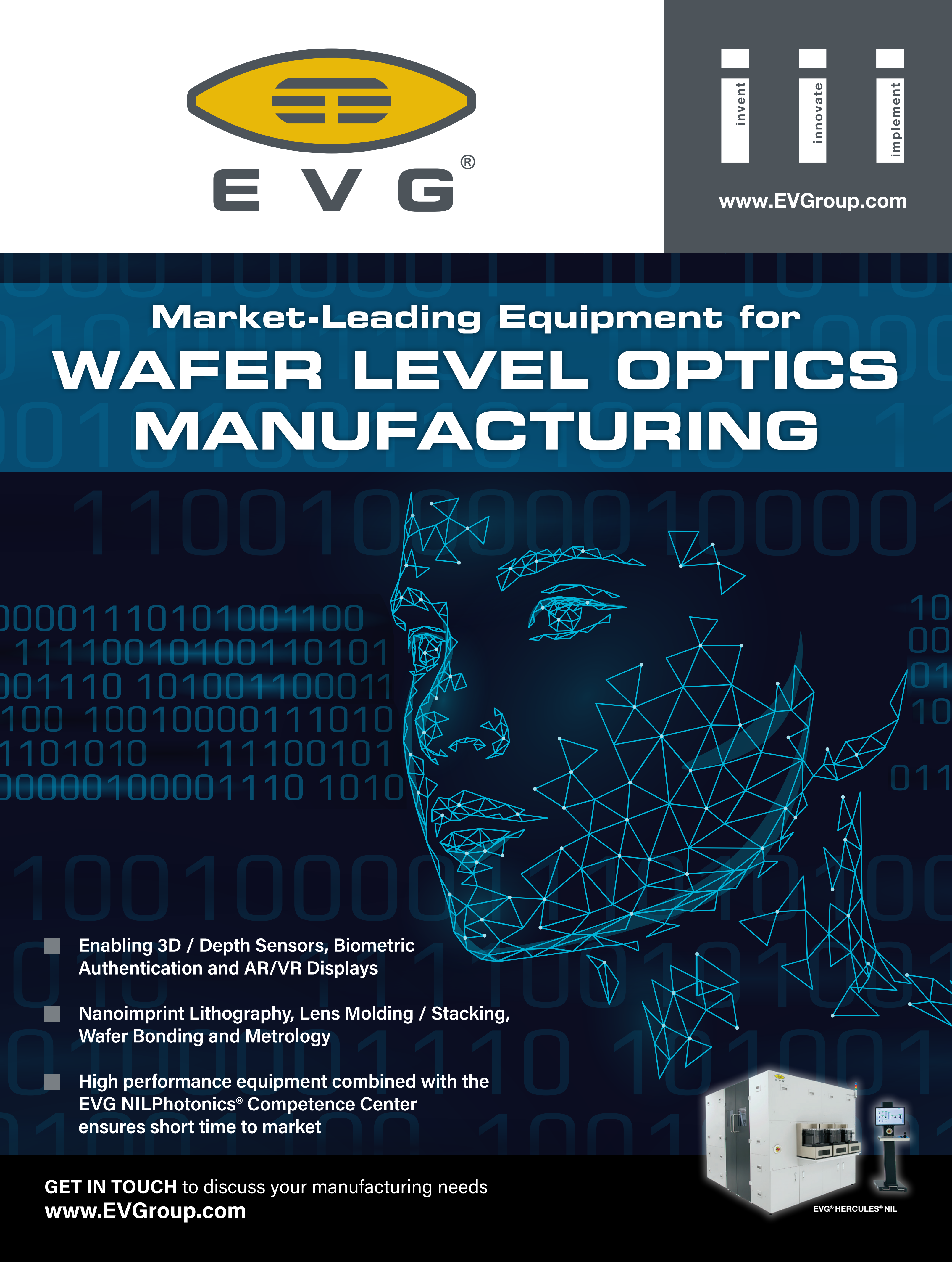
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# semiconductor TODAY

COMPOUNDS & ADVANCED SILICON

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# Bosch manufacturing silicon carbide chips for power electronics in EVs

Qorvo acquires Cavendish Kinetics • Odyssey acquires fab
BluGlass launches direct-to-market GaN laser business unit •

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Cover: Bosch has developed new silicon carbide chips, targeted at power electronics for electro-mobility applications, specifically electric vehicles and hybrid electric vehicles (EV/HEV). Bosch is manufacturing the new generation of chips at its Reutlingen plant. **p10**

# SiC gearing up for high volume

Last issue's editorial highlighted recent investments in silicon carbide (SiC) that are being driven particularly by its adoption in automotive applications for electric vehicles and hybrid electric vehicles (EVs/HEVs). These include (i) Cree's Wolfspeed business expanding its $1bn investment in both SiC materials and device manufacturing to form a 'silicon carbide corridor' on the East Coast of the USA, (ii) Cree partnering with UK-based automotive propulsion technology provider Delphi Technologies for its SiC MOSFET devices to be used in 800V traction drive inverters (and subsequently DC/DC converters and chargers), (iii) Europe's STMicroelectronics being chosen to supply automotive-grade SiC power electronics to car maker Renault–Nissan–Mitsubishi, and (iv) US-based DuPont Electronics & Imaging agreeing to divest its Compound Semiconductor Solutions (CSS) business to South Korean silicon wafer maker SK Siltron.

Soon after the last issue closed, Germany-based automotive system provider Bosch said that, having developed its own silicon carbide chips (targeted at power electronics for electro-mobility applications, specifically EVs/HEVs), it is now manufacturing them in its Reutlingen plant, which has been producing silicon-based chips for decades (using 150mm- and 200mm-diameter wafers), complementing its new 300mm wafer fab in Dresden that it is currently outfitting — see page 10. Beginning in 2020, ASIC silicon chip production will hence migrate to Dresden, freeing up capacity in Reutlingen for production of SiC trench-type MOSFETs (the trench structure of the transistor's gate allowing better isolation and hence denser packing of more transistor cells per chip compared with conventional planar SiC MOSFETs). The SiC MOSFETs will be used internally in Bosch's products (e.g. power converters for automotive applications).

Meanwhile, at the International Conference on Silicon Carbide and Related Materials (ICSCRM) in Kyoto, Mitsubishi Electric said that it has developed a trench-type SiC MOSFET with a unique electric-field-limiting structure for a power semiconductor device that achieves record specific on-resistance (at a breakdown voltage of over 1500V) of 1.84m$\Omega$.cm$^2$ (about half that of existing planar SiC MOSFETs) — see page 12. Mitsubishi reckons that incorporating the transistor in power semiconductor modules should lead to energy savings and downsizing in power electronic equipment.

Trench-type SiC MOSFETs were first mass produced in 2015 by Kyoto-based ROHM, which has just launched 650V and 1200V trench-gate SiC MOSFETs that use 4-pin packages rather than conventional 3-pin packages (see page 13). This separates the driver and power source pins, minimizing parasitic inductance of the source terminal and hence maximizing switching speed, reducing total switching loss by up to 35% and reducing power consumption (targeting not only EVs but also high-output applications such as servers, base stations and solar power generation).

Driven by such prospects for SiC power electronics in not only automotive but also other high-growth applications, also at ICSCRM Aixtron launched its new AIX G5 WW C chemical vapor deposition (CVD) system for high-volume production of SiC epitaxial wafers (see page 24). The power electronic device market is forecasted to exceed $10bn by 2023, of which $1–2bn will be SiC devices, notes the firm. "Aixtron is backing the global trends towards green energy in the fields of electro-mobility, wind and solar energy as well as in highly efficient motor drives," it adds.

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**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.

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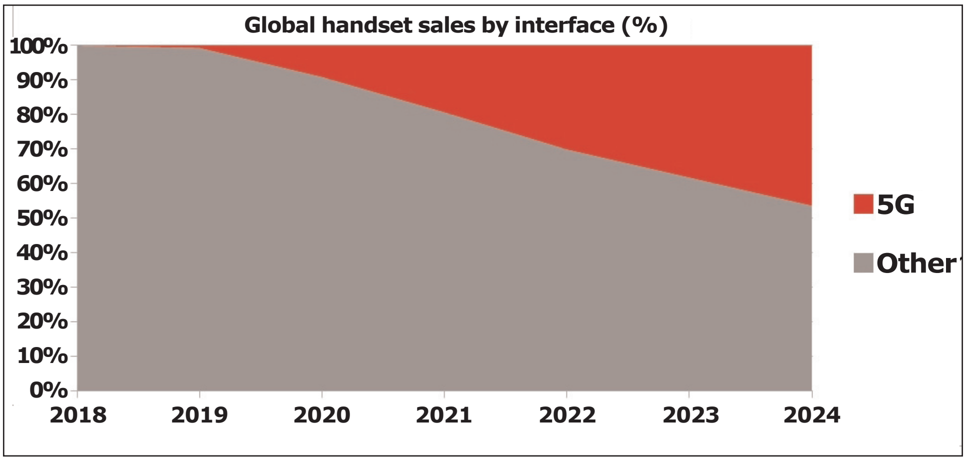
# Global 5G smartphone sales to soar in 2020, then grow rapidly to more than 1 billion by 2025

## 5G's share of total phone handset sales to grow from under 1% in 2019 to nearly 10% in 2020




After a sluggish start in 2019, 5G devices will take off in 2020, forecasts Strategy Analytics in a report 'Global Smartphone Sales Forecast by Technology for 88 Countries to 2024' from the Device Technologies (EDT) practice, which shows that, within five years, 5G phones will equal nearly half of all phones sold.

"South Korea is leading the 5G race at the moment but China intends to quickly become the global 5G leader," comments director Ken Hyers. "The ability of the industry to deliver lower-cost 5G smartphones will be critical to allow China to reach this goal next year."

"The first devices will be premium- and high-tier devices, but by the end of 2020 there will be more mid-range devices available, especially in China," reckons associate director Ville-Petteri Ukonaho.

Strategy Analytics estimates that less than 1% of phones sold in 2019 will be 5G devices, but that share will grow to nearly 10% in 2020. "Price is the main concern for early adopters," says Hyers. "Consumers do not want to spend top dollar on a device when there are few usable networks yet," he adds. "Operators must widen 5G availability significantly in order for the technology to become attractive for consumers."

The current 5G smartphone leader is Samsung. "Samsung has managed to take the lead in 5G predominantly due strong sales in South Korea, as well as by expanding its share in 5G markets like the USA," notes Ukonaho.

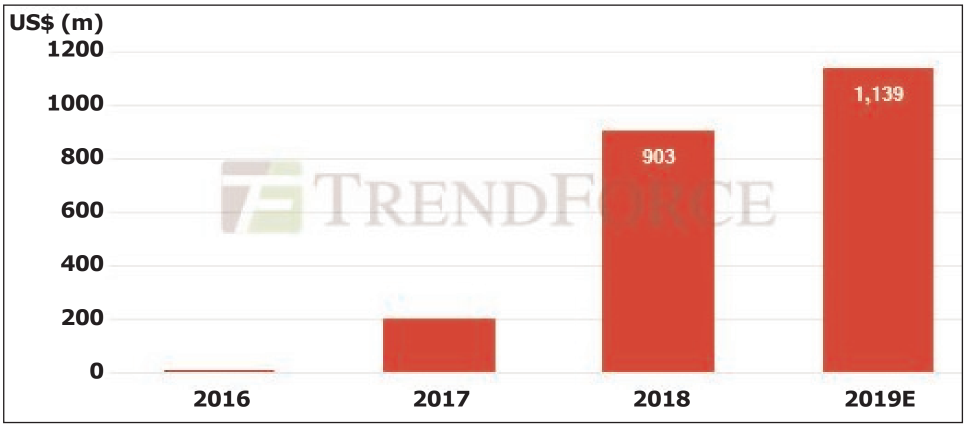
"LG, Huawei, OPPO, Vivo and Xiaomi are also among the first vendors to the market. But 2020 will be the turning point when 5G phone sales take off," says Hyers. "All major smartphone vendors including Apple are developing 5G handsets and many more devices will launch in 2020," he adds. From 2020 onwards, 5G smartphone sales will skyrocket, led by China, the USA and other developed nations in Asia and Western Europe, reckons Strategy Analytics.

"Despite a sluggish start in 2019, 5G is well positioned to take off. Growth will be rapid once prices fall and 5G network buildouts expand next year," reckons Ukonaho. "By 2025, 5G sales will exceed 1 billion."

www.strategyanalytics.com

# Cell-phone 3D sensing market enters growth stage, with VCSEL revenue reaching $1.139bn

As smartphone shipments are predicted to decline for full-year 2019, cell-phone brands are engaging in a 'specs-contest' with their flagship devices for second-half 2019, with 3D sensing modules becoming an important component in that race, according to the latest 'Infrared Sensing Application Market Trend Report' by LEDinside (a division of TrendForce). Revenue for vertical-cavity surface-emitting lasers (VCSELs) used by cell phones utilizing 3D sensing is hence projected to reach $1.139bn.




**Revenue forecast for VCSELs in cell-phone 3D sensing.**

"For 2019, besides Apple, who will be implementing 3D face recognition in its iPhones wholesale, Samsung, Huawei and Sony have also scheduled implementations of world-facing 3D sensing in flagship devices in second-half 2019," says TrendForce research manager Joanne Wu. "Near to 10 high-end phones may use 3D sensing solutions in 2020, with some devices going so far as to implement the solution on both the front- and world-facing cameras and pushing up VCSEL revenue," she adds.

### VCSEL suppliers developing world-facing TOF camera solutions

The 3D sensing solutions currently used in the consumer market are structured light and time-of-flight (TOF). Structured light acquires the image through projected light patterns, and is able to determine depth with extreme precision, although it comes with a high cost and computational complexity. Moreover, Apple holds the patent for the technology, forming a formidable patent barrier.

TOF does not enjoy the precision and depth that structured light does, but its fast reaction speeds and detection range make up for it. TOF cameras may be divided into front-facing and world-facing versions, with front-facing cameras costing more and world-facing cameras using the higher-power VCSELs. Major VCSEL-related companies currently include Lumentum, Finisar, Osram's Vixar, ams, WIN Semiconductors Corp, Advanced Wireless Semiconductor Company (AWSC), VIAVI Solutions Inc etc.

### Android Players eager to penetrate market for varied VCSEL applications

Many acquisitions and investments have taken place in the VCSEL market between 2017 and 2018, demonstrating that suppliers are optimistic towards future VCSEL demand. Since Apple adopted 3D sensing features in its iPhones wholesale in 2018, using it for face recognition and face unlock, many non-Apple companies such as Xioami, Huawei and OPPO caught on and began development. Yet there are serious bottlenecks in 3D sensing technology as well as a patent barrier, causing development by members of the Android camp to be slower than anticipated. Yet many cell phone brands still see 3D sensing as a technology with much potential.

As the 3D sensing market emerges, 3D sensing technology in future cell phones will no longer be limited to simple face recognition and face unlock applications, but extend to 3D object recognition, modeling, AR and various other features, reckons the report.

www.ledinside.com

# Qorvo acquires Cavendish Kinetics

## Team to transition RF MEMS technology into high-volume manufacturing for mobile devices and other markets

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has acquired RF MEMS antenna tuning technology provider Cavendish Kinetics Inc of San Jose, CA, USA. Qorvo has been a lead strategic investor in Cavendish Kinetics since 2015.

The Cavendish Kinetics (CK) team will continue to advance RF MEMS technology for applications across Qorvo's product lines and transition the technology into high-volume manufacturing for mobile devices and other markets.

"The addition of Cavendish Kinetics allows us to build on Qorvo's market leadership in antenna tuning," says Eric Creviston, president of Qorvo Mobile Products. "Several of the world's leading smartphone suppliers have validated significant improvements in antenna performance through lower losses and higher linearity delivered by CK's RF MEMS technology," he adds. "Qorvo will build on the great work CK has done by optimizing and scaling the technology and applying it to other applications like infrastructure and defense."

RF MEMS devices are used to tune both main and diversity smartphone antennas across low, mid and high bands, resulting in stronger signals and faster data rates. The devices maximize performance through outstanding Q-factor, improved linearity and extremely low insertion losses, offering potential for improving 4G and 5G system performance.

**www.cavendish-kinetics.com**

## Qorvo announces closing of $350m offering of senior notes

Qorvo has completed its offering of $350m worth of its senior notes (maturing in 2029). Paying interest semi-annually at a rate of 4.375%, the notes will mature on 15 October 2029, unless earlier redeemed in accordance with their terms.

The notes were issued to qualified institutional buyers (pursuant to Rule 144A under the Securities Act of 1933, as amended) and to certain non-US persons (in accordance with Regulation S under the Securities Act).

Qorvo expects to use the net proceeds of the offering for general corporate purposes.

# Altum RF expands application and sales support by opening Dallas, Texas office

Altum RF of Eindhoven, The Netherlands (a start-up that designs high-performance millimeter-wave to digital solutions for next-generation markets and applications) has opened its application support and sales office in the Telecom Corridor technology business center in Richardson, Texas (an inner-suburb of Dallas).

"Altum RF is opening its first office in Dallas to expand its application and sales support for our growing demand in the United States," says CEO Greg Baker. "This expansion reflects our focus to provide superior technical support for our global customer base."

Founded in 20018, Altum RF's engineers are employing decades of modeling expertise and system applications knowledge to develop products based on proven technologies like gallium arsenide (GaAs), gallium nitride (GaN), silicon germanium (SiGe) or RF CMOS for commercial and industrial applications.

Working with both customers and global partners on technical support and customer service, the firm says it can significantly shorten product development cycles by managing the entire supply chain from design to packaging, testing and qualification. Applications span telecom, 5G, Satcom, radar sensors, test & measurement, aerospace & defense and industrial, scientific & medical (ISM) applications.

Altum RF adds that it has strategic roadmaps to rapidly expand its product portfolio.

**www.altumrf.com**

# WIN's GaAs process optimized for integrated 5G front-ends

WIN Semiconductors Corp of Taoyuan City, Taiwan — the largest pure-play compound semiconductor wafer foundry — has combined a 100GHz $f_T$ enhancement-mode pseudomorphic high-electron-mobility transistor (pHEMT) with monolithic PIN and Schottky diodes to provide what is claimed to be best-in-class millimeter-wave (mmWave) performance for all front-end functions. The PIH1-10 platform is designed for single-chip 5G front ends operating in the 24–45GHz bands.

WIN says that the PIH1-10 technology provides a new set of integrated gallium arsenide (GaAs) solutions that improve mmWave front-end performance. High-efficiency Ka-band GaAs power amplifiers, low-noise amplifiers (LNAs) and low-loss switches on a compact single-chip front-end can enable improved battery life and better 5G mmWave coverage.

Integrated GaAs front-ends can also be used in mmWave access points, and the higher Tx power and efficiency of PIH1-10 enables smaller active antenna arrays with lower total power consumption than existing RAN (radio access network) hardware.

The core of PIH1-10 is an enhancement-mode (E-mode) pHEMT that provides the gain, power density and efficiency for mmWave transmit power amplifiers, and the noise performance needed in the receive LNA. The versatile single-supply transistor can support Tx power levels of 30dBm and an Rx noise figure of 2.5dB at mmWave frequencies. Furthermore, the integrated PIN diode provides mmWave Tx/Rx switch functionality with <1dB insertion loss, enabling monolithic integration of all front-end functions on a single chip.

"GaAs technology outperforms BiCMOS in every front-end function, and mmWave single-chip front ends realized in PIH1-10 can reduce array power consumption, simplify thermal management, and extend battery life in 5G user equipment while reducing total cost of ownership for mmWave network access points," says senior VP David Danzilio. "In addition, the higher-performance integrated GaAs front-ends provide flexible mmWave active antenna solutions to support multiple deployment scenarios," he adds.

**www.winfoundry.com/en_US/Index.aspx**

# Skyworks ramps solutions for next-generation Wi-Fi 6 applications

Skyworks Solutions Inc of Woburn, MA, USA (which makes analog and mixed-signal semiconductors) says that its advanced connectivity solutions are powering next-generation Wi-Fi 6 (802.11ax) devices from the world's leading connected home and mesh network providers, including Arris, Asus, D-Link, Netgear, Ruckus and TP-Link. Specifically, its modules are being leveraged in all of the latest Wi-Fi 6 routers named in a recent CNET article.

Wi-Fi 6 is the newest 802.11 wireless standard that is pushing the performance envelope with speeds up to 30% faster than the previous 802.11ac (Wi-Fi 5) protocol. These routers accommodate the growing number of cloud devices and users in today's connected home by optimizing overall efficiency and data throughput. Skyworks' modules facilitate this enhanced functionality with what is claimed to be best-in-class linearity and performance in the smallest footprint available.

"Faster, more reliable and efficient Wi-Fi coverage is becoming increasingly important as more and more devices and users are connected in smart homes," says Dave Stasey, VP & general manager of diversified analog solutions. "Our portfolio of high-performance solutions provides our customers with all the required functionality to deliver maximum Wi-Fi range and speeds to address the need for always-on connectivity."

According to ABI Research estimates, Wi-Fi 6 chipset shipments are expected to rise at a compounded annual growth rate (CAGR) of about 73% from about 127 million units in 2019 to nearly 2 billion units by 2024.

Skyworks says that its solutions expedite time-to-market by incorporating all the required functionality to deliver maximum performance and contain a logarithmic power detector to support wide dynamic ranges, low power consumption and improved thermal management.

Select products from Skyworks' Wi-Fi 6 portfolio include:

- SKY85006-11 — 2.4GHz high-power WLAN power amplifier (PA);
- SKY85216-11 — 2.4GHz receive front-end module (FEM) with integrated SPDT switch and low-noise amplifier (LNA);
- SKY85331-11 — 2.4GHz high-power WLAN FEM with SPDT transmit/receive switch, LNA with bypass and PA;
- SKY85333-11 — 2.4GHz high-power WLAN FEM with SPDT transmit/receive switch, LNA with bypass and PA;
- SKY85743-21 — 5GHz WLAN FEM with SPDT transmit/receive switch, LNA with bypass and PA;
- SKY85747-11 — 5GHz WLAN FEM with SPDT transmit/receive switch, LNA with bypass and PA;
- SKY85755-11 — 5GHz WLAN FEM with SPDT transmit/receive switch, LNA with bypass and PA.

**www.skyworksinc.com**

# Bosch develops silicon carbide chips, targeting power electronics for EVs/HEVs

## Cleanroom of new Dresden fab being facilitized

Germany's Bosch has developed new silicon carbide (SiC) chips, targeted at power electronics for electro-mobility applications, specifically electric vehicles and hybrid electric vehicles (EV/HEV).

Bosch is manufacturing the new generation of chips at its Reutlingen plant (25 miles south of Stuttgart), where it has been producing several million microchips every day for decades.

Compared with incumbent silicon, silicon carbide (which has higher electrical conductivity) sets new standards for switching speed, heat loss and size. In power electronics, it ensures that 50% less energy is lost in the form of heat. This translates into more efficient power electronics and more energy for the electric motor and therefore for battery range (enabling motorists to drive 6% further on a single charge).

Bosch aims to address one of the stumbling blocks for potential buyers of electric cars: nearly one in two consumers (42%) decide against buying an electric vehicle because they are afraid that the battery will run out in transit. In Germany, this anxiety is even more prevalent, affecting 69% of consumers (according to Consors Finanz Automobile Barometer 2019). Alternatively, car makers can make the battery smaller for a given range, reducing the cost of an electric vehicle's most expensive component, which in turn reduces its price.

SiC technology also offers further potential savings down the line: the much lower heat losses of the chips, combined with their ability to work at much higher operating temperatures, mean that manufacturers can cut back on the expensive cooling of the powertrain components. That has a positive impact on electric vehicles' weight and cost.

**Silicon carbide in Bosch's wafer fab in Reutlingen.**

As the only automotive supplier that also manufactures semiconductors, Bosch will be using the SiC chips in its own power electronics. "Thanks to our deep understanding of systems in e-mobility, the benefits of silicon carbide technology flow directly into the development of components and systems," says board member Harald Kroeger. "As one of the leading manufacturers of automotive semiconductors, Bosch has been exploiting this globally unique advantage for almost 50 years," he adds. In addition to power semiconductors, these include microelectromechanical systems (MEMS) and application-specific integrated circuits (ASICs).

