.bruker-axs.de**

## 13 Characterization equipment

**J.A. Woollam Co. Inc.**
645 M Street Suite 102,
Lincoln, NE 68508, USA
Tel: +1 402 477 7501
Fax: +1 402 477 8214
**www.jawoollam.com**

**Lake Shore Cryotronics Inc**
575 McCorkle Boulevard,
Westerville, OH 43082, USA
Tel: +1 614 891 2244
Fax: +1 614 818 1600
**www.lakeshore.com**

## 14 Chip test equipment

**Keithley Instruments Inc**
28775 Aurora Road,
Cleveland, OH 44139, USA
Tel: +1 440.248.0400
Fax: +1 440.248.6168
www.keithley.com

## 15 Assembly/packaging materials

**ePAK International Inc**
4926 Spicewood Springs Road,
Austin, TX 78759,
USA
Tel: +1 512 231 8083
Fax: +1 512 231 8183
www.epak.com

**Gel-Pak**
31398 Huntwood Avenue,
Hayward, CA 94544, USA
Tel: +1 510 576 2220
Fax: +1 510 576 2282
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

## 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

**Kulicke & Soffa Industries**
1005 Virginia Drive,
Fort Washington, PA 19034,
USA
Tel: +1 215 784 6000
Fax: +1 215 784 6001
www.kns.com

**Palomar Technologies Inc**
2728 Loker Avenue West,
Carlsbad, CA 92010,
USA
Tel: +1 760 931 3600
Fax: +1 760 931 5191
www.PalomarTechnologies.com

**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

## 17 Assembly/packaging foundry

**Quik-Pak**
10987 Via Frontera,
San Diego, CA 92127,
USA
Tel: +1 858 674 4676
Fax: +1 8586 74 4681
www.quikicpak.com

## 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

**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

## 19 Facility equipment

**MEI, LLC**
3474 18th Avenue SE,
Albany, OR 97322-7014,
USA
Tel: +1 541 917 3626
Fax: +1 541 917 3623
www.marlerenterprises.net

## 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

## 21 Computer hardware & software

**Ansoft Corp**
4 Station Square,
Suite 200,
Pittsburgh, PA 15219,
USA
Tel: +1 412 261 3200
Fax: +1 412 471 9427
www.ansoft.com

**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

**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

## 22 Used equipment

**Class One Equipment Inc**
5302 Snapfinger Woods Drive,
Decatur, GA 30035,
USA
Tel: +1 770 808 8708
Fax: +1 770 808 8308
www.ClassOneEquipment.com

## 23 Services

**Henry Butcher International**
Brownlow House, 50–51
High Holborn, London WC1V 6EG,
UK

Tel: +44 (0)20 7405 8411
Fax: +44 (0)20 7405 9772
www.henrybutcher.com

**M+W Zander Holding AG**
Lotterbergstrasse 30,
Stuttgart, Germany
Tel: +49 711 8804 1141
Fax: +49 711 8804 1950
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

## 25 Resources

**Al Shultz Advertising Marketing for Advanced Technology Companies**
1346 The Alameda,
7140 San Jose, CA 95126,
USA
Tel: +1 408 289 9555
www.alshuktz.com

**SEMI Global Headquarters**
3081 Zanker Road,
San Jose,
CA 95134,
USA
Tel: +1 408 943 6900
Fax: +1 408 428 9600
www.semi.org

**Yole Développement**
45 rue Sainte Geneviève,
69006 Lyon,
France
Tel: +33 472 83 01 86
www.yole.fr

# event calendar

**If you would like your event listed in *Semiconductor Today*'s Event Calendar, then please e-mail all details to the Editor at mark@semiconductor-today.com**

**24–26 April 2019**
**International Workshop on Integrated Power Packaging (IWIPP 2019)**
Laplace-ENSEEIHT, Toulouse, France
**E-mail**: iwipp2019@gmail.com
**www.iwipp.org**

**29 April – 2 May 2019**
**2019 International Conference on Compound Semiconductor Manufacturing (CS MANTECH)**
Hyatt, Regency, Minneapolis, MN, USA
**E-mail**: chairman@csmantech.org
**www.csmantech.org**

**2–3 May 2019**
**SEMI Talent Forum**
Bristol, UK
**E-mail**: aniedballa@semi.org
**www.semitalentforum.org**

**7–9 May 2019**
**PCIM Europe (Power conversion and Intelligent Motion) 2019**
Nuremberg Messe, Germany
**E-mail**: daniela.kaeser@mesago.com
**www.mesago.de/en/PCIM/main.htm**

**15–17 May 2019**
**Intersolar Europe 2019**
Munich, Germany
**E-mail**: info@intersolar.de
**www.intersolar.de**

**22–24 May 2019**
**10th International Workshop on CIGS Solar Cell Technology (IW-CIGSTech 10)**
Paris, France
**E-mail**: info@iw-cigstech.org
**www.iw-cigstech.org**