In 2018, the value of the chips in an average car was about $370 (€337) (according to ZVEI). While this amount is growing by 1–2% annually for applications not relating to infotainment, connectivity, automation and electrification, on average an electric vehicle has additional semiconductor chips worth $450 (€410) on board. Experts predict that this will rise again by about $1000 (€910) as a result of automated driving. This makes the automotive market one of the drivers of growth in the semiconductor sector. Furthermore, key applications of the Internet of Things — such as artificial intelligence (AI), cyber security, smart cities, edge computing, smart homes, and connected industry — will drive future growth in the domain.

With its semiconductor fabs in Reutlingen and Dresden, Bosch reckons that it is well prepared for these developments: "Our semiconductor know-how helps us not only to develop new automotive functions and IoT applications but also to continuously improve the chips themselves," Kroeger says.

**Bosch strengthening its competitiveness**

In June 2018, Bosch laid the cornerstone for its new fab in Dresden. Its manufacturing operations will use 300mm-diameter wafers, yielding significantly more chips and correspondingly greater economies of scale than for 150mm and 200mm technologies. Bosch produces the latter in Reutlingen, where it will also manufacture the new SiC chips. The wafer fabs in Reutlingen and Dresden complement each other.

"We want to continuously expand our manufacturing operations," Kroeger says. In its wafer fab in Dresden, Bosch is investing about €1bn — the largest single investment in its history. Facilities are currently being installed in the cleanroom areas. The first associates are due to start work in spring 2020. Bosch will operate the plant as a carbon-neutral site.

**www.bosch.com**

# Mitsubishi Electric develops trench-type SiC MOSFET with electric-field-limiting structure

## Record specific on-resistance of 1.84mΩ.cm² for 1500V breakdown

At the International Conference on Silicon Carbide and Related Materials (ICSCRM 2019) in Kyoto, Japan (29 September – 4 October), Tokyo-based Mitsubishi Electric Corp announced that it has developed a trench-type silicon carbide (SiC) metal-oxide-semiconductor field-effect transistor (MOSFET) with a unique electric-field-limiting structure for a power semiconductor device that achieves record specific on-resistance (at a breakdown voltage of over 1500V) of 1.84mΩ.cm$^2$.

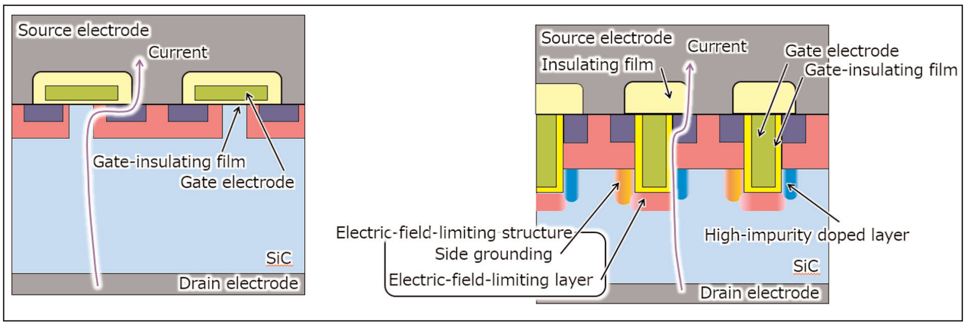



**Figure 1: Cross-sectional view of conventional planar SiC-MOSFET (left) and new trench SiC MOSFET (right).**

**Unique electric-field-limiting structure ensures reliability**

Since SiC MOSFETs control current flowing through the semiconductor layer between the drain and source electrodes by applying a voltage to the gate electrode, in order to achieve control with a small voltage a thin gate-insulating film is required. If a high voltage is applied in a trench-type power semiconductor device, a strong electric field can concentrate in the gate and can easily break the insulating film.

To correct this, Mitsubishi Electric developed a unique electric-field-limiting structure that protects the gate-insulating film by implanting aluminium and nitrogen to change the electrical properties of the semiconductor layer, taking advantage of the trench structure (Figure 1).

First, aluminium is implanted vertically and an electric-field-limiting layer is formed on the bottom surface of the trench (Figure 2). The electric field applied to the gate-insulating film is reduced to the level of a conventional planar power semiconductor device, improving reliability while maintaining breakdown voltage over 1500V.

Next, the side grounding connecting the electric-field-limiting layer and source electrode is formed (Figure 2) by using a newly developed technique to implant aluminium in an oblique direction to enable high-speed switching and reduced switching loss.

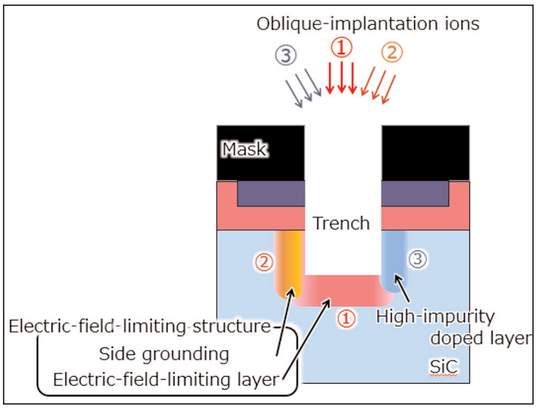



**Fig. 2 Manufacturing process for trench-type SiC MOSFET.**

**Locally formed high-impurity doped layers achieve record low on-resistance**

The trench SiC MOSFET has transistor cells that are smaller than those of planar types, allowing more cells to be arrayed on a single chip. However, if transistor intervals between the gate electrodes are too narrow then current flow becomes difficult and device resistivity increases. Since Mitsubishi Electric developed a new method for implanting nitrogen in an oblique direction to locally form a layer of SiC with a high concentration of nitrogen, this allows electricity to be conducted easily in the current path (Figure 2). As a result, even when cells are arrayed densely, resistivity can be reduced by about 25% compared with the case of no high-concentration layer.

The new manufacturing method also allows intervals of the side grounding to be optimized (Figure 3). The result is a specific on-resistance of 1.84mΩ cm$^2$ at room temperature, about half that of planar types, while maintaining a breakdown voltage of over 1500V.

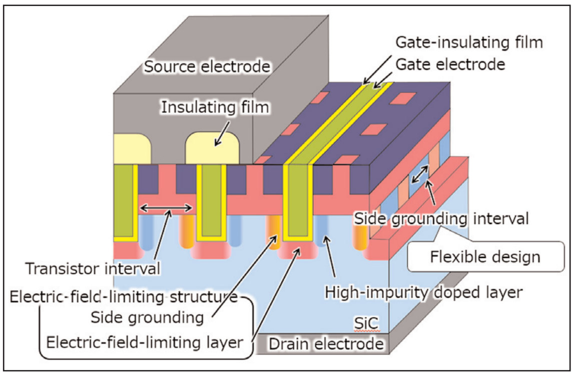



**Figure 3: Three-dimensional schematic of new trench-type SiC MOSFET.**

**Energy savings and equipment downsizing**

Mitsubishi reckons that mounting the transistor in power semiconductor modules for power electronic equipment should lead to energy savings and equipment downsizing.

After improving the performance and confirming the long-term reliability of its new power semiconductor devices, Mitsubishi expects to put its new trench-type SiC MOSFET into practical use sometime after the beginning of fiscal year 2021.

**www.MitsubishiElectric.com**

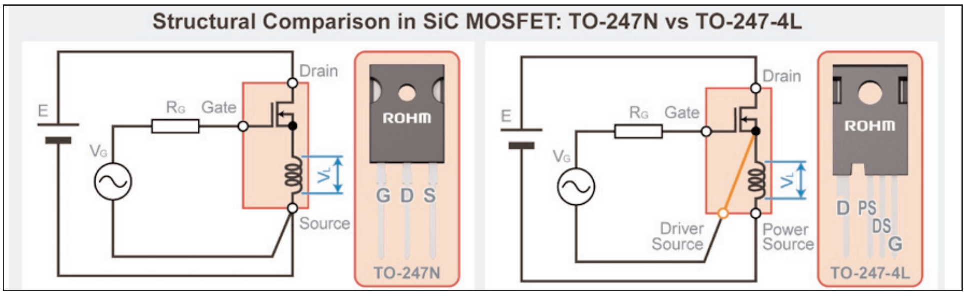
# ROHM launches 4-pin package SiC MOSFETs, cutting switching loss by up to 35%

## Switching loss reduced by up to 35% versus conventional 3-pin TO-247N packages

Power semiconductor maker ROHM of Kyoto, Japan has announced the availability of the SCT3xxx xR-series of six new trench-gate-structure SiC MOSFETs (three each with breakdown voltages of 650V and 1200V, respectively). This follows ROHM in 2015 becoming the first supplier to mass-produce trench-type SiC MOSFETs. The new devices are suitable for uninterruptible power supply (UPS) systems, solar power inverters, power storage systems, electric vehicle (EV) charging stations, and power supplies for server farms and base stations requiring high efficiency.

In recent years, the growing needs for cloud services due to the proliferation of artificial intelligence (AI) and the Internet of Things (IoT) has increased the demand for data centers worldwide, notes Rohm. But for servers used in data centers, a major challenge is how to reduce power consumption as capacity and performance increase. At the same time, SiC devices are attracting attention due to their smaller loss over mainstream silicon devices in the power conversion circuits of servers.

The SCT3xxx xR-series utilizes a 4-pin package (TO-247-4L). With conventional 3-pin packages (TO-247N), the effective gate voltage at the chip is reduced due to the voltage dropped across the parasitic inductance of the source terminal. This causes the switching speed to be reduced. Adopting the 4-pin TO-247-4L package separates the driver and power source pins, minimizing the effects of the parasitic inductance component. This makes it possible to maximize the switching speed of SiC MOSFETs, reducing total switching loss (turn ON and turn OFF) by up to 35% over conventional 3-pin TO-247N packages.



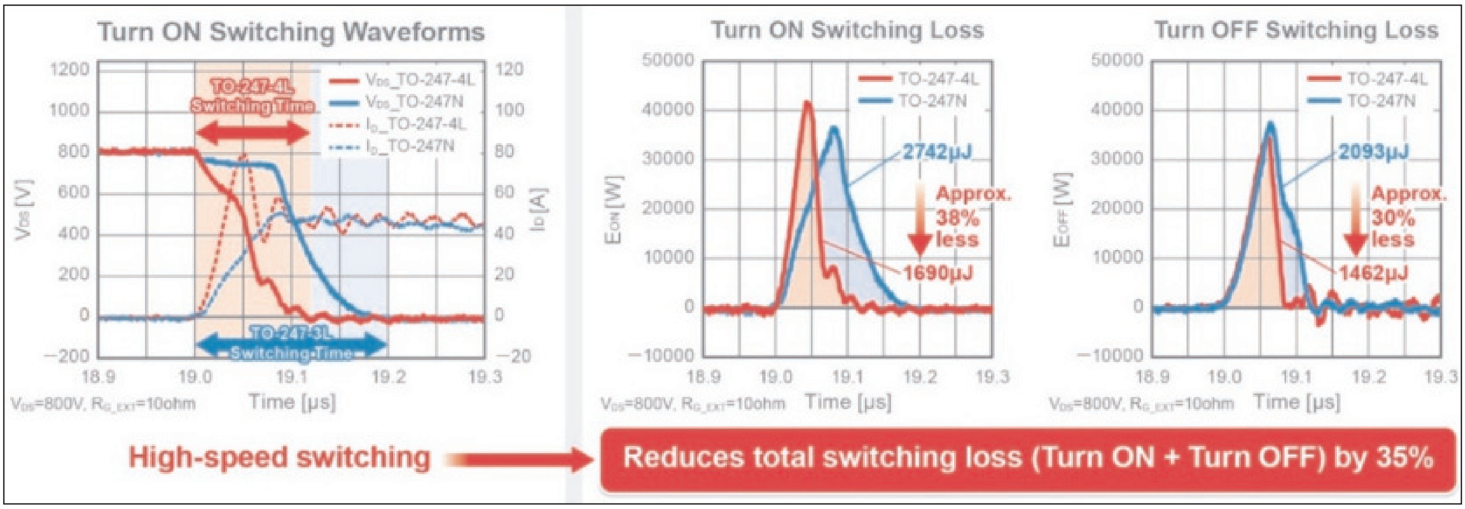

As the TO-247-4L package's reduced switching loss contributes to lower power consumption, it is expected to be adopted in high-output applications such as servers, base stations and solar power generation.

ROHM says that, in addition to these newest 650V/1200V high-efficiency SiC MOSFETs, it is committed to developing devices and proposing solutions that contribute to lower power consumption in a variety of devices, including gate driver ICs optimized for SiC drive.

**Evaluation board**

ROHM also proposes solutions that facilitate application evaluation, including the P02SCT3040KR-EVK-001 SiC MOSFET evaluation board, equipped with ROHM's BM6101FV-C gate driver ICs along with multiple power supply ICs (optimized for driving SiC devices) and additional discrete components that facilitate application evaluation and development. Compatibility with both TO-247-4L and TO-247N package types enables evaluation of both packages under the same conditions. The board can be used for double pulse testing as well as the evaluation of components in boost circuits, 2-level inverters and synchronous rectification buck circuits.

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



# II–VI unveils first 200mm semi-insulating SiC substrates for RF power amplifiers in 5G antennas

Engineered materials and optoelectronic component maker II–VI Inc of Saxonburg, PA, USA, which provides silicon carbide (SiC) substrates for power electronics, has introduced what it says are the first prototype 200mm-diameter semi-insulating silicon carbide substrates for RF power amplifiers in 5G wireless base-station antennas and other high-performance RF applications.

The deployment of 5G wireless is expected to accelerate globally, driving demand for RF power amplifiers that can operate efficiently in new high-frequency bands and be manufactured on a technology platform that can scale to meet the demand. Compared with devices based on silicon, gallium nitride-on-silicon carbide (GaN-on-SiC) RF power amplifiers have superior performance over a wide spectrum of 5G operating frequencies in the gigahertz range, including in the millimeter-wave bands. II–VI's prototype 200mm semi-insulating SiC substrates are aimed at enabling GaN-on-SiC RF power amplifiers, currently produced on 100mm and 150mm substrates, to reach the next level in manufacturing scale.

"II–VI is introducing the world's first 200mm semi-insulating SiC substrates after introducing in 2015 the world's first 200mm conductive SiC substrates for power electronics, two milestones on our roadmap to 300mm," says Dr Gary Ruland, vice president of the Wide Bandgap Semiconductors business unit. "In areas of high bandwidth demand, 5G antennas with beam-forming technology are expected to be densely deployed, increasing the demand for GaN-on-SiC power amplifiers by approximately an order of magnitude or more."

II-VI says that it has a technology portfolio of 30 active SiC substrate patents using highly differentiated and proprietary manufacturing platforms and technologies including crystal growth, substrate fabrication, and polishing. The evolution of semi-insulating SiC substrates to 200mm should enable the RF power amplifier market to continue to scale, increasingly replace functions performed by devices based on silicon, and enable new applications, it is reckoned.

**www.iiviadvmat.com**

# Pre-Switch's two-stage soft-switching IGBT and SiC gate drive architecture slashes solar inverter costs

Pre-Switch Inc of Campbell, CA, USA, a start-up that is delivering soft switching for DC/AC and AC/DC power conversion, says that its soft-switching insulated-gate bipolar transistor (IGBT) and SiC gate driver architecture, including the Pre-Drive3 controller board — powered by the Pre-Flex field-programmable gate array (FPGA) — and the resonant power gate (RPG) driver board, can significantly reduce the cost of solar inverters. The two-stage architecture is claimed to deliver the same switching loss performance — or better — as a five-level design, resulting in reduced cost, control complexity and BOM count. Also, Pre-Switch enables the simplification and size reduction of inverters and filters used in renewable energy systems, enabling energy to be put back into the grid easily and efficiently.


The Pre-Switch soft-switching platform enables a doubling of power output for a typical inverter, or an increase in switching speed by up to 20-fold, it is reckoned. Previously, soft-switching has never been successfully-implemented for DC/AC systems with varying input voltage, temperature and load conditions. However, Pre-Switch says that it has overcome the challenges by using artificial intelligence (AI) to constantly adjust the relative timing of elements within the switching system required to force a resonance to offset the current and voltage wave forms, minimizing switching losses.

"Our benefit for solar energy system designers is that our soft-switching architecture eliminates half of the system losses. So we are able to achieve performance levels with a simple two-stage design that would require five stages using conventional multi-level techniques," says CEO Bruce T. Renouard. "The architecture also allows the grid tie filter size to be reduced by up to 66.67% for IGBT systems and by up to 80% for SiC MOSFETs. That is a huge advantage, not only in system size but also materials and shipping cost savings."

**www.pre-switch.com**

# Aehr wins order from new customer for FOX-XP system for high-volume SiC device production test & burn-in

Aehr Test Systems of Fremont, CA, USA has received an initial order (worth over $3m) from a new customer for its FOX-XP wafer-level test and burn-in system and WaferPak contactors for production test and burn-in of a line of silicon carbide (SiC) devices. The FOX-XP system is configured to test 100% of the devices on 18 silicon carbide wafers in parallel. The new customer is a "leading supplier of semiconductor devices with a significant customer base in the automotive semiconductor market". The order is expected to ship in Aehr's next fiscal quarter.

"This new customer, a Fortune 500 semiconductor supplier company, has selected the unique high-voltage and high-power capabilities of our FOX-XP system to enable wafer-level production test and burn-in of their silicon carbide devices," says president & CEO Gayn Erickson. "Our customers are able to save significant costs by burning-in entire wafers at a time versus the high costs associated with burning-in modules. Also, there are significant cost savings as a result of detecting burn-in yield losses at wafer level compared to yield losses detected at the more expensive module level," he states.

"The higher defect density inherent in today's silicon carbide devices presents an additional test and burn-in challenge to achieve the initial quality and long-term reliability needed by many industries and, in particular, the automotive market," Erickson says. "This is a new and very exciting market opportunity for Aehr and our FOX-P family of products as our wafer-level test and burn-in systems are optimal for reliability qualification in the emerging silicon carbide device market that is expected to grow significantly."

**The automotive sector is a new and very exciting market opportunity for Aehr**

According to research reported by HiTech News in July, the advantages of silicon carbide based compound semiconductors over silicon-based technology, the rise in demand of power electronics modules across various industry verticals, the increase in installation of solar photovoltaic panels for electricity generation, and the surge in demand of electric vehicles, plug-in electric vehicles, and hybrid electric vehicles are the major factors driving growth in the global silicon carbide power semiconductor market.

Future demand will be substantially driven by SiC power semiconductor applications in aerospace, automotive, energy and electronics (requiring a very high level of quality and reliability), forecasts a 'Silicon Carbide Market Size, Share & Trend' analysis published in July by Grand View Research.

The FOX-XP system is Aehr's next-generation multi-wafer and singulated die/module test solution that is capable of functional test and burn-in/cycling of integrated photonics devices, flash memories, microcontrollers, sensors, power, and other leading-edge ICs in wafer form before they are assembled into single or heterogenous stacked packages. The system is designed for high-volume production and can be configured to test and burn in up to 18 wafers simultaneously. The resulting known-good die (KGD) can then be used for high-quality and reliability applications such as enterprise solid-state drives, automotive devices, highly valuable mobile applications, and mission-critical ICs and sensors.

**www.aehr.com**

# WIN offers sample kits for NP15-00 GaN-on-SiC 0.15μm-gate technology

WIN Semiconductors Corp of Taoyuan City, Taiwan — the largest pure-play compound semiconductor wafer foundry — has developed sample kits for its gallium nitride (GaN)-based 0.15μm-gate technology. The NP15-00 millimeter-wave (mmWave) compound semiconductor technology is suitable for transmit power amplifiers used in 5G mmWave radio access networks, satellite communications and radar systems.

Supporting full monolithic microwave integrated circuits (MMICs), the NP15-00 platform allows customers to develop compact, linear or saturated high-power amplifiers up to 35GHz. In the 29GHz band, NP15-00 technology offers saturated output power of 3W/mm with 13dB linear gain and greater than 50% efficiency without harmonic tuning.

For mmWave active arrays, the higher transmit power and efficiency from the NP15-00 platform affords designers greater flexibility to optimize antenna count, power amplifier size and total array power. Depending on the application, mmWave radio access network (RAN) infrastructure will leverage access points of various sizes, shapes and power levels, and a broad trade-space is crucial to optimize the performance and economics of mmWave active antenna systems, says WIN.

The NP15-00 gallium nitride technology employs a source-coupled field plate for improved breakdown voltage, and operates at a drain bias of 20V. This technology is fabricated on 100mm silicon carbide substrates with through-wafer vias for low inductance grounding.

WIN celebrated its 20th anniversary and showcased its compound semiconductor RF and mm-Wave solutions at European Microwave Week (EuMW 2019) in Paris, France (29 September – 4 October).

**www.winfoundry.com**

# Navitas' GaNFast power ICs enable 300W adapter in NVIDIA's ACE reference design for world's fastest laptop

Navitas Semiconductor Inc of El Segundo, CA, USA says that its power technology is enabling the highest-density power adapter for the world's fastest laptop — the Asus ProArt StudioBook One. An NVIDIA RTX Studio system, the ProArt One is the first laptop to feature the NVIDIA Quadro RTX 6000 GPU and is based on NVIDIA's ACE reference architecture.

Founded in 2014, Navitas introduced what it claimed to be the first commercial GaN power ICs. The firm says that its proprietary 'AllGaN' process design kit (PDK) monolithically integrates GaN power field-effect transistors (FETs) with GaN logic and analog circuits, enabling faster charging, higher power density and greater energy savings for mobile, consumer, enterprise, eMobility and new energy markets.

Developed in collaboration with NVIDIA, the new 300W AC–DC adapter design exploits the high-speed power-conversion technology of Navitas' GaNFast power ICs to create a powerful yet lightweight and small-size mobile charger.


"Creatives and other professionals demand the highest computing performance with extreme mobility," says Navitas' CEO Gene Sheridan. "Navitas' dedicated technologists worked alongside the NVIDIA engineering design team to address this challenge as part of the NVIDIA ACE reference design, delivering a 300W laptop adapter in half the size of traditional adapters," he adds.

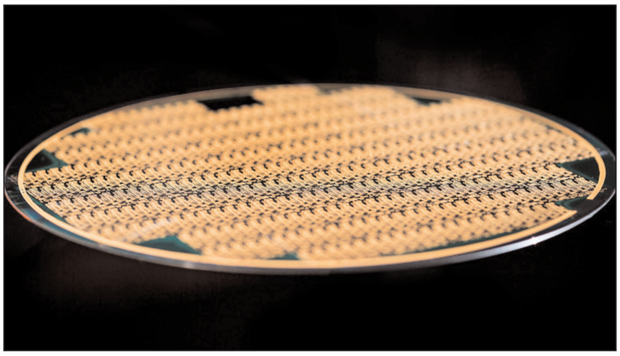
"The high-speed performance of the Navitas GaNFast power ICs is a perfect match for the high-speed NVIDIA Quadro RTX 6000 GPU in the ProArt StudioBook One," comments NVIDIA's director of engineering Gabriele Gorla. The result is a laptop with 16.3 TFLOPs of compute performance powered by a mobile adapter that fits in the palm of your hand.

The power adapter uses highly integrated, speed-optimized, next-generation GaN technology that replaces traditional, slow discrete silicon components, and enables the adapter to utilize high-frequency, soft-switching techniques in both power factor correction (PFC) and downstream DC–DC stages. High-frequency, high-efficiency switching shrinks the size, weight and cost of passive components and heatsinks. Navitas says that its GaNFast power ICs enable a new generation of fast-charging mobile adapters for smartphones, tablets and laptops from 27W to 300W+.

**www.navitassemi.com**

# BAE Systems completes Phase 1 of transitioning USAF's short-gate GaN technology to Advanced Microwave Products Center

## AFRL-sponsored Phase 2 to scale 140nm GaN MMICs to 6" wafers and validate for open foundry service



BAE Systems has completed a Phase 1 effort to transition short-gate gallium nitride (GaN) technology developed by the US Air Force to its Advanced Microwave Products (AMP) Center in Nashua, NH, USA. It has also been selected by the Air Force Research Laboratory (AFRL) for Phase 2 of the program.

The GaN technology provides high efficiency and broad-frequency bandwidth capabilities in a compact form that can be integrated into a variety of systems to enable next-generation radar, electronic warfare (EW) and communications.

As part of Phase 2, the BAE Systems FAST Labs R&D team and the AMP Center will collaborate to further develop and advance the readiness of the technology. Specifically, the project will scale the 140nm GaN monolithic microwave integrated circuit (MMIC) technology to 6-inch wafers and increase its manufacturing level of maturity as part of the validation process, which will include optimizing performance, ensuring process stability, and maximizing wafer-to-wafer uniformity and wafer yields. Custom MMIC design company ENGIN-IC will support the design activities, including process design kit (PDK) validation. This technology will transition to a foundry service product, available through BAE Systems' open foundry service, at the end of Phase 2, where the technology can be leveraged more broadly across different government initiatives.

**The FAST Labs R&D team and the AMP Center will collaborate to further develop and advance the readiness of the technology**

"Our foundry is a trusted partner to the defense community because it is dedicated to the design, creation and implementation of vital technologies such as short-gate GaN," says Chris Rappa, product line director for Radio Frequency, Electronic Warfare, and Advanced Electronics at BAE Systems FAST Labs. "GaN technology fills a unique need for the Department of Defense for low-cost, high-performance amplifier technology, and Phase 2 of this effort brings us one step closer to successfully manufacturing and bringing AFRL's technology to market," he adds.

BAE Systems is researching and developing microelectronic technologies, including GaN, in its 70,000ft$^2$ Microelectronics Center (MEC) in Nashua, NH. The MEC has been an accredited DoD Category 1A Trusted Supplier since 2008, and fabricates integrated circuits in production quantities for critical DoD programs.

**www.baesystems.com**

# EPC expands AEC Q101 product family with automotive qualification of EPC2216 15V eGaN FET for ToF LiDAR

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA — which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications — has announced AEC Q101 automotive qualification of the 15V EPC2216 designed for light detection and ranging (LiDAR) applications where increased accuracy is vital such as in self-driving cars and other time-of-flight (ToF) applications including facial recognition, warehouse automation, drones and mapping.

As an 15V, 26mΩ eGaN FET with a 28A pulsed current rating in a 1.02mm$^2$ footprint, the EPC2216 is suitable use in for firing the lasers in LiDAR systems because the FET can be triggered to create high-current with extremely short pulse widths. The short pulse width leads to higher resolution, and the small size and low cost make eGaN FETs suitable for time-of-flight applications from automotive to industrial, healthcare to smart advertising, gaming and security.


To complete testing for AEC Q101 automotive qualification, EPC's enhancement-mode field-effect transistors underwent environmental and bias-stress testing, including: humidity testing with bias (H3TRB), high-temperature reverse bias (HTRB), high-temperature gate bias (HTGB), temperature cycling (TC), as well as several other tests.

EPC says that its wafer-level chip-scale (WLCS) packaging passed all the same testing standards created for conventional packaged parts, demonstrating that the performance of chip-scale packaging does not compromise ruggedness or reliability. The eGaN devices are produced in facilities certified to the Automotive Quality Management System standard IATF 16949.

"This new automotive product joins a rapidly expanding family of EPC transistors and integrated circuits designed to enable autonomous driving and improve resolution and reduce cost in all time-of-flight applications," says CEO & co-founder Alex Lidow.

The EPC2216 eGaN FET is priced at 2.5Ku/reel at $0.532 each and is available from distributor Digi-Key Corp.

**www.epc-co.com**
**www.digikey.com/en/supplier-centers/e/epc**

## EPC launches third edition of GaN textbook with power conversion applications focus

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA — which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications — has announced publication of the third edition of 'GaN Transistors for Efficient Power Conversion', a textbook written by power conversion industry experts and published by John Wiley and Sons (available at amazon.com).

The textbook is designed to provide power system design engineering students, as well as practicing engineers, basic technical and application-focused information on how to design more efficient power conversion systems using gallium nitride-based transistors.

The third edition has been substantially expanded to keep students and practicing power conversion engineers ahead of the learning curve in GaN technology advancements and emerging applications. The book serves as a practical guide for understanding basic GaN transistor construction, characteristics, and a wide range of applications. Included are:

- discussions on the fundamental physics of these power semiconductors;
- practical guidance on layout and other circuit design considerations;
- application examples employing GaN including LiDAR for autonomous vehicles, DC–DC power conversion, RF envelope tracking used in 5G communication networks, wireless power, class-D audio and high-radiation environments.

The book offers "a comprehensive view, from device physics, characteristics and modeling to device and circuit layout considerations and gate drive design, with design considerations for both hard switching and soft switching," comments Dr Fred C. Lee, director of the Center for Power Electronics Systems at Virginia Tech. "Additionally, it further illustrates the utilization of GaN in a wide range of emerging applications."

All four authors have doctorates in scientific disciplines and are widely recognized published authors. They are pioneers in the emerging GaN transistor technology, with Dr Alex Lidow concentrating on transistor process design and Drs Michael DeRooij, Johan Strydom, David Reusch and John Glaser focusing on power transistor applications.

# Odyssey acquires fab to allow small-scale production over 10,000 wafers/year

## Facility to speed development of >1000V GaN power-switching transistor technology

Odyssey Semiconductor Technologies Inc, which is developing high-voltage power switching components and systems based on proprietary gallium nitride (GaN) processing technology, has completed the acquisition of an integrated semiconductor design, fabrication, test and packaging facility (as well as associated tooling) in Ithaca, NY, USA.

Complete with a mix of class 1000 and class 10,000 cleanroom space as well as tools for semiconductor development and production, the 10,000ft$^2$ facility is suitable for compound semiconductor device development and small-scale production with a wafer capacity exceeding 10,000 wafers/year.

Lithography capabilities include i-line steppers adapted for handling small pieces up through 200mm-diameter wafers. High-throughput metal and dielectric deposition equipment and advanced etch and packaging tools should allow Odyssey to accelerate development of its proprietary >1000V GaN power-switching transistor technology. The facility will also expand Odyssey's existing device development and foundry service.

Odyssey has been developing its proprietary vertical-conduction GaN transistor technology at various user-facility labs. The firm reckons that, with the new facility, it can significantly accelerate the development of its GaN power-switching transistor products operating above 1000V.

"This acquisition dramatically improves our ability to design and manufacture our proprietary disruptive GaN-based high-voltage switching power-conversion devices and systems and should accelerate our timeline into

prototype and commercial production," says co-founder & CEO Dr Rick Brown.

Odyssey is currently developing its technology to produce GaN-based high-voltage switching power-conversion devices and systems, targeted at supplanting silicon carbide (SiC) as the dominant premium power-switching device material.

GaN-based systems outperform silicon- and SiC-based systems due to GaN's superior material properties. To date, processing challenges have limited GaN devices to operating voltages below 1000V. Odyssey says that it has developed a novel technique that will allow GaN to be processed in a manner that, for the first time, will make production of high-voltage GaN power-switching devices operating above 1000V viable.

Currently dominated by silicon carbide, the premium power switching device market (i.e. applications where silicon systems perform insufficiently) is projected to exceed $3.5bn by 2025, driven largely by the rapid adoption of electric vehicles (EV) and hybrid electric vehicles (HEV) and the growing number of installations of renewables such as solar and wind power as well as increased demand for more efficient industrial motor drives.

www.odysseysemi.com

# IQE acquires 100% of Singapore joint venture CSDC

## Under-utilization-driven losses to be addressed by targeting emerging opportunities in localization of Asian supply chain for China 5G market

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has announced the acquisition of third-party shareholdings in its Compound Semiconductor Development Centre (CSDC) joint venture in Singapore, taking its ownership to 100%.

CSDC was formed in March 2015 as a joint venture between IQE's Singapore-based subsidiary MBE Technology Pte Ltd (51%), WIN Semiconductors Corp (25%), Nanyang Technological University (18%) and individuals at NanYang University (6%). It was established as a vehicle for the development and commercialization of compound semiconductor technologies for academic and industrial customers based on molecular beam epitaxy (MBE) technologies in Asia.

Since CSDC's formation, the geo-political landscape has changed significantly, notes IQE. During 2019 in particular, the localization of Asian technology supply chains is rapidly becoming evident and significant opportunities are emerging for the China 5G market.

By taking 100% control of CSDC, IQE reckons that it is best placed to:

- take the necessary steps to restructure the operation, which is currently loss-making as a result of under-utilization of assets and property lease obligations; and
- pursue Asian market sales opportunities for MBE-based products to return the operation to profitability.

Revenue recognised by IQE and its Singaporean subsidiary will be unaffected by the transaction. It is anticipated that post-acquisition adjusted EBITDA and adjusted operating profit in the consolidated group accounts for fiscal year 2019 will be adversely affected by about £0.5m.

**The geo-political landscape has changed significantly... During 2019 in particular, the localization of Asian technology supply chains is rapidly becoming evident and significant opportunities are emerging for the China 5G market. IQE reckons it is best placed to pursue Asian market sales opportunities for MBE-based products to return the operation to profitability**

The acquisition is for a nominal fee of US$1 to WIN Semiconductors and SGD$1 to each of the other third-party shareholders, to be settled in cash. The non-cash balance sheet impacts will be finalized as part of the completion of acquisition accounting for the shareholdings.

For the year ended 31 December 2018, CSDC recorded net losses of SGD$8.9m. The net liabilities attributable to CSDC as of end-December 2018 were SGD$15.4m.

IQE's CEO Drew Nelson will remain as a director of CSDC and MBE Technology's general manager LG Yeap will become a director of CSDC.

Having consulted with Peel Hunt LLP in its capacity as the firm's nominated adviser for the purposes of the AIM Rules, IQE's directors consider the terms of the transaction to be fair and reasonable as far as the firm's shareholders are concerned.

"In the current geopolitical context, Singapore represents a strategically significant site for IQE," comments Nelson. "The capabilities of the CSDC team and skills availability in that location, coupled with proximity to Asian chip customers and OEMs, provide a strong opportunity to contribute to IQE's global growth opportunities," he adds. "With 100% control, IQE will be best positioned to address the current financial position and secure the strategic direction of the operation."

**www.iqep.com**

## IQE qualified for VCSEL epiwafers by Asian OEM

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has announced the successful device and module qualification for vertical-cavity surface-emitting laser (VCSEL) epiwafers for a major Asian OEM. The firm reckons that this represents an important development in the adoption of 3D sensing technology by Android smartphones, with production volumes anticipated to commence in 2020.

VCSELs are key components in multiple existing and future 3D sensor systems, using both structured light and time-of-flight (ToF) technologies. Applications range from 3D facial identification (front facing) systems and world-facing cameras on mobile handsets to light detection and ranging (LiDAR) and in-cabin sensing for autonomous drive vehicles.

Production volumes are expected to ramp strongly over the next few years as adoption across multiple mobile platforms and other use cases proliferate. IQE says that, in anticipation of this strong growth, over the last two years it has invested in building the world's largest VCSEL epiwafer facility in Newport, UK (IQE's 'mega epi foundry').

**www.iqep.com**

# AXT reduces Q3 revenue guidance from $24.5–26m to $19.6–20m

## Cut attributed to weaker demand for data-center connectivity and LED applications and low raw materials revenue

AXT Inc of Fremont, CA, USA — which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials — has reduced its guidance for third-quarter 2019 revenue from $24.5–26m (given on 24 July) to $19.6–20m (down from $24.8m in Q2/2019 and $28.6m in Q3/2018). The cut is attributed to a weaker-than-expected demand environment (particularly in data-center connectivity and LED applications) as well as lower-than-forecasted raw materials revenue.

"Coming into Q3, we saw early signs of an improvement in the demand environment, as projected by our customers. But the orders did not materialize during the quarter," says CEO Morris Young. "While we do believe that all of our key markets are positioned for a return to growth, visibility is poor. The ongoing geopolitical and global economic environment has created near-term uncertainty in terms of the timing of the recovery," he adds.

"Despite the disappointing shortfall in the third quarter, we remain confident about the many trends that are expected to drive growth in our business, such as the ongoing build-out of passive optical networks (PONs), hyperscale data-center upgrade, 5G telecommunications, LED lighting for an array of applications, as well as a number of emerging opportunities in healthcare monitoring, VCSELs [vertical-cavity surface-emitting lasers], and more," Young continues.

"As we navigate a difficult near-term demand environment, we remain highly focused on the successful completion of the relocation of our manufacturing facilities in China, and on strengthening our business and driving greater efficiencies in our model."

**www.axt.com**





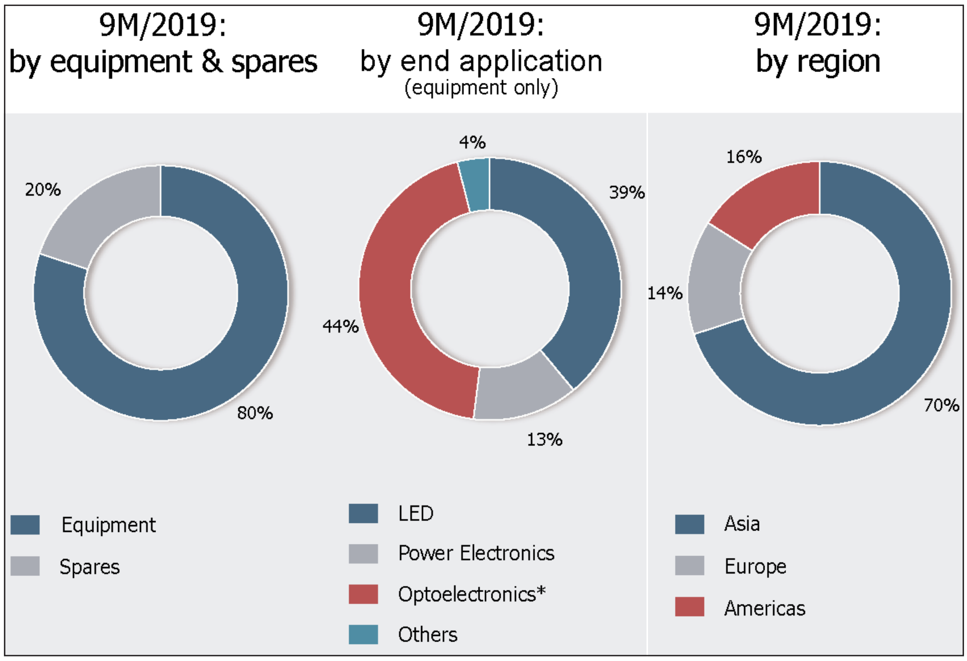
# Aixtron year-to-date revenue grows despite export license delays hitting Q3

## Orders rebound by 17% in Q3; further increase expected in Q4

For third-quarter 2019, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €52.6m, down 17% on €63.3m last quarter and €63.4m a year ago, due partly to longer-than-expected processes involved with obtaining export licenses for some of customers.

Nevertheless, sales for the first 9 months were up 2% year-on-year, from €180.9m to €184.6m. Of this, equipment rose from €145.4m to €148.1m (remaining 80% of total revenue), while spare parts & services rose from €35.5m to €36.5m.

On a regional basis, revenue from Asia rose year-on-year by 42% from €90.9m to €128.8m (rebounding from just 50% to 70% of total revenue), while Europe fell by 53% from €54.2m to €25.6m (going from 30% to 14% of total revenue) and the Americas fell by 16% from €35.8m to €30.2m (going from 20% to 16% of total revenue).




Of equipment revenue, metal-organic chemical vapor deposition (MOCVD) systems for 'Optoelectronics' (consumer optoelectronics, telecom/datacom and solar) contributed 44%, systems for 'LEDs' 39%, and systems for 'Power Electronics' 13%.

Gross margin for the first nine months fell year-on-year from 43% to 40% due to a change in the product mix. However, despite still being down from 44% a year ago, quarterly gross margin recovered slightly from 41% in Q2 to 42% in Q3/2019. This was despite the effect of the low level of sales in relation to fixed costs, because of the continuing strong dollar, a good sales mix with a lower proportion of shipments into the display market, and continuing cost improvements.

Operating expenses for the first nine months have been cut by 13% year-on-year, from €57.6m to €50.2m (including €16.7m in Q3), due mainly to other operating income rising to €5m (driven largely by higher R&D grants received of €2.2m, counteracting R&D spending rising from €12.5m in Q2 to €14.7m in Q3). "The further reduction in costs as well as the still advantageous USD/€ exchange rate are helping us to achieve our targets," says president Dr Bernd Schulte.

Despite operating result (EBIT) falling from €9.3m (15% of revenue) in Q2 to €5.5m (10% of revenue) in Q3, EBIT for the first 9 months improved year-on-year by 18% from €20.7m (11% of revenue) to €24.5m (13% of revenue), due mainly to the business and cost developments.

Quarterly net profit has fallen further, from €11.7m a year ago and €7.3m (12% of revenue) in Q2 to €4.4m (8% of revenue) in Q3. Net profit for the first nine months fell year-on-year from €27.7m (15% of revenue) to €20.2m (11% of revenue), although the prior-year period was positively impacted by the recognition of deferred tax assets of €9m.

Despite operating cash flow falling further, from €13.9m a year ago and €13.6m in Q2 to €4.9m in Q2, operating cash flow for the first nine months rose year-on-year from €5.4m to €6.5m.

Capital expenditure (CapEx) has risen from €1m in Q2 to €2.6m in Q3, taking CapEx in the first nine months of 2019 to €9.2m (up year-on-year from €6.8m).

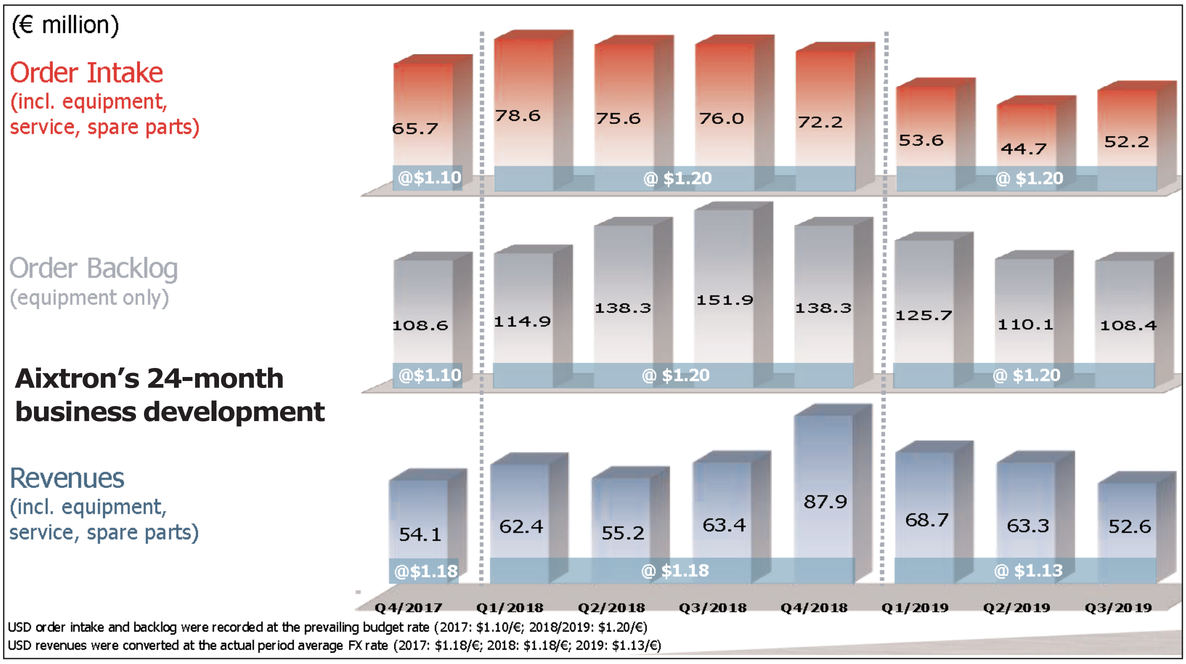
Free cash flow in the first nine months hence worsened year on year from −€1.4m to −€2.7m, due mainly to the increased working capital (including investment in beta tools) as well as the growth of inventories, and reflecting the current order situation. Quarterly free cash flow also fell from €12.6m in Q2 to €2.3m in Q3.

Cash and deposits hence rose during Q3 from €258.9m to €260.6m, although this is still slightly below the €263.7m at the end of 2018.

Order intake (including spare parts and service) in the first 9 months fell 35% year-on-year, from €230.3m to €150.6m as a result of the reluctance of customers to invest in capacity expansion. However, orders recovered in Q3 to €52.2m, up 17% on the trough of €44.7m in Q2, due mainly to demand for datacom lasers plus silicon carbide (SiC) and gallium nitride (GaN) power electronics.

So, despite being down 29% on €151.9m a year ago, equipment order backlog of €108.4m is down just 2% on €110.1m at the end of Q2.

"Increased order intake in the third quarter makes us optimistic that we will achieve our targets for the current fiscal year," says Schulte. Despite low visibility, growth in both revenue and order intake are expected in Q4/2019. Based on customer agreed shipment schedules and despite the issues with the export license, Aixtron expects Q4 revenue to increase to the highest level for 2019. "In Q4, assuming no further export delays, we expect to meet our guidance of a positive free cash flow of around €15m," notes VP of finance & administration Charles Russell.




The market developments of an increasing use of lasers for optical data transmission and 3D sensor technology, a progressive expansion of the 5G network and an increasing use of energy-efficient power electronics remain positive and are reflected in ongoing customer discussions, says Aixtron.

"We continue to assess the medium- and long-term prospects for our core markets in optoelectronics and power electronics as positive," comments president Dr Felix Grawert. "As the market and technology leader in optoelectronics, we are in an excellent position both in laser and special LED applications as well as in power electronics," he believes.

As part of the review of its technology and product portfolio, at the end of September Aixtron officially unveiled its new fully automated AIX G5 WW C silicon carbide epiwafer production system. "We have received positive customer feedback and initial orders in recent months," notes Grawert.

In addition, Aixtron's organic light-emitting diode (OLED) subsidiary APEVA is working with customers to prove the performance of the organic vapor phase deposition (OVPD) technology. "Our Gen2 OLED system is being operated in a pilot production line at our customer's plant jointly by engineers from our customer and our subsidiary APEVA in a pilot-production line," says Grawert. "Intensive efforts are being made to optimize the system as well as the process parameters for manufacturing OLEDs using the OVPD process. This is expected to confirm the performance of the OVPD technology in the coming months and create the data required for the customer's decision to place a follow-up order for a further OVPD tool — even if we do not expect this in the current fiscal year."

Based on the revenue of €185m in the first nine months of 2019, assessment of the development of demand in the current market environment (including estimated Q4 spares & service revenue of about €11m and 2019-shippable order backlog of about €64m) and the budget exchange rate of 1.20$/€, for full-year 2019 Aixtron now targets the bottom of its previous guidance ranges for revenue (€260–290m), orders (€220–260m) and free cash flow (€15–25m). "Due to the uncertain timing of granting the export license as well as the potential OLED order and respective revenues having been shifted into next year, we have set our expectation on orders and revenues and, as a consequence of that also on the free cash flow, to the low end of the respective original ranges," explains Schulte.

However, due to cost control and the strength of the US dollar, Aixtron still expects gross margin of about 40% and EBIT margin of 13% of revenue (both at the top end of the originally guided ranges).

This forecast accounts for the longer-than-expected review processes for granting export licences as well as the follow-up OLED order no longer being expected in 2019. Expectations fully include the results of Aixtron's APEVA subsidiary, including all necessary investments to continue the development of OLED activities.

"Developments in Aixtron's markets are positive," concludes the firm. "In particular, the increasing use of lasers in optical data transmission and 3D sensor technology, the expansion of the 5G network and the increasing use of energy-efficient power electronics are expected to lead to further growth in the corresponding target markets."

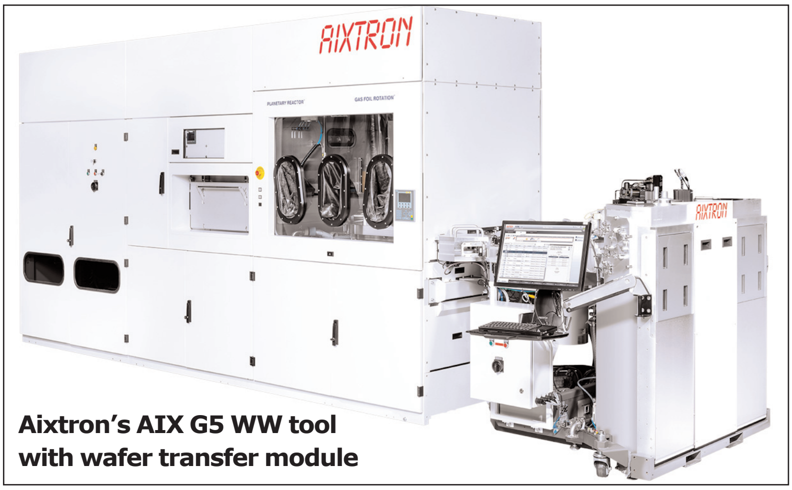
**www.aixtron.com**

# Aixtron presents next-generation AIX G5 WW C silicon carbide epiwafer production system

## Fully automated Planetary Platform enables high-volume manufacturing of SiC power electronics

At the International Conference on Silicon Carbide and Related Materials (ICSCRM 2019) in Kyoto, Japan (29 September – 4 October), deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has presented its new AIX G5 WW C system for the high-volume production of next-generation silicon carbide (SiC) epitaxial wafers. Aixtron says it has already obtained orders from several customers, while multiple performance demonstrations to additional customers have been addressed successfully.