**27–31 May 2019**
**ICPE 2019 – ECCE Asia: 10th International Conference on Power Electronics**
BEXCO, Busan, South Korea
**E-mail**: icpe2019@icpe2019.org
**www.icpe2019.org**

**2–7 June 2019**
**Microwave Week, including:**
**IEEE MTT-S 2019 International Microwave Symposium (IMS 2019)**
**Radio Frequency Integrated Circuits Symposium (RFIC 2019)**
Boston, MA, USA
**E-mail**: nannette@mpassociates.com
**www.ims-ieee.org**

**9–14 June 2019**
**2019 Symposia on VLSI Technology and Circuits:**
**Pushing the Limits of Semiconductors for a United and Connected World**
Rihga Royal Hotel Kyoto, Japan
**E-mail**: vlsisymp@jtbcom.co.jp
**www.vlsisymposium.org**

# advertisers' index

**17–21 June 2019**
**Wireless Power Week (WPW 2019), including: IEEE MTT-S Wireless Power Transfer Conference (WPTC)**
**IEEE PELS Workshop on Emerging Technologies: Wireless Power (WoW)**
IET London, UK
**E-mail**: info@wpw2019.org
**www.wpw2019.org**

**24–27 June 2019**
**LASER World of PHOTONICS 2019**
Messe München, Germany
**E-mail**: info@world-of-photonics.com
**www.world-of-photonics.com**

**24–28 June 2019**
**PVSC 2019: IEEE 46th Photovoltaic Specialists Conference**
Chicago, IL, USA
**E-mail**: info@ieee-pvsc.org
**www.ieee-pvsc.org**

**8–10 July 2019**
**2019 Summer Topicals Meeting Series**
Fort Lauderdale, FL, USA
**E-mail**: i.donnelly@ieee.org
**www.sum-ieee.org**

**9–11 July 2019**
**SEMICON West 2019**
Moscone Center, San Francisco, California, USA
**E-mail**: semiconwest@xpressreg.net
**www.semiconwest.org**

**10–11 July 2019**
**UK Semiconductors 2019 (UKS'19)**
University of Sheffield, UK
**E-mail**: edmund.clarke@sheffield.ac.uk
**www.uksemiconductors.com**

**21–24 July 2019**
**AVS 19th International Conference on Atomic Layer Deposition (ALD 2019), featuring the 6th International Atomic Layer Etching Workshop (ALE 2019)**
Bellevue, Washington, USA
**E-mail**: della@avs.org
**www.ald2019.avs.org**

**22–24 July 2019**
**International Congress on Advanced Materials Sciences and Engineering (AMSE-2019)**
ANA Crown Plaza Osaka, Japan
**E-mail**: eve@istci.org
**www.istci.org/icamse2019**

**11–15 August 2019**
**SPIE Optics + Photonics 2019**
San Diego Convention Center, San Diego, CA, USA
**E-mail**: customerservice@spie.org
**http://spie.org/Optics_Photonics**

**2–5 September 2019**
**21st Conference on Power Electronics and Applications (and Exhibition), EPE'19 ECCE (Energy Conversion Congress & Expo) Europe**
Genova, Italy
**E-mail**: info@epe2019.com
**www.epe2019.com**

**4–7 September 2019**
**CIOE 2019: 21st China International Optoelectronic Exposition**
Shenzhen Convention & Exhibition Center, China
**E-mail**: cioe@cioe.cn
**www.cioe.cn/en**

**18–20 September 2019**
**SEMICON Taiwan 2019**
Taipei Nangang Exhibition Centre, Taiwan
**E-mail**: semicontaiwan@semi.org
**www.semicontaiwan.org**

**22–26 September 2019**
**45th European Conference on Optical Communications (ECOC 2019)**
Dublin, Ireland
**E-mail**: ecoc2019@thiet.org
**www.ecoc2019.org**

**24–26 September 2019**
**19th International Metrology Congress (CIM 2019)**
Paris, France
**E-mail**: info@cfmetrologie.com
**www.cim2019.com**

**29 September – 3 October 2019**
**Eleventh Annual Energy Conversion Congress and Exposition (ECCE 2019)**
Baltimore, MD, USA
**E-mail**: ecce@courtesyassoc.com
**www.ieee-ecce.org/2019**

**30 September – 3 October 2019**
**SCTE-ISBE Cable-Tec Expo 2019**
Ernest N Morial Convention Center, New Orleans, LA, USA
**E-mail**: expo@scte.org
**https://expo.scte.org**

# semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

## www.semiconductor-today.com

Join our LinkedIn group: Semiconductor Today

Follow us on Twitter: Semiconductor_T

## Choose *Semiconductor Today* for . . .


### MAGAZINE

Accurate and timely coverage of the compound semiconductor and advanced silicon industries

Targeted 82,000+ international circulation

Published 10 times a year and delivered by e-mail and RSS feeds

### WEB SITE

Average of over 26,000 unique visitors to the site each month

Daily news updates and regular feature articles

Google-listed news source

### E-BRIEF

Weekly round-up of key business and technical news

E-mail delivery to entire circulation

Banner and text marketing opportunities available