"We expect the demand for SiC power electronics to grow rapidly in the coming years. By 2023, the market for power electronic devices is forecasted to have a volume of approximately US$10bn+, of which US$1–2bn will be made of highly efficient SiC devices," says president Dr Felix Grawert. "Our cost-efficient epi deposition tool supports SiC device makers in the race for gaining share from silicon-based power electronic devices," he adds. "With this, Aixtron is backing the global trends towards green energy in the fields of electro-mobility, wind and solar energy as well as in highly efficient motor drives."



**Aixtron's AIX G5 WW tool with wafer transfer module**

Based on Aixtron's proven Planetary Reactor platform and equipped with a cassette-to-cassette (C2C) wafer handling system, the fully automated AIX G5 WW C provides what is claimed to be the largest batch capacity and highest throughput in the industry. Initially offering an 8x6-inch configuration with single-wafer control, the system addresses the cost challenge in SiC device manufacturing: specifically, the AIX G5 WW C brings the epi costs of SiC devices to a minimum while maintaining production quality. Furthermore, it is compatible with fabs in the silicon industry allowing the integration of SiC epiwafer manufacturing into existing facilities and production lines.

"The AIX G5 WW C not only incorporates the automated cassette-to-cassette wafer loading for high-temperature wafer transfer, but also considers the demanding requirements of our customers in the semiconductor industry," notes Dr Frank Wischmeyer, VP business development & marketing Power Electronics.

**www.icscrm2019.org**
**www.aixtron.com**

# Pfeiffer Vacuum opens new plant in Wuxi China

Pfeiffer Vacuum of Asslar, Germany (which provides vacuum solutions for the semiconductor, industrial, coating, analytical and R&D markets) has celebrated the expansion of its facility in Wuxi, China with a grand opening ceremony. Double its original size, the expanded facility marks a milestone in the firm's development in China, allowing it to better respond to local customers' needs while supporting its strategic growth in the local coating and semiconductor market.

"This is part of our new growth strategy which includes a global investment program of €150m," says management board representative Hugh Kelly. "In addition to providing after-sales service, the bigger facility will now also allow for the production of dry pumps and our new leak detection systems ATC, as well as the assembly of pumping stations," he adds.

At its 2019 annual general meeting, Pfeiffer Vacuum shared eight strategic pillars of the company, with Dr Eric Taberlet, CEO of Pfeiffer Vacuum Technology, highlighting the importance of the Chinese market to the firm's development. As one of the key cities in the Yangtze River Delta region, Wuxi has been receiving strong government support to develop its semiconductor, electronics and solar industry. Pfeiffer Vacuum says the expanded facility not only strengthens its presence in China but also enables closer proximity to its customers in China and the wider Asia market.

Pfeiffer Vacuum says that, since entering the China market in 2007, it has maintained steady growth with over 150 staff, largely part of the country's booming economy as well as strong market demand for scientific and high-precision vacuum technology.

**www.pfeiffer-vacuum.com**

# k-Space starts construction of second manufacturing facility

## Expansion includes increased demo space, production capacity, and R&D and office space

k-Space Associates Inc of Dexter, MI, USA — which supplies in-situ, ex-situ and in-line metrology tools for the thin-film, semiconductor, photovoltaic (PV), solar, automotive, glass and building materials industries — has broken ground for the construction of its second building (to be ready for move-in in June 2020) located next to its existing headquarters in the Dexter Business and Research Park.

The new building is an expansion as k-Space continues to grow in the thin-film and industrial metrology markets. It will accommodate increased industrial metrology demonstration space, increased production capacity (including its 3D printing capabilities) as well as additional research, development and office space.

Founder & CEO Darryl Barlett has seen the firm grow from a one-person operation in the basement of his University of Michigan student housing over 25 years ago to an international company in metrology.

"There is significant local technical talent and component suppliers [in the Dexter/Ann Arbor area], making it an ideal location for us," Barlett comments. "And the new facility will allow us to expand our industrial metrology capabilities while continuing to develop our cutting-edge thin-film metrology tools."

**www.k-space.com**

# MRSI demonstrating 1.5μm high-speed die bonding at Productronica

In parent firm Mycronic's booth #341 in Hall A3 (SMT Cluster) of Messe München at Productronica 2019 in Munich, Germany (12–15 November), MRSI Systems of North Billerica, MA, USA (which makes fully automated, high-precision eutectic and epoxy die bonding systems) is demonstrating its MRSI-H-LD 1.5μm die bonder for high-volume manufacturing of photonics and RF/microwave devices.


**An MRSI-H die bonding system.**

The system is optimized for applications that bond large die for high-power laser diodes, industrial lasers, optical fiber amplifiers, power amplifiers, lighting and sensors. MRSI says that the versatile assembly solution enables customers to scale their business by delivering high throughput, high reliability and high flexibility.

In August, MRSI announced the upgrade of the machine accuracy to from 3μm to ±1.5μm (at 3 sigma) for the high-speed product line, under their new names MRSI-HVM and MRSI-H.

**www.mrsisystems.com/mrsi-h**

# Cornell NanoScale Facility and Plasma-Therm collaborate on atomic layer etching

## Plasma-Therm providing ALE system; CNF providing ALE process and device development

The Cornell NanoScale Science and Technology Facility (CNF, a research facility at Cornell University in Ithaca, NY) and Plasma-Therm LLC of St Petersburg, FL, USA (which makes plasma etch, deposition and advanced packaging equipment for specialty semiconductor and nanotechnology markets) have announced a joint development agreement (JDA) to advance atomic layer etching (ALE) for nanoscale device fabrication. Plasma-Therm will provide an ALE system, while CNF will provide ALE process and device development on a wide range of materials serving a broad research community.

ALE is derived from its counterpart atomic layer deposition (ALD) in that it is composed of sequential self-limiting chemical steps, essentially etching one atomic layer per cycle, providing the precise control and low-damage etching required for the fabrication of nanostructure devices.

"Our acquisition of ALE and our collaboration with Plasma-Therm will ensure that CNF can meet the many challenges posed by the increasingly complex fabrication requirements of nanoscale photonics, advanced III-V devices, 2D electronics, magnetic, and quantum-based device applications," says Vince Genova, a research staff member leading the ALE effort at Cornell.

CNF operates as an open user facility for nanofabrication, open to academic, industrial and government users, as part of the National Nanotechnology Coordinated Infrastructure (NNCI) a US National Science Foundation (NSF)-sponsored network of 16 regional user facilities. CNF will be the first site within NNCI to acquire ALE, adding an asset to the fabrication capabilities of NNCI.

The CNF has had a long-term relationship with Plasma-Therm since the early 1980s and currently has six etch platforms including four inductively coupled plasma (ICP) chambers serving its extensive user community.

"The joint development program with Cornell is another example of Plasma-Therm's focus on partnering with our customers in developing next generation technologies," notes Dwarakanath Geerpuram, Plasma-Therm's director of product development engineering.

**www.plasmatherm.com**

# OIPT supplies HLJ with plasma etch & dep systems for fabricating VCSELs on 6 inch wafers

UK-based plasma etch and deposition processing system maker Oxford Instruments Plasma Technology (OIPT) says that HLJ Technology Co Ltd of HsinChu, Taiwan has selected multiple Oxford Instruments inductively coupled plasma (ICP) etch and plasma-enhanced chemical vapor deposition (PECVD) systems on cluster platforms for the production of 6-inch vertical-cavity surface-emitting laser (VCSEL) wafers.

As a pioneer of VCSEL production in Taiwan, HLJ recently built a mass-production line for 6-inch VCSEL wafers to enhance efficiency and to expedite greater control of production lead-times, capacity and quality. The in-house line integrated epitaxial structure design, growth, wafer processes and reliability tests, as HLJ aims to provide a one-stop-shop for VCSEL devices for global customers.

"We chose Oxford Instruments to supply our ICP etch and PECVD systems because they offer cutting-edge plasma processing solutions and unrivalled process support, which will be invaluable to us," comments HLJ's general manager Dr Lai. The Cobra ICP and PECVD process solutions are designed to support leading-edge device fabrication such as VCSELs.

"We continue to strengthen our position as a solution provider for compound semiconductors, including the VCSEL market," says Oxford Instruments' CEO Dr Ian Barkshire. "This partnership reinforces our commitment to enhance market-leading production capabilities."

**www.hlj.com.tw**

**www.oxford-instruments.com/plasma**

# Riber enters loss in first-half 2019 despite MBE system revenue more than doubling

## Loss driven by collapse of evaporators revenue & change in product mix

Riber S.A. of Bezons, France — which makes molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells — has confirmed revenue of €13.9m for first-half 2019, down 17% on first-half 2018's €16.7m.

Evaporators revenue has fallen by 90% from €10.4m to €1m, but this is deemed to be temporary following the major investments made in previous years.

Systems revenue has more than doubled, rising by 132% from €3.7m to €8.6m, reflecting the strengthening of Riber's commercial positions in the industrial sector, with four production systems delivered, compared with just one production system and three research systems in first-half 2018.

Services & Accessories revenue grew by 65% from €2.6m to €4.3m, in line with the strategy to develop this activity.

Gross margin has fallen from 48.8% to 29.5% due to the drop in revenue plus a product mix that is currently less favorable.

Net loss was €0.4m, compared with income of €2.4m in first-half 2018.

Net cash at end-June 2019 was €2.5m, level with end-December 2018, while shareholders' equity has fallen from €19.2m to €17.6m due mainly to the first-half loss and recognition of the distribution of amounts drawn against the issue premium to shareholders for 2018, paid out in July and September 2019.

The order book at end-June has fallen year-on-year by 17% from €34.3m to €28.4m, but this is still high, confirming the positive market environment for the production MBE business. Systems orders were down by just 3% from €22.2m to €21.5m (comprising 13 systems, including six production units). Services & Accessories orders fell by 17% from €8.3m to a still "satisfactory" €6.9m. These order book figures do not include the order received in September from Asia for an MBE 6000 production system.

Riber says that, on the basis of the first-half 2019 results, it can hence confirm its full-year forecast for revenue growth and improved operational profitability compared with 2018. The firm adds that, in a buoyant environment driven by information technology innovations over the coming years, it is moving forward with its development, consolidating its market shares, expanding its portfolio of technologies and clients, and supporting the development of its service activities.

www.riber.com

# StratEdge offering assembly services for high-frequency, high-power device die attach on CMC tabs

StratEdge of Santee, near San Diego, CA, USA (which designs and makes packages and provides chip assembly & test services for microwave, millimeter-wave and high-speed digital devices) has announced its assembly services for attaching gallium nitride (GaN) and other high-frequency, high-power devices using gold-tin (AuSn) and gold-silicon (AuSi) onto copper-molybdenum-copper (CMC) tabs. The firm says its proprietary eutectic die attach method maximizes the power output that a chip can achieve, optimizing its performance and providing an efficient way to dissipate heat to avoid overheating and failures during normal operation.

StratEdge uses the latest high-volume automated system in a cleanroom environment to perform eutectic AuSn die attach of compound semiconductor devices that have a backside gold surface finish. The bonder has micron placement accuracy. Solder preforms are matched to the size of the die to reduce solder bond line thickness to less than 6μm, maximizing power output for GaN devices, lowering junction temperatures, and increasing device reliability. For silicon devices, a AuSi eutectic die attach method is used to create a reliable solder joint with what is claimed to be excellent thermal dissipation.

"GaN on CMC is perfect for chip-on-board (COB) applications because organic boards cannot withstand the eutectic die attach temperature," says Casey Krawiec, VP of global sales. "Eutectic die attach is a highly controlled die attach process that provides void-free, high-reliability, high-accuracy chip attachment. The chip's performance benefits from the superior thermal characteristics of the CMC heat spreader before the chip is installed onto the board," he adds. "StratEdge provides the service along with the custom-built CMC tabs, which allows the chip to be placed directly on a layer of high thermally conductive copper."

StratEdge is exhibiting at the 2019 IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS) in Nashville, TN (3–6 November).

**www.bcicts.org**
**www.stratedge.com**

# CSC collaborates on commercializing Kubos' cubic GaN technology for green and amber LEDs

## Kubos to use MOCVD production system at St Mellons facility

The Compound Semiconductor Centre Ltd (CSC) — a joint venture founded in 2015 between Cardiff University and epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK — and Kubos Semiconductors Ltd of Cambridge, UK have signed a memorandum of understanding (MoU) to pursue the commercialization of cubic gallium nitride (GaN) epitaxial technology for high-efficiency LED lighting applications. The agreement aims to accelerate the development of Kubos' IP on metal-organic chemical vapor deposition (MOCVD) reactors at CSC's St Mellons facility, via the collaboration of CSC, Kubos, IQE and Cambridge University staff.

Kubos is an early-stage start-up formed in 2017 to develop and commercialize its proprietary cubic GaN intellectual property (IP). The firm has an exclusive license to the technology, which was originally developed in partnership with the Department of Materials at the University of Cambridge and Anvil Semiconductors.

Kubos' cubic GaN growth technology is reckoned to have the potential to circumvent some of the key limitations in conventional GaN-based LED devices. In particular,


the removal of internal electric fields and a narrower bandgap mean that cubic GaN can deliver more efficient green and amber LEDs, overcoming the so-called 'green gap' problem. This can facilitate improved displays and also light bulbs that can be varied to mimic the natural changes in daylight through the day.

The CSC facility in St Mellons is co-located with significant volume manufacturing capacity of its JV owners IQE, so the infrastructure provides the advantage of seamless scale up from low-volume R&D and prototyping activities through to process transfer onto Aixtron MOCVD production tools, installed during a £10m capital investment completed at the site in 2017.

"This is a great example of our ability to accelerate new epitaxial technologies to market by supporting an ecosystem where academic researchers work in an industrially relevant environment," says CSC's director Dr Wyn Meredith. "It provides a very low-cost model for spinouts and new ventures to leverage the significant capital investment required to commercialize new epitaxial technologies. The cost and risk of commercialization is reduced with the added benefit of working with a wide range of relevant capability and partners in the emerging CSconnected compound semiconductor cluster in South Wales," he adds.

"CSC is an ideal partner for Kubos as it supports our fabless business model and assists with the tight control of R&D costs," comments Kubos' CEO Caroline O'Brien. "As our technology matures it will also mean that we have an established relationship with a partner who can support the move to high-yield, high-volume processes that is required for a commercially viable LED technology," she adds. Once mature, Kubos plans to license the technology to major LED makers.

www.kubos-semi.com
www.compoundsemiconductorcentre.com

# Innovations in Optics launches compact UV LED light engine for flood curing equipment

Innovations in Optics Inc of Woburn, MA, USA has launched the LumiBright UV-LED Light Engine Model 2990B-100 designed for UV flood curing systems to cure large parts or many small parts simultaneously. The light engine can be used alone or placed in tiled arrays to provide large area coverage.

The 2990B-100 is intended for use within OEM equipment or integrated into automated assembly systems for photocuring of light-curable adhesives, coatings, encapsulants, gaskets, maskants and potting compounds. Other applications include UV curing of photoresist and solder masks for printed circuit boards and inkjet curing of printed electronics.

All LumiBright UV-LED Light Engines feature UV LED die arrays on MCPCB substrates manufactured with proprietary techniques that enhance thermal performance to support high-current-density operation. With active cooling, a single Model 2990B-100 provides a uniform irradiance field of 50mm x 50mm with a flux density up to 500mW/cm$^2$.

Three standard versions are available with UV LED wavelengths centered near 365nm, 385nm and 405nm.

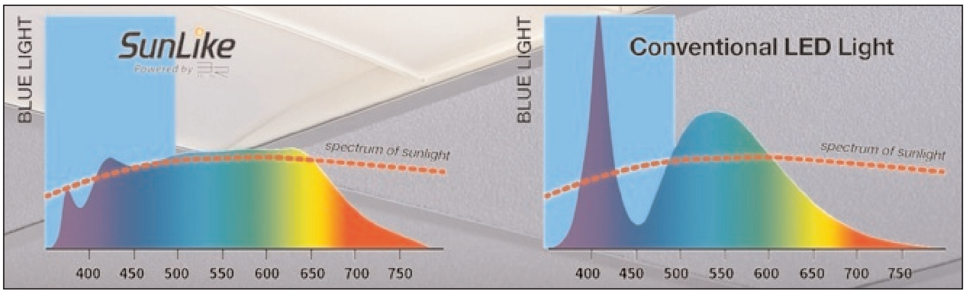
Additional LED curing wavelengths of 395nm and 435nm are also available on request.

www.innovationsinoptics.com

# Seoul Semi's SunLike Series natural-spectrum LEDs adopted by UK lighting firm WILA for human-centric lighting in office and educational buildings

South Korean LED maker Seoul Semiconductor Co Ltd says that its SunLike Series natural-spectrum LEDs (developed in collaboration with Toshiba Materials' TRI-R spectrum technology in 2017 as the first LED light source to closely match the spectrum of natural sunlight) have been adopted by personalized lighting specialist WILA Lighting (part of The Nordeon Group) of Oxfordshire, UK, for its new Visic product range.

Visic is a uniquely shaped recessed ceiling luminaire (with textured surfaces and soft contours) that features a human-centric lighting design closely matching the spectrum of natural sunlight. The technology lowers the blue light peak to be similar to sunlight's spectral curve in order to reduce scattered reflection and glare common in conventional LEDs. This is achieved with SunLike Series LEDs, which are said to promote well-being by creating a more healthy and productive working environment in offices and educational buildings.




The Visic luminaire is extremely efficient, operating up to 162Llm/W, with a Unified Glare Rating (UGR) that achieves low glare UGR<19 rated in accordance with International Commission on Illumination (CIE) discomfort glare evaluation system, enabling lighting designers to meet challenging design requirements.

Seoul says that its SunLike Series natural-spectrum LEDs have been identified as a key light source for promoting human well-being, based on the results of a recent comprehensive sleep study conducted by professor Christian Cajochen and his team at the University of Basel in Switzerland ('Effect of Daylight LED on Visual Comfort, Melatonin, Mood, Waking Performance, and Sleep', Journal of Lighting and Research Technology, 24 March). "We have evidence that a daylight [natural spectrum] LED solution has beneficial effects on visual comfort, daytime alertness, mood, and sleep intensity in healthy volunteers," Cajochen says.

Light sources with SunLike Series LEDs are said to more accurately show the colour of objects as they would appear in natural sunlight. Optimized to natural light spectra and a colour rendering index of CRI-97 (close to the CRI-100 of sunlight, and higher than the CRI-80 of conventional LEDs), it is claimed that SunLike Series LEDs deliver significant benefits in vivid colour, contrast detail, and quality of light consistency.

The SunLike Series LEDs have also achieved the highest level of eye-safety certification from the International Commission on Illumination as an RG-1-level light source with no photo-biological risks.

"As the paradigm of lighting shifts to human-centric lighting, there is an increasing demand for healthy light sources for people who spend a lot of time indoors," says Seoul Semiconductor's Europe sales VP Carlo Romiti. "Beyond the function to illuminate the darkness, light sources with SunLike Series LEDs certainly bring differentiated value to the lighting industry compared to conventional LEDs," he adds.

**www.seoulsemicon.com/en/technology/Sunlike**
**www.wila.co.uk**

## Seoul Semi wins permanent injunction against Fry's

In a patent infringement lawsuit filed by Seoul Semiconductor, the United States District Court for the Eastern District of Texas has issued a permanent injunction against Fry's Electronics (one of the largest big-box retailer of consumer electronics in the USA) selling several TV and lighting products, including a Philips TV product as well as light bulbs from Feit Electric.

Seoul asserted 19 patented technologies significant for LED TV and bulb components, including a multi-wavelength insulation reflector widely used for '0.5W to 3W'-level mid-power LED packages, BLU (back-light unit) lens technology for providing an even distribution of light on a display, LED packages with enhanced durability, and WICOP (wafer-level integrated chip on PCB) patents enabling LED chips to be soldered to a PCB without an LED package.

In particular, Seoul's 'BLU Lens Technology' is claimed to be unique technology applicable to not only TVs and monitors but also any type of flat display that distributes light evenly on a wide area of the display unit.

**www.SeoulSemicon.com**

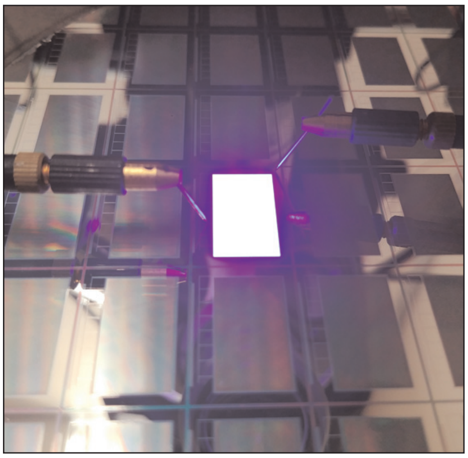
# Compound Photonics and Plessey partner on micro-LED displays for AR/MR applications

## Plessey's micro-LED fabrication technology to combine with CP's microdisplay module engineering and packaging

Compound Photonics US Corp (CP) of Vancouver, WA, USA, a provider of compact high-resolution micro-display technologies for augmented reality (AR) and mixed reality (MR) applications, and UK-based embedded micro-LED technology developer Plessey Semiconductors Ltd, have announced a strategic partnership to develop and introduce the smallest 1080p (1920x1080 pixel) gallium nitride-on-silicon (GaN-on-Si) micro-LED-based microdisplay solution suitable for integration into AR and MR smart glasses.

Plessey will bond CP's high-speed digital low-latency backplane silicon wafer with its proprietary GaN-on-Si monolithic micro-LED array wafer. In turn, CP will utilize its experience in microdisplay assembly, test and packaging to create display modules from the bonded wafers in combination with its NOVA high-performance display driver architecture to deliver a complete solution compatible with the industry-standard MIPI display pipeline.

"CP is the best partner for Plessey because of its deep and extensive decade-long experience with developing fully realized microdisplay-based projection solutions," comments Plessey Semiconductors' president Mike Lee. "Moreover, CP's flexible high-performance end-to-end digital architecture and leading-edge display driver IP are key enablers for delivering micro-LED displays with improved brightness at smaller pixel sizes, higher frame rates, extended greyscale bit depth and low power consumption to best serve next-generation emissive-display-based AR/MR smart glasses and heads-up/head-mounted displays (HUD/HMDs) applications," he adds.



**Compound Photonics and Plessey join forces to develop smallest 1080p (1920x1080 pixel) micro-LED display.**

"Plessey's monolithic GaN-on-silicon IP, fabrication technology and bonding process are well optimized for very small high-brightness pixels that match perfectly with CP's industry-leading 3.015μm pixel-pitch backplane design to deliver compact high-resolution microdisplays," comments Compound Photonics' CEO Yiwan Wong. "Through this partnership, Plessey and CP now lead the industry in addressing the full breadth of current, emerging and future requirements for AR/MR smart glasses and HUD/HMDs that span the range from CP's existing production-ready LCoS (liquid crystal on silicon) reflective displays to emerging micro-LED emissive display technology, and ultimately to achieving true holographic 3D display via CP's LCoS phase display solutions in the future," he reckons. "For the first time, we can provide customers in AR/MR space with an extensible software-configurable platform based on CP's efficient drive architecture that can operate with a wide range of display types to support various application requirements."

Initial samples of a 0.26"-diagonal, full-HD 1080p-resolution micro-LED display integrated with display driver IC to accept industry-standard MIPI input are expected to be available by mid-year 2020.

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

# Plessey's micro-LED growth technology combines native blue and green epi on single wafer

## Roadmap targets production of full RGB micro-LED displays by 2020

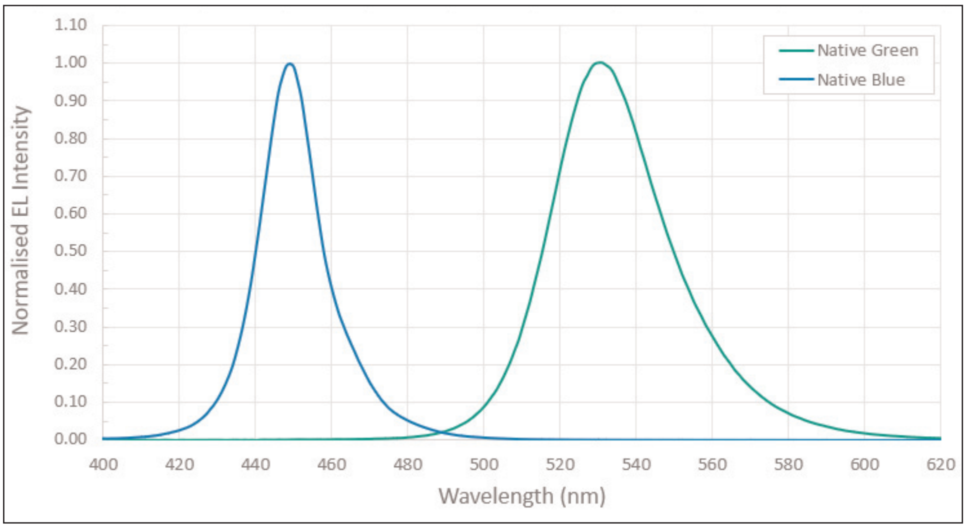
UK-based Plessey, which develops embedded micro-LED technology for augmented-reality and mixed-reality (AR/MR) display applications, has extended the capability of its proprietary gallium nitride on silicon (GaN-on-Si) process to enable native blue and native green emission from the same wafer.

The potential of micro-LEDs is well known but several challenges remain before ramping up to large-scale consumer applications. To form RGB micro-LED displays, typical approaches are to use a pick & place process to transfer discrete R, G & B pixels or to use native-blue LEDs as the light source for subsequent colour conversion to red and green.

Plessey's latest patented growth approach creates both native-blue and native-green emission layers on the same wafer. The monolithic formation of two colours significantly simplifies display manufacture. Green micro-LEDs have high efficiency with a narrow spectral width resulting in what is said to be an excellent colour gamut when operating alongside the high-performance blue micro-LEDs. The firm's new approach forms micro-LEDs that exhibit high-current-density operation and long operational lifetime.

The monolithic integration of both the native-blue and green micro-LEDs on the same silicon substrate is the result of a concerted effort aimed at solving several challenges previously considered insurmountable. Among the issues preventing the integration of multiple wavelength diode junctions are, firstly, a magnesium memory effect and diffusion from the p-type cladding of the lower junction into the upper junction.

An additional process challenge to the integration of blue and green micro-LEDs is the precise tuning of the thermal budget during growth of the second junction to prevent indium phase separation in the blue active region. Plessey says it has precisely engineered the thermal budget to maintain high efficiency (IQE), low defectivity and high electrical conductivity required for high-brightness display applications.




A final operation in the formation of GaN micro-LEDs is a post-growth treatment aimed at removing hydrogen atoms that would otherwise compromise the conductivity of p-type layers. The presence of a second junction complicates the removal of hydrogen from the buried device structure, negating the effect of standard post-growth activation treatments.

Plessey says it has overcome all these challenges and created a monolithic blue and green micro-LED fabrication process that integrates these junctions vertically, separated by a sub-micron layer thickness, resulting in very reproducible and stable diode performance well beyond what is typical in the LED industry, it is reckoned.

"Our latest breakthrough has a multiplier effect on our previous successes with high-efficiency monolithic native blue arrays, native green arrays and hybrid bonding to backplane by demonstrating a way to synthesize the best of our know-how into a single die," says Dr Wei Sin Tan, director of Epitaxy and Advanced Product Development. "This has enormous implications and will open the doors towards new innovations across a wide range of display applications. For mobile and large displays, a high-efficiency single RGB tile can now be used for mass-transfer and for micro-displays; this creates a path to the elusive single RGB panel ultra-high-resolution micro-LED AR display," he adds. "This new process paves the way to commercial, high-performance micro-LED displays, bringing mass adoption of micro-LEDs in displays ever closer to reality."

Micro-LED technology is continuing to emerge as the most likely successor to today's smart high-performance display applications, making displays with smaller form factor even brighter and more power efficient than existing display technologies available, says Plessey.

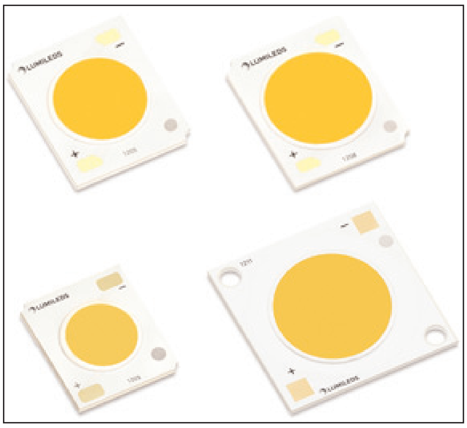
Other recent milestones from Plessey includes the first wafer-level bonded monolithic 3000ppi (pixels per inch) GaN-on-Si micro-LED emissive display hybridized to an active-matrix CMOS backplane, and a high-efficiency native-green technology. Plessey says it is continuing to develop micro-LED display solutions with its roadmap including the production of full RGB micro-LED displays by 2020.

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

# Lumileds launches high-efficacy, high-quality LUXEON CoB Core Range PW LED line for high-impact retail and indoor area lighting

Lumileds LLC of San Jose, CA, USA has introduced LUXEON CoB Core Range PW, a line of chip-on-board LEDs specifically built for high efficiency and the light quality. The CoBs deliver convenient below-blackbody color point, bringing out the vibrancy and saturation of colors, making the new line suited to high-impact retail, indoor area lighting and other commercial lighting applications.

Lumileds proprietary SLA phosphor technology enables what is claimed to be the highest efficacy in the industry at 138lm/W and a color temperature of 4000K 90CRI (color rendering index). "We're always testing new phosphors to hit on the ideal combination of color point and performance," says LUXEON CoB Core Range PW product manager Keen Oun Yap. "This new line of CoBs features outstanding color stability and performance over time."



**LUXEON CoB Core Range PW LEDs.**

LUXEON CoB Core Range PW is offered in a variety of light-emitting surfaces (LES), from 9mm to 19mm, and in correlated color temperatures (CCTs) of 3000K, 35000K and 4000K at 90CRI to suit various applications and requirements. The CoB utilizes what is claimed to be the industry's lowest thermal resistance MCPCB package, which reduces heat-sink requirements and final fixture size.

**www.lumileds.com/ products/ cob-leds/luxeon-cob-core-range-pw**

## Lumileds' LUXEON Fusion platform wins Architectural SSL Product Innovation Award

The LUXEON Fusion platform of Lumileds LLC of San Jose, CA, USA has been named Architectural SSL magazine's Product Innovation Award (PIA) winner for 2019.

LUXEON Fusion is claimed to be the only solution on the market combining consistent white output over wide tuning ranges, dim to warm capability and color selection even after fixture installation. Because color temperature can now be set later in the process, fixture manufacturers can streamline manufacturing to capture real-time demand levels and reduce SKU count. Lighting users can adjust color temperature on-site or designate a signature color tone.

"LUXEON Fusion is a result of Lumileds listening to the wants and the pain points of lighting designers and luminaire manufacturers, and this holistic solution addresses all of them," says Leon Pikaar, senior director, Segment Marketing. "This includes delivering the flexibility that human-centric lighting demands, while helping to streamline fixture manufacturing."

The Architectural SSL Product Innovation Awards (PIA) recognize innovative LED and solid-state luminaires and fixtures on the market, while also spotlighting the players behind the components that make up these light sources. With judging and evaluation of products and systems from a panel of 18 designers and lighting specialists skilled in product evaluation, the SSL PIA program awards manufacturers based on attributes, qualities, functionality and/or performance beyond industry standards.

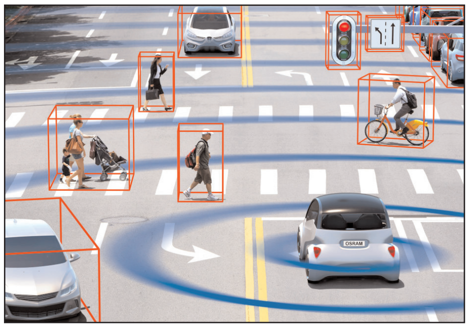
**www.lumileds.com/fusion**

# Osram launches 125W-per-channel infrared SMT lasers for longer detection-range LiDAR in autonomous vehicles

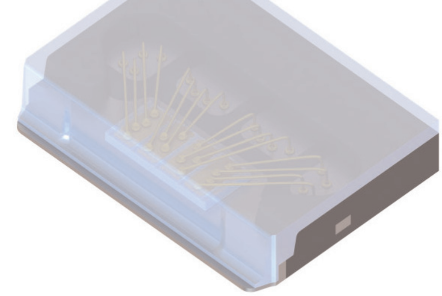
Osram Opto Semiconductors GmbH of Regensburg, Germany says that, with what it claims is the first AEC-Q102-qualified four-channel and single-channel pulse laser, system developers can now choose from a greater variety of infrared components. The two new products offer performance of 125W per channel and an efficiency of up to 33%.

The requirements for safety systems in (semi-)autonomous vehicles are complex. They must be reliable, work in all lighting and weather conditions, and identify potential hazards and obstacles in time to take appropriate driving decisions. There is now widespread agreement that only a combination of light detection & ranging (LiDAR), camera and radar can fulfill autonomous driving requirements. Osram introduced the first 905nm laser to the market over ten years ago. Today it is the most commonly used wavelength in LiDAR solutions. For example, the 905nm has a significant advantage compared with 1550nm-wavelength solutions, especially in total system costs.

A central aspect in terms of safety is the range of the infrared light source. A powerful laser is required to be able to look as far ahead as possible. Both products have an output power of 125W at 40A per channel. Due to its particularly low thermal resistance of only 30K/W for the single-channel SPL S1L90A_3 A01 and 17K/W for the four-channel SPL S4L90A_3 A01, heat is easily dissipated from the component, even at high current.



**Multi-chip solutions enable even higher system resolution and better measurement signals for AVs.**



**SPL S4L90A_3 A01 four-channel laser**

The four-channel version features a chip with four emission areas that deliver optical power of 480W. The laser enables a much longer detection range, at a size of just 3.35mm x 2.45mm x 0.65mm, making it only slightly larger than the 2.0mm x 2.3mm x 0.65mm single-channel version.

The two new high-power SMT (surface-mount technology) lasers expand Osram's photonics portfolio for LiDAR applications and offer ease of use in system integration, it is claimed.

"Thanks to their higher power and extended duty cycle range of up to 0.2%, our customers can reach a longer detection range in the application and better resolution," says product manager Rena Lim. "Additionally, eye-safe system designs can be achieved with these high-power 905nm products," he adds. "Due to its excellent package design, the new products enable short pulse widths of around 2ns."

**www.osram.com**

# Marktech expands surface-mount SWIR reflective sensor range

Marktech Optoelectronics Inc of Latham, NY, USA, a privately held designer and manufacturer of standard and custom optoelectronics components and assemblies — including UV, visible, near-infrared (NIR) and short-wave infrared (SWIR) emitters, detectors, indium phosphide (InP) epiwafers and other materials — has expanded its surface-mount (SMD) SWIR reflective sensor family.

Marktech says that the alignment and sensitivity of its surface-mount SWIR reflective sensors make them suitable for position sensing and detection applications, including card, barcode, edge sensing and money bill readers.

The firm's surface-mount SWIR reflective sensors combine both a short-wavelength infrared emitter and a high-sensitivity InGaAs photodiode. Emitted light from the sensor is reflected back to the detector side as an object enters the sensing area, with an optimal short detection distance of 0.5–1.5mm. The series is offered in six standard models, each with its own unique peak emission wavelength from 1040nm to 1625nm. Each element is spectrally and mechanically matched and then seamlessly integrated within a single, compact, 4-pad SMD black molded housing. The black housings are designed to help reduce the risks of measurement uncertainty created by external ambient light effects. The series' overall footprint measures just 5.1mm x 3.3mm, easing installation within space-constrained environments. Units are both REACH and RoHS compliant.

Small-to-medium-sized quantities of standard surface-mount SWIR reflective sensors are typically available with 24-hour shipment from stock via Marktech's distribution partner Digi-Key Electronics. Sensor customization is available on request, in quantities ranging from prototypes to OEM volumes. Full production volumes are typically available within 6-8 weeks from customer prototype approvals.

**www.marktechopto.com**

# BluGlass launches direct-to-market GaN laser business unit to capture downstream manufacturing

## RPCVD tunnel-junction technology to enable higher brightness and higher efficiency GaN lasers

BluGlass Ltd of Silverwater, Australia — which was spun off from the III-nitride department of Macquarie University in 2005 — has launched a new direct-to-market business unit to leverage its unique remote-plasma chemical vapor deposition (RPCVD) technology in the high-value, high-margin gallium nitride (GaN) laser diode market. High-brightness GaN laser diodes are used in applications including industrial lasers (cutting and welding), automotive and general lighting, displays, and life sciences.

Compared with the industry's incumbent technology, BluGlass says that its patented RPCVD platform and unique tunnel-junction capabilities offers laser diode manufacturers performance and cost advantages including: higher-performing devices and reduced optical loss; productivity and cost improvements; and unique laser diode design.

BluGlass' is developing GaN laser diode prototypes and expects to deliver its first laser diode product in 2020. The new products are expected to deliver a clear path to significant revenues from 2021.

The new business unit will be headed by VP of business development Brad Siskavich out of BluGlass' US office. Siskavich has over 20 years of experience in laser diode business management. "This new business stream fits well with our strategy of commercializing the competitive advantages of the RPCVD technology to maximise returns," he says. "This highly customizable, end-to-end approach will enable BluGlass to generate revenue in this high-value market and build our leadership in the manufacture of novel GaN laser diodes."

The total market for laser applications is forecasted to reach US$27bn by 2025. The GaN laser diode segment is an emerging market opportunity, expected to grow to a US$658m serviceable addressable market for BluGlass by 2025. GaN lasers require a higher-performance, lower-cost technology solution to help address significant unmet needs in the industry, says BluGlass. The firm will hence initially focus on industrial laser diodes for welding and cutting applications, targeting an initial market share of 6-10% (US$40-65m) of this SAM by 2025.

"BluGlass is entering the laser diode market as a result of our success in demonstrating tunnel junctions as a building block for high-performance cascade LEDs," says managing director Giles Bourne. "Our RPCVD tunnel-junction technology has unique, compelling advantages to drive performance and cost improvements for the GaN laser diode market," he believes. "LEDs and laser diodes are, in their physics and material growth, very similar, which allows us to accelerate our entry into this new market space without diluting our activities on other RPCVD applications."

BluGlass notes that, with the opening of its Paul Dunnigan Laboratories in August, it now has the pre-installed RPCVD capacity onsite in Silverwater to accrue significant laser diode revenues and build a profitable business unit.

**www.bluglass.com.au**

# SMART develops commercially viable manufacturing of integrated silicon III–V chips, available by 2020

## Singapore–MIT Alliance for Research and Technology targets intelligent optoelectronic and 5G devices

The Singapore–MIT Alliance for Research and Technology (SMART), Massachusetts Institute of Technology's Research Enterprise in Singapore, has developed a commercially viable way to manufacture integrated silicon III-V chips with high-performance III-V devices inserted into their design.

"By integrating III-V into silicon, we can build upon existing manufacturing capabilities and low-cost volume production techniques of silicon and include the unique optical and electronic functionality of III-V technology," says SMART's CEO & director Eugene Fitzgerald. "The new chips will be at the heart of future product innovation and power the next generation of communications devices, wearables and displays," he adds.

"However, integrating III-V semiconductor devices with silicon in a commercially viable way is one of the most difficult challenges faced by the semiconductor industry, even though such integrated circuits have been desired for decades," says Kenneth Lee, senior scientific director of the SMART Low Energy Electronic Systems (LEES) research program. "Current methods are expensive and inefficient, which is delaying the availability of the chips the industry needs," he adds. "With our new process, we can leverage existing capabilities to manufacture these new integrated silicon III-V chips cost-effectively and accelerate the development and adoption of new technologies that will power economies."

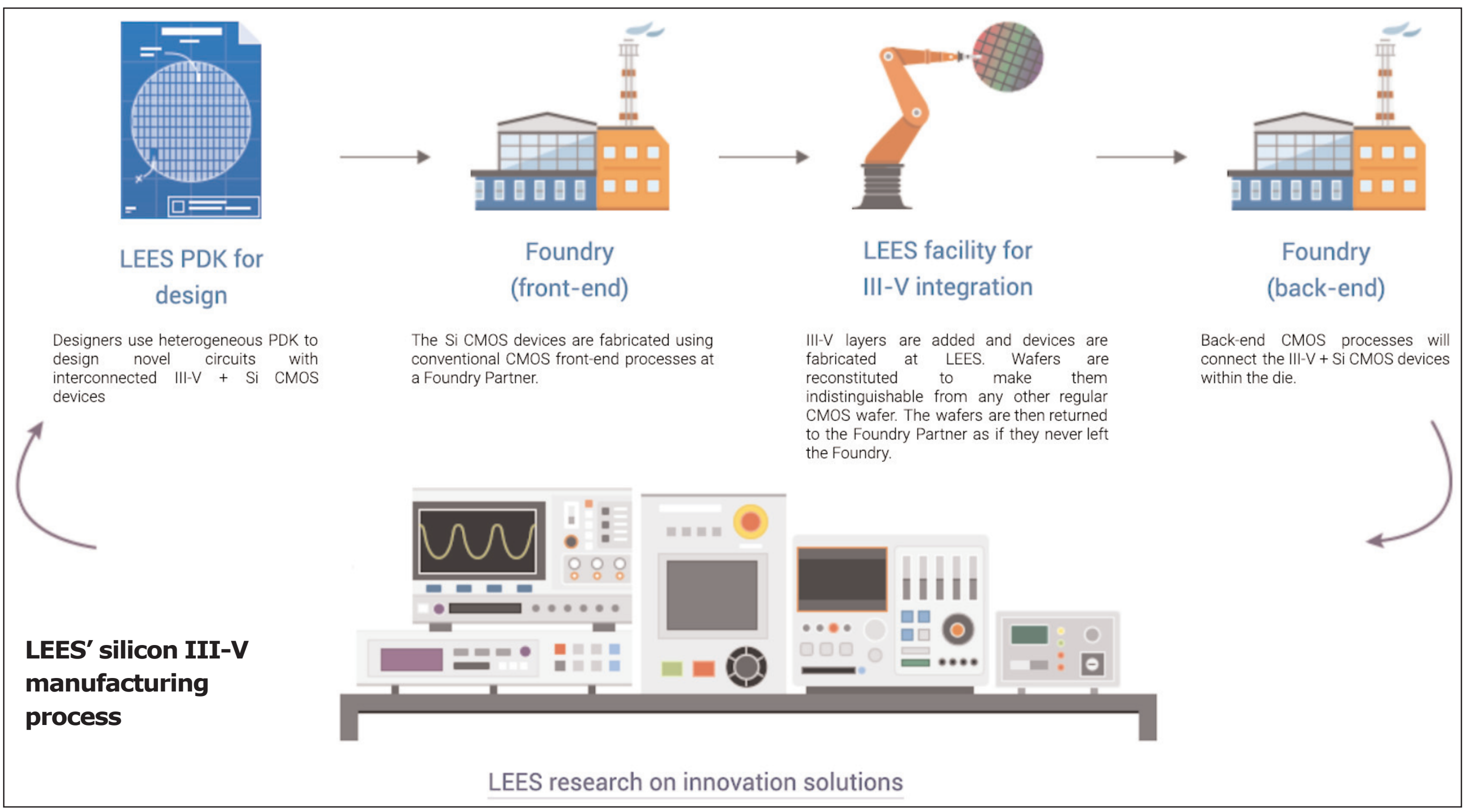
The new technology developed by SMART builds two layers of silicon and III-V devices on separate substrates and integrates them vertically together within a micron. The process can use existing 200mm manufacturing tools, allowing semiconductor manufacturers to make new use of their existing equipment. Currently, the cost of investing in a new manufacturing technology is tens of billions of dollars, so the new integrated circuit platform is highly cost-effective and can result in much lower-cost novel circuits and electronic systems, says SMART.

SMART is focusing on creating new chips for pixelated illumination/display and 5G markets (a combined potential market over US$100bn). Other potential markets include wearable mini-displays, virtual reality (VR) applications, and other imaging technologies.

The patent portfolio has been exclusively licensed by SMART's Singapore-based spin-off New Silicon Corporation Pte Ltd (NSC), which is said to be the first fabless silicon IC firm with proprietary materials, processes, devices and design for monolithic integrated silicon III-V ICs.

SMART's integrated silicon III-V chips will be available next year and should be in products by 2021.

**http://smart.mit.edu**




**LEES' silicon III-V manufacturing process**

# Emcore launches Model 1999 6GHz-bandwidth coaxial laser module for 5G applications

At the Mobile World Congress Americas (MWCA) in Los Angeles (22–24 October), Emcore Corp of Alhambra, CA, USA — which provides indium phosphide (InP)-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets — launched the Model 1999 coaxial distributed feedback (DFB) laser module for next-generation wireless fiber-optic link applications. The 1999 laser module features wide bandwidth above 6GHz and is designed for 5G, Distributed Antenna Systems (DAS), L-band and wireless remoting link applications.

The 5G wireless migration is underway, with all three of South Korea's mobile network operators now offering the world's first ultra-fast 5G services in multiple cities. Full-blown 5G smartphones are available, and early results show a significant uptick in data use among 5G customers, according to SK Telecom.

The new 1999 laser module is an ultra-linear, coaxial DFB laser module operating at wavelengths of 1270–1550nm that is optimized for 5G wireless fiber-optic links. It is designed to enhance bandwidth and signal integrity to meet the increased data demands of 5G networks for delivery of consistent, reliable wireless signals.

Featuring optical output power up to 10dBm, the 1999 laser delivers what is claimed to be superior optical performance over an enhanced temperature range from –40°C to +75°C with very low power consumption. It can be cooled with external thermo-electric coolers (TECs) for high stability or run without TECs to further reduce power consumption. The unit is packaged in a compact, hermetic assembly together with a monitor photodiode and isolator for flexible integration into various transmitter configurations.

"Our new 1999 laser follows the successful release of the model 1998 at last year's MWCA in Los Angeles and builds on Emcore's track record of high-performance designs for wireless and high-speed digital applications," says Gyo Shinozaki, VP & and general manager of Broadband. "With bandwidth above 6GHz, the 1999 will deliver maximum high-speed signal integrity, raising the performance bar in linear fiber-optic transmission in 5G, DAS and long-distance fiber-optic link networks," he adds.

www.emcore.com

## Emcore appoints Noel Heiks to board of directors

Emcore has announced the appointment of Noel Heiks to its board of directors.

Heiks has extensive executive management and entrepreneurial experience in high-tech companies, including defense and optoelectronics companies. From March 2018 to April 2019, she served as president & chief operating officer of Duos Technologies (which specializes in artificial intelligence and machine learning for inspection and security applications). From August 2017 until March 2018, she served as interim CEO of MVTRAK, an early-stage health monitoring company. In 2008, Heiks founded Nuvotronics, a manufacturer of radar and wireless systems for defense and telecom organizations, serving as its CEO and then board member until its eventual acquisition by Cubic Corp this March. In 1996, she founded microfabricated optoelectronics component maker Haleos, and served as its VP until its eventual acquisition by Rohm & Haas in 2002, where she went on to serve as marketing director of Rohm and Haas (now Dow Chemical) from 2002 until 2007.

Heiks has a B.S. degree in Physics and an M.S. degree in Electrical Engineering from Virginia Tech University and holds about 30 awarded or pending patents.

"Noel's significant experience managing high-growth defense and optoelectronics companies positions her well to make valuable contributions to Emcore and our board of directors," comments chairman Dr Gerald Fine.

# EU-funded project TERIPHIC developing transceivers for low-emission 1.6Tb/s Internet

## Use of indium phosphide EML arrays and polymer host platform target halving power consumption per Gb/s

The European Union (EU) Horizon 2020-funded consortium TERIPHIC ('TERabit optical transceivers based on InP EML arrays and a Polymer Host platform for optical InterConnects') is developing new optical transceiver modules used in Internet data centers that will reduce power consumption by 50% per Gb/s and in turn see lower carbon emissions.

The TERIPHIC group expects the new transceivers to solve problems faster and reduce queue times. Shortening processing intervals for high-performance computing, edge computing and machine learning, the new ultra-high-capacity, low-power-consumption pluggable modules are capable of both 800Gb/s and 1.6Tb/s. Aiming to surpass current 'gold' standards of 400GB per second, TERIPHIC expects their modules to cost €0.3 per Gigabyte per second.

The three year, €5.6m project will operate until December 2021 and has received a grant of €4.7m from the European Commission via its Photonics PPP (public–private partnership).

**Photonic integration**

"Photonics is essential for the future of data centers. TERIPHIC intends to develop low-cost terabit optical transceivers through the automation of current photonic integration concepts and processes in commercial assembly machines," says Panos Groumas of the TERIPHIC project coordination team. "While 400G is impressive, and was demonstrated in 2018, high-performance computing, edge computing and machine learning end-user experiences will not run on existing speeds of 400Gb/s," he adds.

"We are developing mass-production-compatible 800Gb/s pluggable modules with eight lanes and 1.6Tb/s mid-board modules with 16 lanes having at least 2km reach," Groumas continues. "When the Gb/s power consumption is reduced, data centers will consume less power and, given that they are powered by power plants relying on various fuel sources including coal, we will see a significant reduction in carbon emissions."

"TERIPHIC will bring together EML [electro-absorptively modulated laser] arrays in the O-band, PD [photodiode] arrays and a polymer chip that will act as the host platform for the integration of the arrays and the wavelength mux–demux of the lanes," says professor Hercules Avramopoulos, project leader. "The integration will rely on butt-end-coupling steps, which will be automated via the development of module-specific alignment and attachment processes on commercial equipment," he adds.

"The new transceiver design introduced by TERIPHIC will allow significant cost savings, due to assembly automation of both the transmitter and receiver optical subassembly (TOSA/ROSA) parts, and also at the packaging level, resulting in a cost of around €0.3 per Gb/s for the transceiver modules."

**HHI provides the photonic platform, the active components, and is responsible for the hybrid integration of the latter with the photonic platform using ficonTEC machines. FiconTEC provides custom equipment for the automated assembly processes while III-V Lab provides the high-speed electronic driver chips. Finally, Mellanox will take up the packaging of the transceivers**

"TERIPHIC is an industrially driven project with specific and well-defined technical objectives. The technology that will be developed and delivered by the project is feasible due to the unique expertise that each one of the consortium partners brings to TERIPHIC," Avramopoulos continues.

"ICCS and Telecom Italia are responsible for providing the system specs and, together with Mellanox, are responsible for the testing of the devices in both lab and real settings. Fraunhofer-HHI provides the photonic platform, the active components, and is responsible for the hybrid integration of the latter with the photonic platform using ficonTEC machines. FiconTEC provides custom equipment for the automated assembly processes while III-V Lab provides the high-speed electronic driver chips. Finally, Mellanox Technologies will take up the packaging of the transceivers," concludes Avramopoulos.

The project is coordinated by the Photonics Communications Research Laboratory (PCRL) of the Institute of Communication and Computer Systems (ICCS) at NTU Athens, Greece.

The consortium comprises five additional partners from four European countries: Heinrich-Hertz Institute of Fraunhofer Gesellschaft Zur Foerderung der Angewandten Forschung e.v, ficonTEC Service GmbH (Germany); III-V Lab (France); Mellanox Technologies Ltd Mlnx (Israel); and Telecom Italia Spa (Italy).

**www.photonics21.org/ppp-projects/workgroup-1/TERIPHIC.php**

# ADVA leading three-year project to create optical transceiver chiplets

## PEARLS consortium integrating quantum dot lasers onto silicon-based electro-photonic integrated circuits

Germany's ADVA Optical Networking SE says that it is leading a three-year initiative to create the industry's most advanced optical transceiver chiplets, which will be key to tackling urgent bandwidth needs by enhancing density, flexibility and efficiency in data-center interconnect (DCI) networks.

The project 'Photonic Embedding silicon-based electro-photonic integrated circuits of Active Region Laser chips in Silicon' (PEARLS) — involving a consortium comprising ADVA, FormFactor, Fraunhofer IZM, IHP, IHP Solutions, Sicoya, Technion and the University of Kassel — aims to integrate quantum-dot lasers onto (ePICs). By combining silicon photonics, BiCMOS electronics and lasers on a single chip, the size and cost of optical transceivers can be dramatically reduced.

"With this project we're taking integration and compact design to new levels," says Jörg-Peter Elbers, ADVA's senior VP, advanced technology. "By squeezing more technology onto a single chip than ever before, we're creating a platform for miniaturized optical transceivers able to deliver the space and bandwidth density needed for tomorrow's DCI networks," he adds. "PEARLS not only paves the way for a new generation of intra-data-center transceivers, but also facilitates more compact and cost-effective integrated coherent transmitter-receiver optical sub-assemblies (IC-TROSAs) for inter-data-center applications."

The PEARLS project is funded by Germany's Federal Ministry for Education and Research (BMBF). Its multi-disciplinary engineering team is aiming to take a silicon-based electro-photonic chip platform — which offers monolithic integration of electronics and photonics, as already proven in the ADVA-led SPEED project — and extend it to incorporate a third key element: Quantum-dot lasers will be added to the chip, saving space and reducing energy consumption compared to off-chip approaches. Able to withstand extreme temperatures, they facilitate wafer-scale integration without the need for a thermo-electric cooler or a hermetic package.

**By combining silicon photonics, BiCMOS electronics and lasers on a single chip, the size and cost of optical transceivers can be dramatically reduced**

"Within this very exciting project, IHP will develop the technology platform," IHP GmbH's managing director Bernd Tillack. "Together we're breaking new ground and laying the foundations for the next generation of low-energy, space-efficient optical transceivers," he adds. "The PEARLS project will pave the way for optical transceiver chiplets — modular transceiver chips with an unprecedented level of optical and electronic integration. Built on top of a standard BiCMOS process flow, the new technology will also be a major step forward for sustainable DCI networking."

**www.advaoptical.com**

# AOI announces 400G transceiver switch interoperability

Applied Optoelectronics Inc (AOI) of Sugar Land, TX, USA — a designer and manufacturer of optical components, modules and equipment for fiber access networks in the Internet data-center, cable TV broadband, fiber-to-the-home (FTTH) and telecom markets — has announced interoperability between AOI's 400G QSFP-DD SR8 and 400G QSFP-DD DR4 transceivers with Celestica's Silverstone DX400 400G switch platform.

"As the 400G ecosystem matures, AOI continues to expand the interoperability of our 400G transceiver portfolio with Celestica's 400G Ethernet switch," says David Chen, AOI's assistant VP of product management. "AOI is proud to partner with Celestica as a world-class switch provider to demonstrate seamless 400G data transmission with our MSA-compliant 400G QSFP-DD SR8 and 400G QSFP-DD DR4 transceivers," he adds. "This demonstration only deepens our commitment to being a leading provider of 400G solutions to our customers and the cutting-edge data speeds they require."

"Celestica's robust 400G networking solutions are driven by our customers' accelerated need for increased bandwidth. Leading-edge hardware solutions, supported by ecosystem partners with aligned solutions, are critical to our customers' continued success," says Randy Clark, Celestica's senior director of Service Provider Platform Solutions. "AOI is confirming interoperability of their 400G portfolio with our Silverstone platform. We believe this synergy will help to build customer confidence and drive faster adoption of 400G technology in a quickly changing industry," he adds.

**www.ao-inc.com**

# Stanford Solar Car shows potential of Alta's flexible, high-efficiency technologytfor automotive applications

Alta Devices of Sunnyvale, CA, USA (a subsidiary of Hanergy Thin Film Power Group Ltd of Beijing, China) says that its solar technology is powering the Stanford Solar Car competing in October's Bridgestone World Solar Challenge (BWSC) race.

Alta says that, for the first time in the BWSC, a solar car will use flexible, glass-free solar that also delivers high levels of power, and can also be manufactured at cost-effective prices.

"For solar to be realistic for the broad auto market, it needs to have several important characteristics," says CEO Jian Ding. "It must be flexible enough to conform to the surfaces of innovative vehicle designs, maintain high efficiency even in the hottest weather conditions, and be manufacturable at scale."

To date, solar technology used on solar race cars, luxury cars or concept vehicles has typically been silicon solar or specialized solar developed for space applications. Silicon solar, while low-cost, is very brittle, which makes it difficult to handle and integrate into curved automotive surfaces. Silicon has relatively low energy conversion efficiency compared with other materials, making it harder to generate the desired amount of power from the limited area of a car roof. Moreover, silicon solar quickly becomes warm during operation and loses efficiency as temperatures rise. Overall, this results in less vehicle range or available power per day. Space solar cells are high efficiency but, like silicon, are very brittle and don't manage heat well. In addition, the traditional complex and time-consuming manufacturing process makes them very expensive.

**The 2019 Stanford Solar Car.**

Alta's thin-film gallium arsenide solar technology is newer than silicon and space solar, and is flexible, lightweight, high efficiency and has structural properties that allow it to run much cooler. It can also be produced at mass-market scale.

**2019 BWSC and Stanford Solar Car Project (SSCP)**

The Bridgestone World Solar Challenge (BWSC) road race is over 30 years old, held every two years in the Australian outback, and covers a route more than 3000km (1864 miles) long from Darwin to Adelaide. Over 50 teams, composed of students from high schools and colleges, are competing. The race rules mandate that the cars must be designed, built and raced by the teams, and run primarily on solar power, with very limited use of stored energy.

The 2019 Stanford Solar Car Project (SSCP) solar car 'Black Mamba' has a sleeker design than previous team cars, and the Stanford team built a custom oven in which to cure the large shell composites. The car is the 14th solar car that the Stanford team has designed. This year's design is asymmetrical with a single aerodynamic shell covering the body. Alta's solar cells have been integrated onto the top surface of the vehicle.

Due to the ability of the solar to flex, the curves of the vehicle design were preserved. "In the future, mass-market electric vehicles will be designed for long range, as well as safety, and sustainability," says Jian Ding. "They will use extremely lightweight and aerodynamic materials. Solar will be incorporated to seamlessly cover the body of the car, maximize range, and power auxiliary systems. Whenever there is sunlight, the car will always be charging."

**www.altadevices.com**
**https://solarcar.stanford.edu**
**www.worldsolarchallenge.org**

# ClassOne's Solstice CopperMax plating system chosen for MicroLink's UAV solar cells

ClassOne Technology of Kalispell, MT, USA (which manufactures electroplating and wet-chemical process systems for ≤200mm wafers) has sold a Solstice S8 electroplating system to MicroLink Devices of Niles, IL, USA, a manufacturer of lightweight, flexible gallium arsenide (GaAs)-based solar cells. The new 8-chambered Solstice equipment, designed specifically for ≤200mm processing, will be used for electroplating of solar cells for use on unmanned aerial vehicles (UAVs) and space satellites.

"We were especially interested in the Solstice's high-speed automation and its ability to maximize control and uniformity of our electroplating processes," says MicroLink's CEO & president Dr Noren Pan. "Compared with our previous wet-bench processing, the new Solstice will enable us to control the electroplating process much more precisely and maintain tighter consistency week to week across production runs. This is critical for achieving the high reliability required for solar cells that power unmanned aerial vehicles and satellites," he adds.

"MicroLink is getting the special CopperMax version of our Solstice plating system," says ClassOne Group's CEO Byron Exarcos. "This unique tool is specifically designed to optimize copper plating processes, and it's getting a great deal of attention today for its high performance and low cost of ownership," he adds. "It's more than just supplying equipment, because our depth of experience in automated wet processing also enables us to assist MicroLink in setting up and optimizing their next-generation processes. Partnering with our customers in this way allows us to more deeply understand their objectives and achieve more effective solutions using the Solstice."

The Solstice S8 is a fully automated 8-chamber system with up to 75wph throughput. Special CopperMax and GoldPro versions of the tool provide additional optimizations of copper and gold processes respectively.

The Solstice is also available in 4-chamber and 2-chamber configurations. In addition to electroplating, the tool's Plating-Plus capabilities enable it to handle a number of other important functions, including wafer cleaning, high-pressure metal lift-off, resist strip, UBM etch and more. This multi-processing flexibility often reduces the number of different tools a user needs to purchase, says ClassOne.

**www.mldevices.com**
**www.classone.com/products**

# First Solar becomes largest PV module maker in Western hemisphere

## Second Ohio plant scales US manufacturing footprint to $1.9GW_{DC}$

First Solar Inc of Tempe, AZ, USA has begun production at its new cadmium telluride (CdTe) photovoltaic (PV) module manufacturing facility in Lake Township, Ohio, its second factory in the USA. The firm still operates its flagship factory in Perrysburg, Ohio, effectively scaling its total annualized production capacity in the USA to $1.9GW_{DC}$.

First Solar's expanded manufacturing footprint in the USA, which represents over $1bn in cumulative investment and directly created about 500 new jobs, makes it the largest solar manufacturer in the USA and the Western hemisphere, it is reckoned. The investment includes a new $265m TCO (transparent conductive oxide)-coated glass factory being built by the NSG Group in Troy Township, Ohio, its first new float glass line in the country since 1980.

"Eighteen months ago, we announced that we would expand our manufacturing footprint in the United States in response to demand," says CEO Mark Widmar. "We were able to transform a greenfield site into a high-tech manufacturing facility in that time, and on time," he adds.

"Its levels of automation, digitalization, machine learning, and artificial intelligence demonstrate that the ambitions of Industry 4.0 are not out of reach for the PV manufacturing industry," says chief operating officer Tymen de Jong. "We are proud to have achieved it in Northwestern Ohio, the technological home of American solar."

Both facilities produce First Solar's Series 6 module technology. Designed and developed at the firm's R&D centers in California and Ohio, the module is produced in just 3.5 hours using fully integrated manufacturing processes. Each large-format Series 6 module leverages First Solar's proprietary thin film technology, retaining the proven performance and reliability advantages of earlier-generation modules. The carbon footprint is up to six times lower than crystalline silicon PV panels that are manufactured using conventional, energy-intensive production methods.

First Solar is also celebrating two decades since its founding in 1999, and $25GW_{DC}$ of PV modules shipped, making it the only US solar module manufacturing company to achieve this milestone. First Solar also operates manufacturing facilities in Vietnam and Malaysia with a current global annualized manufacturing capacity of $6.7GW_{DC}$.

## Intersect selects First Solar for 1.7GW multi-year PV supply contract

First Solar is to supply over $1.7GW_{DC}$ of modules (the largest order for Series 6 modules to date) to utility-scale renewable energy developer Intersect Power as part of a multi-year supply agreement, for delivery from fourth-quarter 2020 through to the end of 2021.

Modules will be deployed at five projects developed by Intersect Power and built by Signal Energy in Texas and California. In addition, Intersect has a multi-gigawatt pipeline of projects in early- and mid-stage development.

"With the scale of this transaction, we knew it was critical to partner with a top-tier module manufacturer like First Solar that can reliably deliver a world-class, high-performance product at competitive prices," says Intersect's CEO & co-founder Sheldon Kimber. "Our decision to contract with First Solar was based on our confidence in its Series 6 technology and its ability to stand behind its obligations. There has never been more noise and chaos in the module market, which makes trusted partners with widely proven technologies more valuable than ever."

Produced in just 3.5 hours using fully integrated manufacturing processes, each large-format Series 6 module uses First Solar's proprietary thin-film technology, retaining the performance and reliability advantages of earlier-generation modules. With its larger form factor and under-mount, single cross-bar frame, the design is said to improve installation rates and balance of system (BOS) costs.

"Intersect Power's decision to invest in Series 6 on such a large scale validates the technology's performance advantage over conventional solar panels, its competitiveness and its bankability," says First Solar's chief commercial officer Georges Antoun.

First Solar is expanding its manufacturing capacity to meet demand for Series 6 modules, with its second facility in the USA — representing nearly $1bn in cumulative investment — expected to start production in early-2020. Once operational, the new facility in Perrysburg, Ohio, will take First Solar's aggregate Series 6 manufacturing capacity to 5.4GW per year.

**www.intersectpower.com**
**www.firstsolar.com/Modules/Series-6**

# Midsummer celebrates opening of new R&D facility

Midsummer AB of Järfälla, near Stockholm, Sweden — a provider of turnkey production lines as well as flexible, lightweight copper indium gallium diselenide (CIGS) thin-film solar panels for building-integrated photovoltaics (BIPV) — has celebrated the opening of its new solar energy technology R&D facility together with a new production line for building-integrated solar roofs. Sweden's first astronaut, professor Christer Fuglesang of KTH Royal Institute of Technology, formally inaugurated the new facility in the presence of solar energy industry leaders, media, clients and partners.

"During my stay at the ISS space station we were of course completely powered by the sun," commented Fuglesang. "It is good to have one of the best and most advanced research facilities based in Sweden."

The new R&D facility includes a 1000m$^2$ (10,800ft$^2$) expansion of the firm's factory and head office with more than 100 staff. It will also house a new production line for energy-producing standing seam metal roofs for the Nordic consumer market. The 'Midsummer solar roof' brand was launched in April.

"At our new research and development facility, the future of 100% environmentally friendly renewable energy technology will be developed," says CEO Sven Lindström. "It will be one of the world's leading laboratories, perhaps the foremost, for research and development of production-friendly CIGS technologies and building-integrated photovoltaics," he reckons.

**Midsummer's R&D facility was inaugurated by Sweden's first astronaut, professor Christer Fuglesang of KTH.**

**www.midsummer.se**

## Midsummer strengthens its sales and marketing department

To strengthen its position in the Nordic market, Midsummer has expanded its sales & marketing department with three new area sales managers and a marketing manager for its BIPV product, Midsummer solar roofs and solar panels.

New marketing manager Joel Brink holds a degree in International Marketing from the University of Turku University, School of Business and Economics and was most recently retail performance & employer branding manager at BMW.

New area sales manager Europe (Solar Modules) Lars Norrman has more than 15 years of experience in sales and international marketing of Swedish products and services and Swedish technology. Most recently he was sales manager with responsibility for business development and sales in the business areas SunCool (thermal solar panels) and Enerstore (salt storage), focusing on Europe and Latin America.

Mikael Lindström is area sales manager for Midsummer solar roofs aimed at the private market in Sweden. He most recently held a position in sales support/IT/projects service at Hjältevadshus AB.

Daniel Månér has been recruited as area sales manager for Midsummer solar roofs targeting corporate customers in the Swedish market. He was previously area sales manager & customer service manager at Bauhaus & Co KB.

The sales & marketing focus for Midsummer solar roofs remains the Swedish private and corporate market, but sales of thin-film solar cells are also being strengthened with a focus on the European market for membrane and metal roofs for industrial and commercial properties.

"We have had a great interest from the market and will now be able to respond even better to it, further strengthen the brand and develop stronger customer relationships," says Christoffer Löfquist, sales manager for integrated solar roofs and solar panels.

**www.midsummer.se**

# Monolithic AC InGaN light-emitting chips

**Circuit integrates Schottky barrier diode rectifier with 28 LEDs operating at 110V root-mean-square at 60Hz.**

Pennsylvania State University in the USA claims the first monolithic integration of high-breakdown Schottky barrier diodes (SBDs) and indium gallium nitride (InGaN) light-emitting diodes to give single chips operated by alternating current (AC) [Jie Liu et al, IEEE Transactions On Electron Devices, vol66, issue 9 (September 2019), p3881]. The 3W device therefore combines the high voltage and light-emitting capabilities of the III–nitride platform. The SBDs are used to convert the AC power source to direct current (DC).

Key to the development was the use of a cyclic etching process involving 'dry' plasma and 'wet' solution steps to reduce surface defect energy levels interfering with the performance of the SBDs. The researchers comment: "We believe that the approach of fixing the reactive ion etching-induced defects of III-nitrides with cyclic mixed-etching could potentially be extended to the development in micro-LED display devices where the pixelated LEDs suffer from low efficiency due to the presence of high-density surface states on the pixel sidewalls."

The epitaxial material used for the AC-LEDs (Figure 1) was from a commercial off-the-shelf product supplied by "a major LED wafer manufacturer".

Inductively coupled plasma (ICP) etch to a depth of 4.5μm created isolation mesas for the SBD and LED

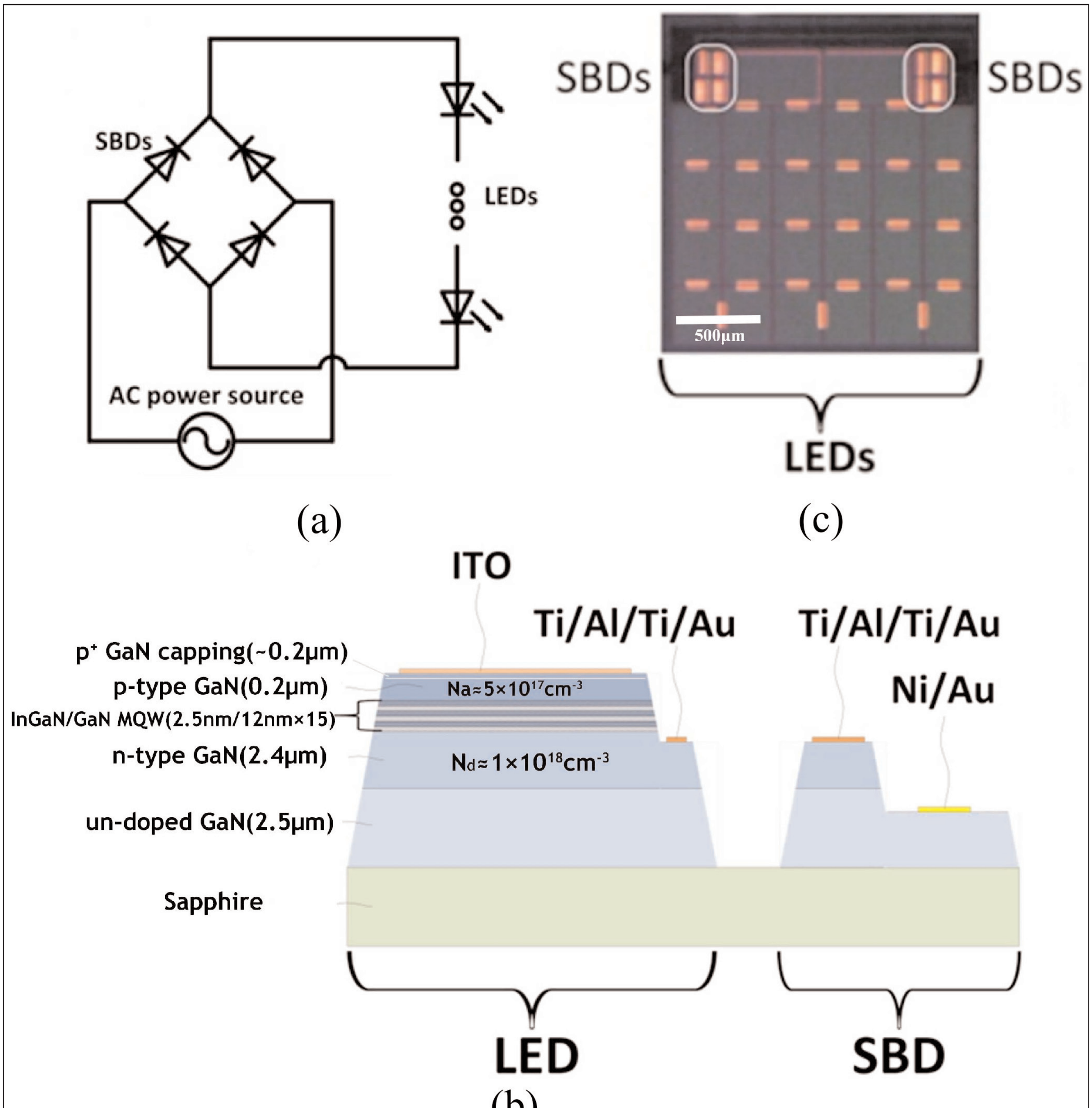



**Figure 1. (a) Circuit configuration of AC-LED. (b) Schematic of monolithically integrated LED and SBD. (c) Microphotograph of fabricated AC-LED die.**

devices. Further ICP etch exposed the n-GaN Ohmic contact regions of the LEDs at a depth of 1.2μm.

The mixed wet/dry etch process was used to remove the LED layers from the SBD mesa, leaving the unintentionally doped GaN surface. Three cycles of the mixed etch was used to give a low density of the surface defects on the unintentionally doped GaN layer of the SBD. The cycle consisted of reactive ion etch using a chlorine-based ICP, followed by boiling potassium hydroxide (KOH) solution. The unetched regions were protected using a patterned nickel hard mask. After the mixed etch, an anneal step raised the temperature to 750°C for 2 minutes in a nitrogen atmosphere.

The p-GaN contact of the LED was indium tin oxide (ITO). The n-GaN contacts of the LED and SBD consisted of titanium/aluminium/titanium/gold (Ti/Al/Ti/Au). These electron-beam evaporated contacts were designed to be Ohmic. The nickel/gold (Ni/Au) Schottky contact on the unintentionally doped GaN was thermally evaporated.

The device surfaces were passivated with plasma-enhanced chemical vapor deposition (PECVD) 500nm-thick silicon dioxide. Contact was made through the passivation using via holes. The metal interconnects for the micro-LED arrays and Schottky diode-based bridge rectifier monolithic circuit consisted of Ti/Al/Ti/Au.

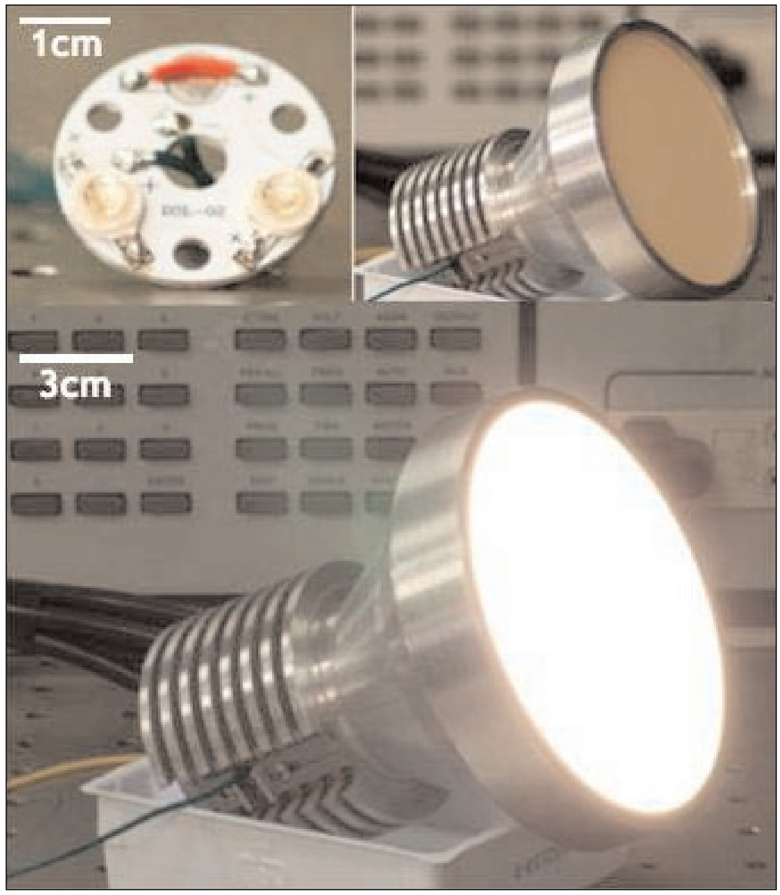


**Figure 2. Packaged AC-LED devices mounted on circuit board and prototype AC-LED lamp with remote phosphor.**

The cyclic etch process gave SBDs with a reverse breakdown voltage of more than 120V, compared with ~27V for devices produced using a conventional etch. The forward voltage of the 120V SBDs was ~2.6V at 20mA injection. The reverse leakage was less than 10μA at 100V bias.

The researchers comment: "The measurement result clearly reveals that the cyclic mixed-etching recipe developed in this work restores the ICP-etched GaN surface to device quality and suppresses the reverse leakage of the Schottky junction of Ni/GaN effectively." They further suggest that the KOH treatment removes nitrogen vacancies in the GaN, reducing the surface defect donor density.

The micro-LED pixels measured 390μmx325μm. The turn-on voltage for 0.1mA current was 2.56V. The external quantum efficiency was 41.5% at 3.8V and 25mA injection.

Single-chip AC-LED circuits were produced with lateral dimensions of 2.12mmx2mm. The monolithic circuit integrated 28 cascaded micro-LEDs and a bridge rectifier circuit of 8 SBDs. The bridge circuit used 2 SBDs in each branch to handle higher voltages. The SBD had 3 interdigitated Schottky contact fingers that were 20μm wide and spaced at 20μm intervals. The bridge circuit accounted for 11% of the device area. Putting 2 SBDs in each branch enabled rectifying voltages of up 240V, which should be sufficient to enable DC conversion of single-phase US line voltages. The AC–DC conversion efficiency of the bridge circuit was estimated to be 89% from various tests.

The chips were attached to copper heat-sinks with thermally conductive adhesive. Gold wiring connected the devices to the external leads of the packaging. The die was encapsulated in high-refractive-index silicone with a transparent hemispheric plastic cover. The device was then mounted on a printed circuit board and placed in a lamp fixture with a remote phosphor plate with the aim of producing ~5000K white light.

The AC-LED assembly was subjected to 110V root-mean-square (rms) 60Hz power. The measured rms current was 20.6mA with around 82% power factor. The luminous efficacy was 89lm/W. The researchers estimate the heat load of the SBDs at $120V_{AC}$ was 0.28W, or 9.2% of the overall LED power. The researchers comment: "This power loss is comparable with that (~10%) of a reactive ballast used in compact fluorescent lamps as reported in the general electric technical bulletin. While the incandescent lamps operate in the black-body radiation mode and do not have any drivers as well as the relevant power losses, the luminous efficacy of incandescent lamps is less than 1/5th of the AC-LED lamps reported herein." ■

https://doi.org/10.1109/TED.2019.2930467

*Author: Mike Cooke*

# Improving white LED luminous efficiency CRI

**Researchers combine phosphors, quantum dots and metal nanoparticles to fill out visible spectrum through a range of physical mechanisms and interactions.**

Researchers based in China have combined phosphors, quantum dots and metal nanoparticles to create blue-to-white light converters for indium gallium nitride (InGaN) light-emitting diodes with simultaneously improved luminous efficiency and color rendering [Rongqiao Wan et al, Optics Letters, vol44, p4155, 201]. Often improved color rendering comes at the cost of reduced luminous efficiency.

The approach adopted by Central South University, Semiconductor Lighting Technology Research and Development Center, and University of Chinese Academy of Sciences, enables a broader spectrum of light over the visible range, filling in the red end of the spectrum, compared with the lost-cost white LEDs using yellow phosphors that are presently in mass production.

The researchers combined green- and red-emitting phosphors with silver (Ag) and gold (Au) nanoparticles (NPs). The broadband green emitter consisted of cerium-doped lutetium aluminium garnet (LuAG:Ce, $Al5Lu_3O_{12}$). Core/shell cadmium selenide/zinc sulfide (CdSe/ZnS) quantum dots (QDs) in toluene solvent provided a narrowband blue-to-red converter. The Ag NPs, on average, were 15nm diameter, and the Au NPs 70nm diameter. The NPs were dispersed in toluene.

The materials were mixed into silicone gel, and the mixture was placed in vacuum for 90 minutes to remove the toluene. The gel was then dropped onto 10milx23mil 451nm blue LED chips in a lead frame. The blue electroluminescence of the LEDs had a full-width at half maximum (FWHM) of 17nm. Thermal curing at 130°C lasted 15 minutes. All the samples contained the green phosphor and red QDs, but some also contained silver (Ag-WLEDs) or silver and gold (AgAu-WLEDs) NPs to give white LEDs. The samples without NPs were designated wo-WLEDs.

The blue-to-white conversion layer was designed to take advantage of a variety of physical processes (Figure 1). The green (544nm wavelength under photoluminescence, 106nm FWHM) and red (613nm, 30nm FWHM) phosphors/QDs operated through Stokes processes of absorption of blue photons and emission of the longer-wavelength, lower-energy green and red light. Since green light has higher photon energy than red, some green-to-red conversion might also be expected. The use of QDs was also expected to add non-radiative energy transfer (NRET) channels between the green and red emitters.

The metal NPs were also hoped to provide NRET enhancement. The Ag NPs also absorbed the main blue light (454nm absorption peak) from the LED active region through localized surface plasmon resonance (LSPR). The team comments: "Due to the resonant light scattering effect, the absorption cross section of LuAG:Ce and CdSe/ZnS QDs for blue light increases, thus enhancing color conversion efficiency." Plasmons are oscillations of electron density.

The Au NPs were designed to have localized surface plasmon resonance with the green emissions (531nm peak). The researchers also suggest that the resonance may provide an environment that gives Purcell-effect

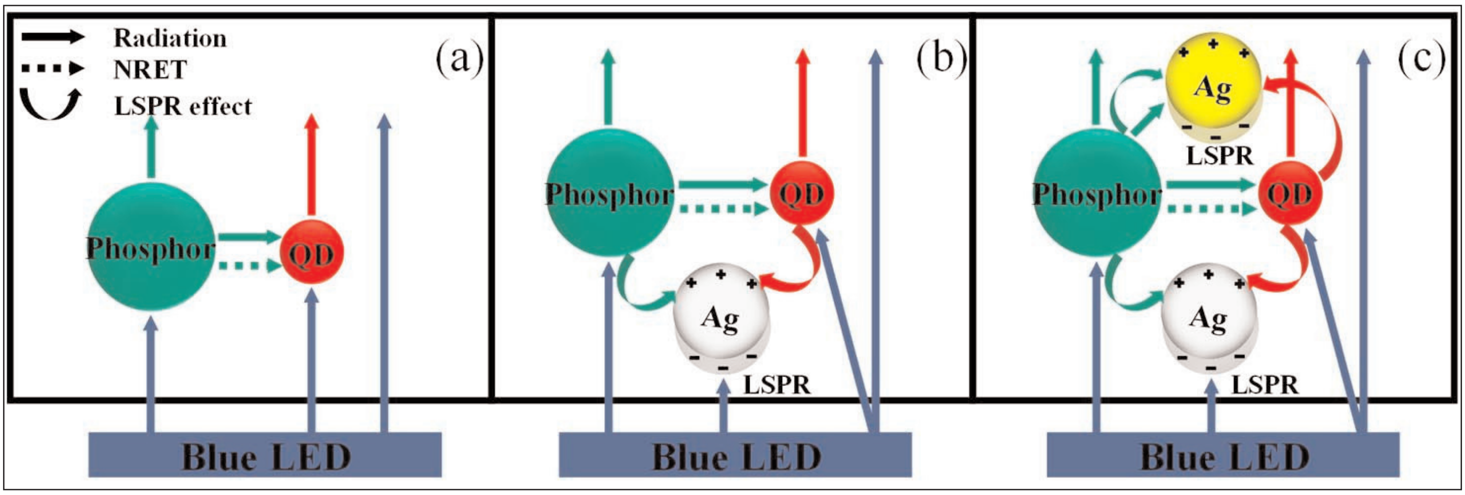



**Figure 1. Schematic mechanisms and energy transfer paths for (a) wo-WLEDs; (b) Ag-WLEDs; (c) AgAu-WLEDs.**

enhancement of spontaneous emission of the phosphor and QDs.

The researchers first investigated the improvements achievable with varied concentrations of Ag NPs (Table 1). The peak color rendering index (CRI) of 93.6 was achieved with 5 parts per million (ppm) NPs, by weight, and 4A/cm$^2$ current injection. Higher luminous efficiency (LE) of 87 lumens per watt (lm/W) was found with 3ppm NPs at 4A/cm$^2$. The 3ppm Ag-WLEDs also demonstrated the lowest correlated color temperature (CCT) of 5100K at 4A/cm$^2$. A low CCT indicates higher red and green content in the 'white' light, which is associated with 'warmer' illumination compared with regular white light.

The Ag-WLEDs were further enhanced with Au NPs (Table 2). The Ag NP concentration was fixed at 3ppm. The incorporation of 1ppm Au NPs enabled an increase in luminous efficiency to 92lm/W at 4A/cm$^2$, while the CRI and CCT were 93.2 and 5070K, respectively. Increasing the injection current to 120A/cm$^2$ enhanced the CRI to 94.5 (Figure 2). With 1.5ppm Au NPs the luminous efficiency increased to 92.5lm/W at 4A/cm$^2$, but at the cost of reduced 86 CRI.

The team expects further enhancements from "package and energy transfer structure optimization" to reduce energy losses. ■

https://doi.org/10.1364/OL.44.004155

*Author: Mike Cooke*

**Table 1. CRI, CCT and LE of Ag-WLEDs with varied NP concentrations.**

| Ag NPs (ppm) | Current density (A/cm$^2$) | CRI | CCT (K) | LE (lm/W) |
|---|---|---|---|---|
| 0 | 4 | 89 | 5800 | 81 |
| 0 | 40 | 90.8 | 6000 | 61 |
| 1 | 4 | 90 | 5500 | 82 |
| 1 | 40 | 92 | 5700 | 61 |
| 3 | 4 | 93 | 5100 | 87 |
| 3 | 40 | 91 | 5200 | 66 |
| 5 | 4 | 93.6 | 5230 | 86 |
| 5 | 40 | 92.6 | 5450 | 64 |

**Table 2. CRI, CCT and LE of AgAu-LED with varied Au NP concentrations and constant 3ppm Ag NPs.**

| Ag NPs (ppm) | Current density (A/cm$^2$) | CRI | CCT (K) | LE (lm/W) |
|---|---|---|---|---|
| 0 | 4 | 93 | 5100 | 87 |
| 0 | 40 | 91 | 5200 | 66 |
| 0.5 | 4 | 92 | 4750 | 89 |
| 0.5 | 40 | 89 | 4880 | 67 |
| 1 | 4 | 93.2 | 5070 | 92 |
| 1 | 40 | 92 | 5200 | 68 |
| 1.5 | 4 | 86 | 4950 | 92.5 |
| 1.5 | 40 | 84.3 | 5010 | 69.5 |

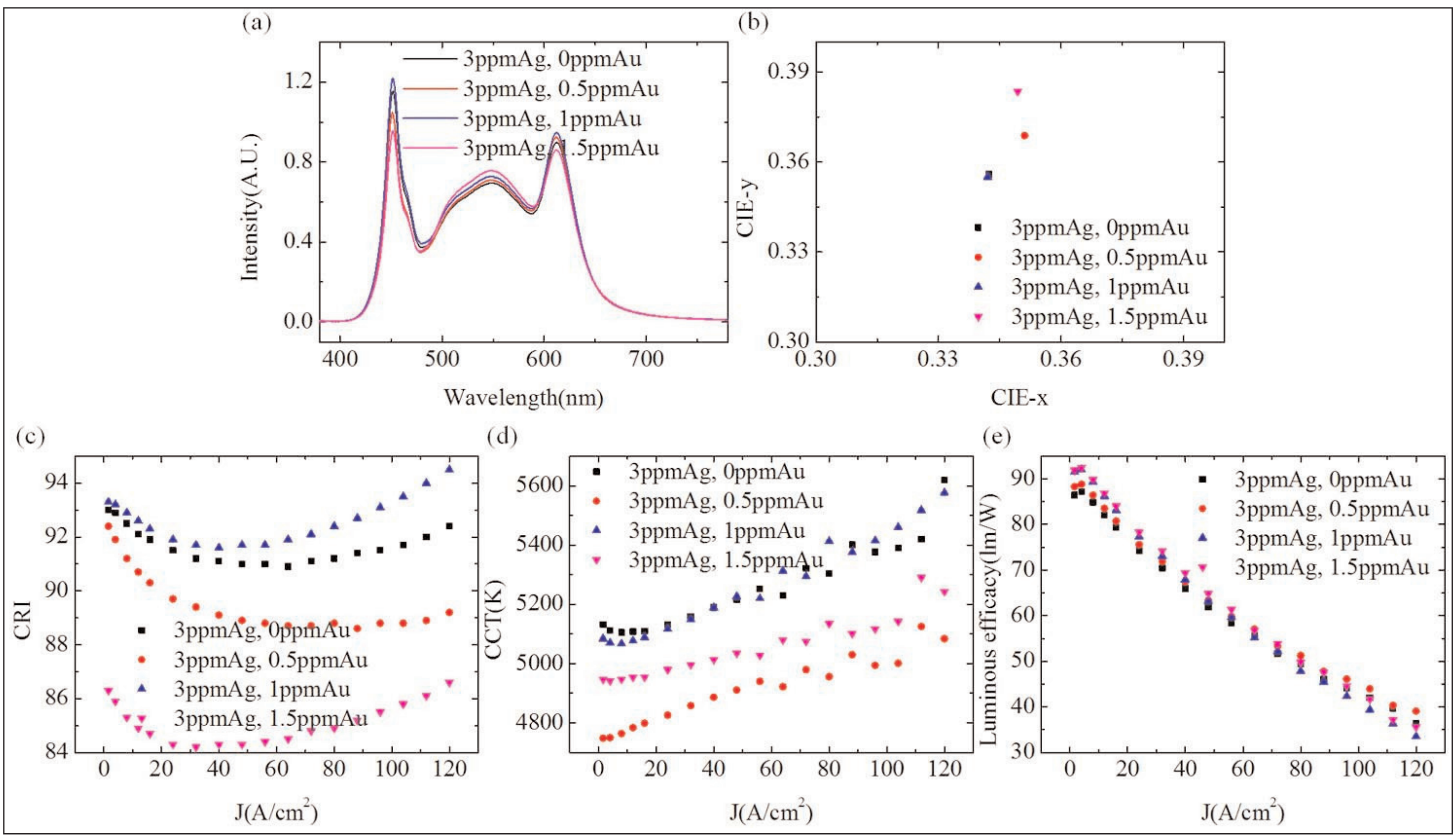



**Figure 2. (a) Electroluminescence spectra of Ag-WLEDs and AgAu-WLEDs with varied concentration of Au NPs and constant 3ppm Ag concentration under 20mA (16A_cm$^2$) injection current. (b) CIE-1931 chromaticity coordinates of AgAu-WLED, (c) CRI, (d) CCT and (e) LE of Ag-WLEDs and AgAu-WLEDs versus current density.**

# Micro-LED technologies make significant progress over last 18 months

**But challenges remain before ramping up for large-volume consumer applications, says Yole Développement.**

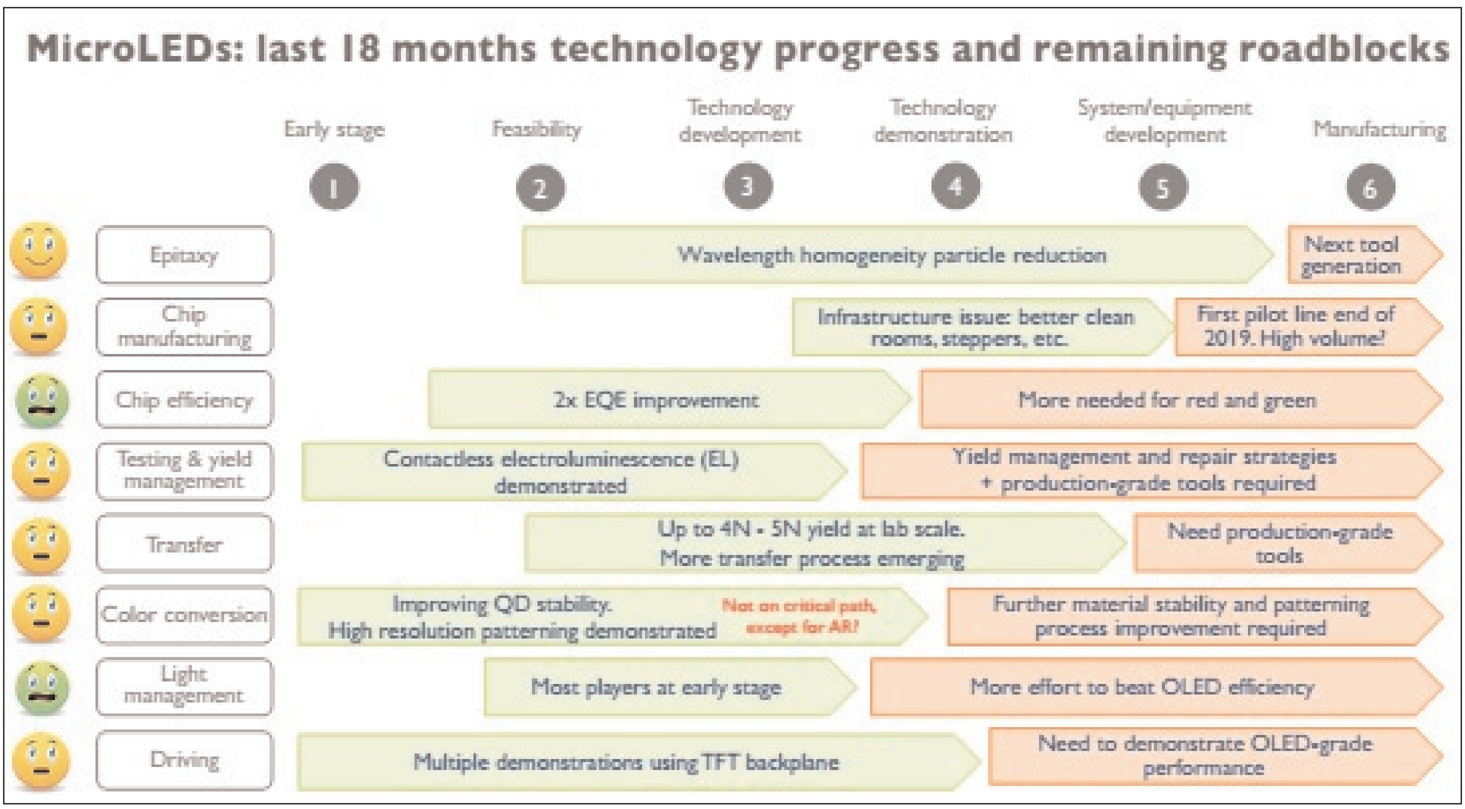
With micro-LEDs drawing an increasing amount of attention, startups have raised more than $800m to date, including at least $100m in 2019, and Apple has spent $1.5–2bn on the technology over the last five years, reckons market analyst firm Yole Développement in its report 'MicroLED Displays'. Panel makers such as Samsung Display, LG Display, AUO or Innolux have also significantly increased their efforts.

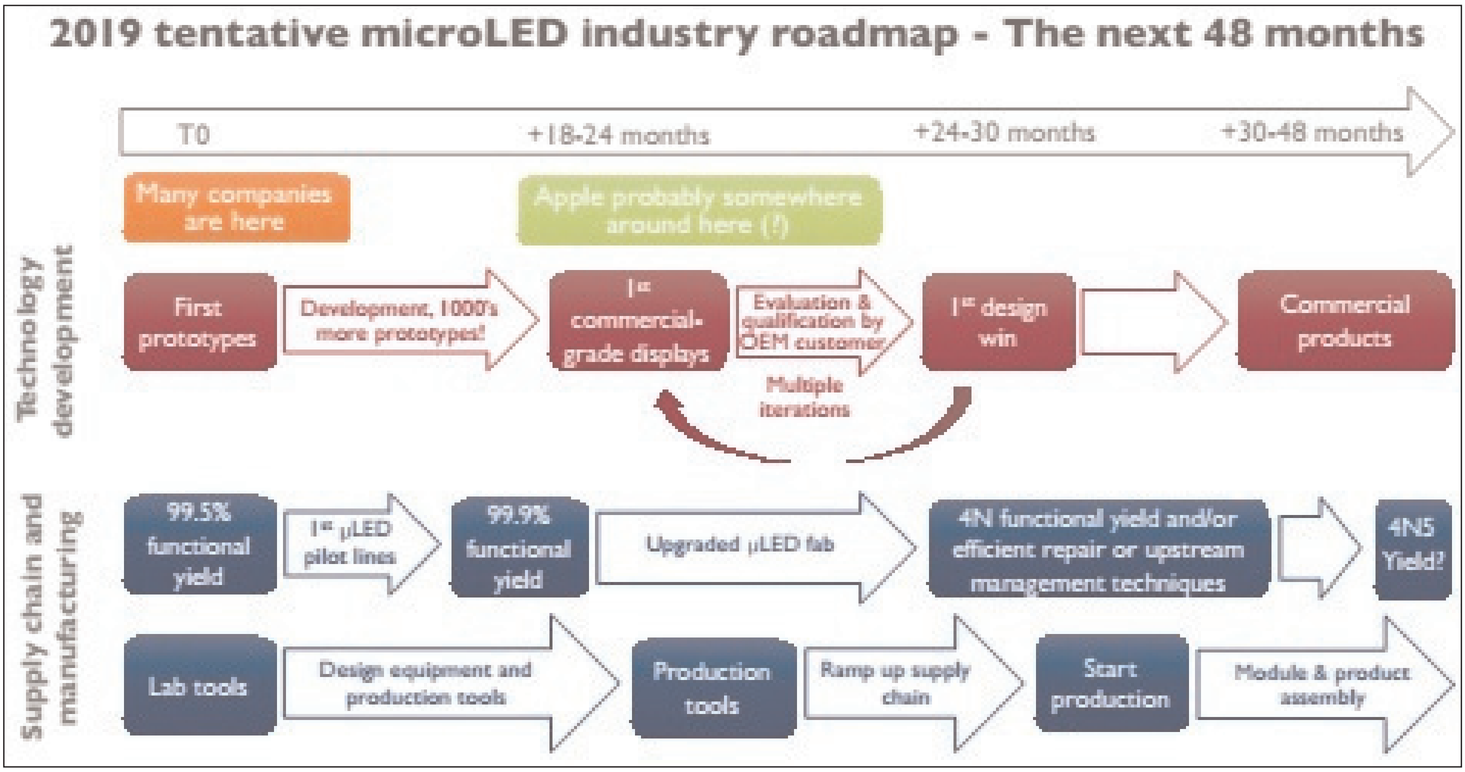
"Without doubt, micro-LEDs are today progressing on all fronts," says principal display market & technologies analyst Eric Virey PhD. Patent filings are growing exponentially and technology is progressing. The external quantum efficiency of blue and green micro-LED chips has more than doubled over the past 24 months. Some transfer and assembly processes are reaching performance close to what is required to enable some micro-LED consumer applications. Progress is also visible in the proliferation of prototypes presented over the last 18 months by nearly 20 companies.

"The demos cover a broad range of display types, sizes and technologies," notes technology & market analyst Zine Bouhamri PhD, part of the Display team at Yole.

"Native RGB or color-converted displays on TFT [thin-film transistor] backplanes are offered by many companies, with some examples including Playnitride, CSOT, Samsung, LG, gl_, AUO, eLux and Kyocera. Lumiode has developed native RGB or color-converted displays on monolithically integrated LTPS [low temperature polysilicon]," he adds.

Micro-displays on CMOS backplanes have also been demonstrated by companies including Plessey, glo, Lumens, JB Display, Sharp and Ostendo. Finally,

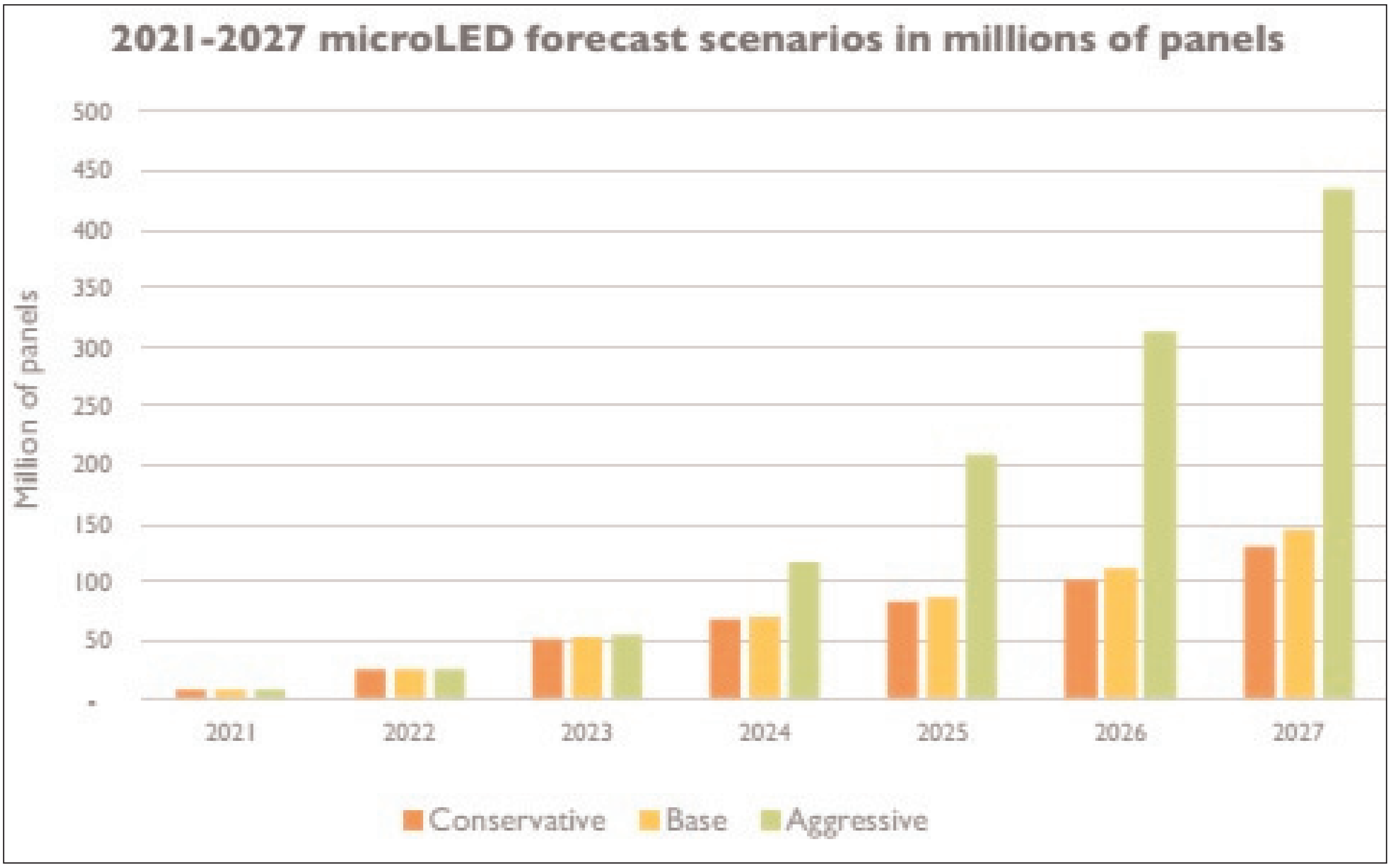





discrete micro-driver ICs have been developed by X-Display. The multiple prototypes based on TFT backplanes give credence to the idea that micro-LED displays could leverage existing panel makers' capacity, simplifying and streamlining the supply chain.

"Equipment makers have taken notice and are starting to develop micro-LED-specific tools for assembly, bonding, inspection, testing and repair," notes Eric Virey of Yole.

LED makers are also showing interest, with San'an planning to invest $1.8bn to set up a mini- and micro-LED manufacturing base. Osram, Seoul Semiconductor, Nichia and Lumileds are also increasing their activity and Playnitride is completing its first micro-LED pilot line.



However, significant roadblocks still exist for key applications. For many of them, economics are pushing die size requirements below 10μm. This compounds efficiency, transfer and manufacturability challenges and, despite significant improvement, small-die efficiency remains low. In most cases, display efficiency based on this technology still cannot match that of organic light-emitting diode (OLED) technology. Significant effort is therefore needed to further improve the internal quantum efficiency, light extraction and beam shaping of green and red micro-LED chips.

For micro-LED companies, the first few prototypes provide useful experience, but maturing toward consumer-grade displays could require thousands more. Startups are entering the 'valley of death': many might fail to raise enough money to successfully go through this more capital- and resource-intensive phase. Support from and partnership with large display makers or OEMs, either as strategic investors or development partners, is therefore critical, concludes Yole.

Bouhamri is presenting key results of Yole's micro-LED analysis in 'Impressive Technologies for MicroLED Displays' on 29 November at the International Display Workshop (IDW '19) in Sapporo, Japan (27–29 November). ■

**www.idw.or.jp**
**www.i-micronews.com/products/microled-displays-2019**

# Implementing III–nitride light-emitting devices on silicon substrates

**Mike Cooke reports on recent advances in putting indium gallium nitride laser, superluminescent and light-emitting diodes on silicon using epitaxy and wafer-bonding technologies.**

Silicon has been the electronics material of choice since the 1960s when mass production of complementary metal-oxide-semiconductor (CMOS) integrated circuits opened the way to the multiple communication technologies that dominate our thought-world today, at least in the rich countries of the West and east Asia.

One of the main drivers of this trend has been the low cost of the basic material and its combination with silicon dioxide ($SiO_2$) insulation. These materials are also increasingly being deployed in photonics applications, but suffer from the lack of low-cost light generation in group IV semiconductors like silicon.

Combining light-emitting III–V semiconductors with silicon at low cost is the project of many research groups around the world. In the short-wavelength visible and ultraviolet ranges, that means 'group III' metal — gallium, indium and aluminium — nitrides.

Although silicon-substrate indium gallium nitride (InGaN) light-emitters should be manufacturable at less expense, efficiencies suffer from the energy-sapping effects of high defect levels. One problem has been that the lattice mismatch between silicon and gallium nitride (GaN) is about 17%. The thermal expansion mismatch is even greater — around 54%. The lattice/thermal mismatches are presently bridged by using various aluminium gallium nitride (AlGaN) alloy layers before the main device layers.

The integration of InGaN light generation into a silicon platform raises the prospect of complex visible-light photonics and optoelectronics through waveguides, photodetectors and CMOS drive and control circuitry.

Here we examine recent advances in putting InGaN laser, superluminescent and light-emitting diodes on silicon using epitaxy and wafer-bonding technologies.

## Reducing laser power losses

Researchers in China have reduced the point defects in InGaN laser diode (LD) material on silicon with the aim of reducing operating voltages and injection current and increasing device efficiency [Jianxun Liu et al, Optics Express, vol. 27, p25943, 2019]. Laser diodes on silicon tend to have high threshold currents and voltages, indicating high electrical and optical power losses.

The research team from Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO), University of Science and Technology Beijing, and University of Science and Technology of China, developed a lower-temperature growth process and alternative material structure in particular layers to reduce threshold currents and voltages by an approximate factor of 2 (72mA/150mA, 4.7V/8.2V).

The laser diode material (Figure 1) was grown on (111) Si with metal-organic chemical vapor deposition (MOCVD). The n-GaN contact layer was 2.7μm, while the lower cladding was 1.2μm n-$Al_{0.05}Ga_{0.95}N$. The multiple quantum well (MQW) active layer consisted of three pairs of 2.7nm/12nm 770ºC $In_{0.12}Ga_{0.88}N/In_{0.02}Ga_{0.98}N$. The top p-GaN contact was 30nm thick, and the electron layer (EBL) was $Al_{0.2}Ga_{0.8}N$.

Two laser diode material samples, A and B, were produced (Table 1). Sample B used cooler growth temperatures in the lower and upper waveguides (WGs), and in the p-type contact layer (CL) superlattices (SLs). Lower temperatures reduced thermal degradation of the MQW region and carbon incorporation from the organic precursors used.

Carbon tends to compensate, reducing the effectiveness of the magnesium doping used for the p-type layers needed for hole injection. This is expected to increase series resistance and operation voltage, adding to laser diode power losses. Lower carbon levels are also associated with lower optical absorption.

The researchers comment: "It is noted that the adoption of InGaN/GaN SL WG would cause little effect on the thermal conductivity of the laser diode structure, because there was only a trace amount (1% in average) of indium in such SL WGs (sample B), and the total

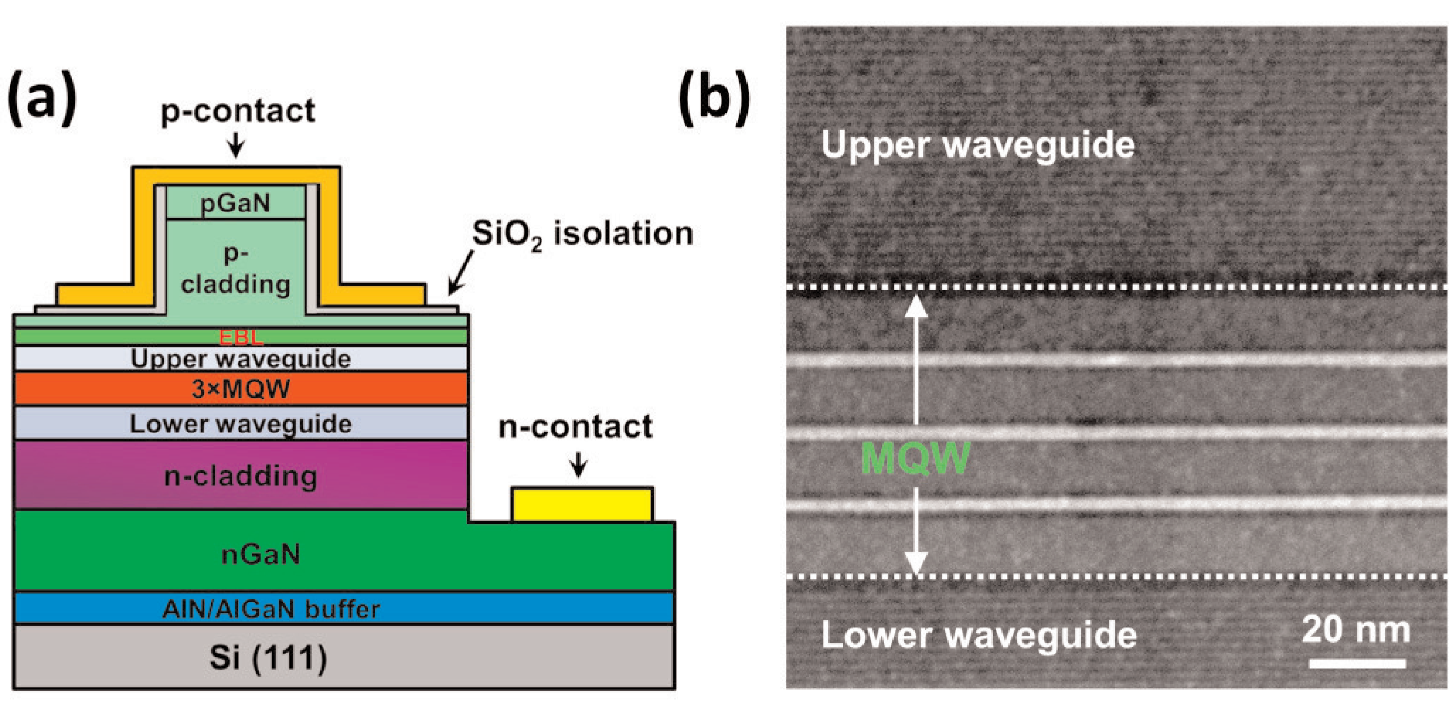



**Figure 1. (a) Schematic diagram of InGaN-based laser diodes grown on silicon. (b) Cross-sectional high-angle annular dark-field scanning transmission electron micrograph of InGaN MQW active region.**

thickness of the $In_{0.01}Ga_{0.99}N$ layer was only 70nm (40nm and 30nm for the lower and upper waveguide, respectively), which was negligibly smaller than that of the AlGaN cladding layers (1.8μm in total) and the n-GaN contact layers (2.7μm)."

Due to the lower growth temperatures, microscopic inspection of photoluminescence (PL) in sample B showed greater uniformity, compared with sample A. The more even PL suggests less degradation of the delicate MQW region. In addition, sample A suffered from a short decay time of 3.5ns, compared with 6.3ns for B, in time-resolved PL. The researchers suggest that the faster decay is due to non-radiative Shockley–Read–Hall (SRH) recombination through mid-gap defect levels. The team adds that SRH recombination results in reduced internal quantum efficiency (IQE, photons/electron) and increased junction temperatures and threshold currents.

The researchers also attribute some of the improvement in sample B's IQE to replacement of the waveguide layer with InGaN SLs. The high-temperature GaN material tends to contain vacancies on the Ga ion site. Reducing the number of vacancies reduces optical absorption from strong band-tail effects. The silicon doping of the n-GaN layer also contributes band-tail energy states. "Such absorption will increase the internal optical loss and reduce the IQE, resulting in an increase in junction temperature and threshold current for the laser diodes," the team writes.

The team fabricated edge-emitting laser diodes with ridges 800μm long and 4μm wide. The cleaved front and rear facets of the laser diodes were coated with titanium dioxide/silicon dioxide ($TiO_2/SiO_2$) multi-layers to increase reflectivity with low optical loss.

Electroluminescence experiments (Figure 2) demonstrated lasing peaks at 413.4nm and 418nm for samples A and B, respectively. The laser diodes were operated in 400ns pulse mode with 10kHz repetition to avoid self-heating effects. The wavelength difference is attributed tentatively to differences in MQW growth temperatures, which can significantly affect indium incorporation.

Sample B showed reduced threshold voltage — 4.7V, compared with 8.2V for sample A. The threshold current for B was also about half that of A: 72mA ($2.25kA/cm^2$) versus 150mA ($4.7kA/cm^2$). Reduced current and voltage, and hence input power, for a given output mean increased efficiency.

In lifetime tests under pulsed-mode operation, sample B laser diodes showed little degradation in output power after 620 hours, unlike devices based on sample A material.

**Table 1. Comparison of growth conditions between samples A and B.**

| Layer/Sample | A | B |
|---|---|---|
| p-type CL SL, 600nm | 950ºC p-$Al_{0.11}Ga_{0.89}N$/GaN | 920ºC p-$Al_{0.11}Ga_{0.89}N$/GaN |
| Upper WG, 60nm | 1050ºC u-GaN | 770ºC u-$In_{0.01}Ga_{0.99}N$/GaN SL |
| Lower WG, 80nm | 1050ºC n-GaN | 770ºC u-$In_{0.01}Ga_{0.99}N$//GaN SL |

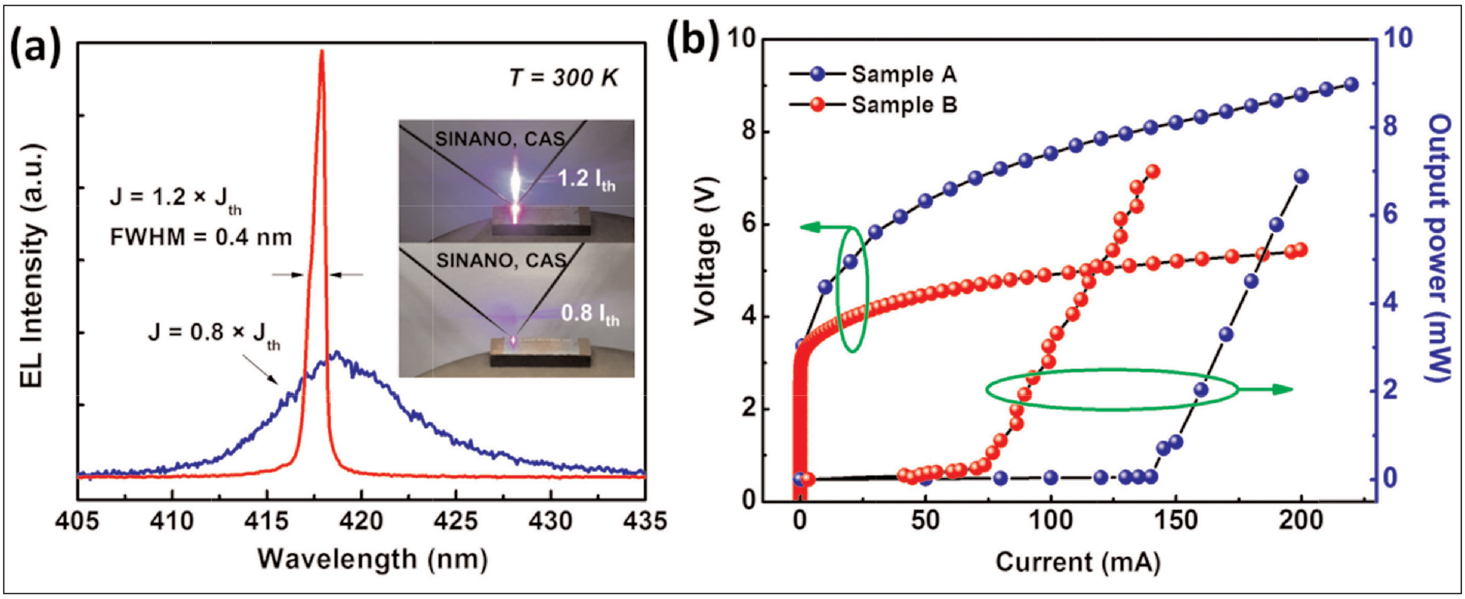



**Figure 2. (a) EL spectra of sample B above (1.2x) and below (0.8x) threshold current. Inset: corresponding far-field patterns. (b) On-bar light output power-current-voltage (L–I–V) characteristics under pulsed injection for samples A and B.**

## Superluminescent displays and communication

The same group of institutions, and many of the same researchers, have also developed InGaN superluminescent diodes (SLDs) monolithically integrated on silicon substrates [Jianxun Liu et al, ACS Photonics, vol6 (2019) no8, p2104]. The team sees opportunities for compact on-chip light sources for speckle-free displays and visible light communications (VLC).

The researchers used MOCVD on (111) Si substrates to create the III–nitride structure (Figure 3) for the SLD (Figure 4). The index-guided SLD featured a 4μm-wide ridge, which was J-shaped to suppress optical feedback oscillation in the 800μm-long cavity. Optical feedback runs the risk of laser action, which is not desired in SLDs. The J-bend of 6º occurred halfway down the cavity. The bend resulted in a facet that was not perpendicular to the cavity direction, allowing light to escape more easily.

The ridge waveguide and device mesa were formed with plasma etch. The p- and n-electrodes consisted, respectively, of palladium/platinum/gold and titanium/platinum/gold. After thinning, lapping and chemical mechanical planarization (CMP), the wafer was cleaved into bars containing 24 devices each. Comparison laser diodes were produced with straight waveguides. The devices were tested without packaging or facet coating.

The superluminescence of the device was demonstrated from the reduction in linewidth as the current injection increased from 400mA to 800mA, giving a reduction in full-width at half-maximum (FWHM) from 13.8nm (102meV) to 3.6nm (26meV), respectively (Figure 5). The main part of the reduction of FWHM occurred around 500mA when the value was 8.5nm (67meV), indicating the main onset of amplified spontaneous emission (ASE). In laser diodes, the reduction in FWHM is sharper, and generally results in linewidths narrower than 1nm — the fabricated comparison laser diodes had FWHMs of ~0.5nm (3.7meV) above threshold.

As the current through the SLD increased, there was at first a red-shift and then a blue-shift of the electrolumi-

| | | |
|---|---|---|
| Contact | $p^+$-GaN | 30nm |
| Cladding (p-type) | 132x($Al_{0.2}Ga_{0.8}N$/GaN) | 132x(1.5nm/3nm) |
| Electron blocking | p-$Al_{0.2}Ga_{0.8}N$ | 20nm |
| Waveguide | 30x($In_{0.02}Ga_{0.98}N$/GaN) | 30x(1nm/1nm) |
| Quantum wells | 3x($In_{0.12}Ga_{0.88}N$/$In_{0.02}Ga_{0.98}N$) | 3x(2.7nm/12nm) |
| Waveguide | 40x($In_{0.02}Ga_{0.98}N$/GaN) | 40x(1nm/1nm) |
| Cladding (n-type) | 14x($Al_{0.085}Ga_{0.915}N$/GaN) | 14x(75nm/10nm) |
| Contact | n-GaN | 1.3μm |
| Buffer | GaN | 1.4μm |
| Buffer | $Al_{0.17}Ga_{0.83}N$ | 450nm |
| Buffer | $Al_{0.35}Ga_{0.65}N$ | 340nm |
| Nucleation | AlN | 300nm |
| Substrate | (111) Si | |

**Figure 3. III–nitride epitaxial structure of SLD, using combinations of AlInGaN alloys.**

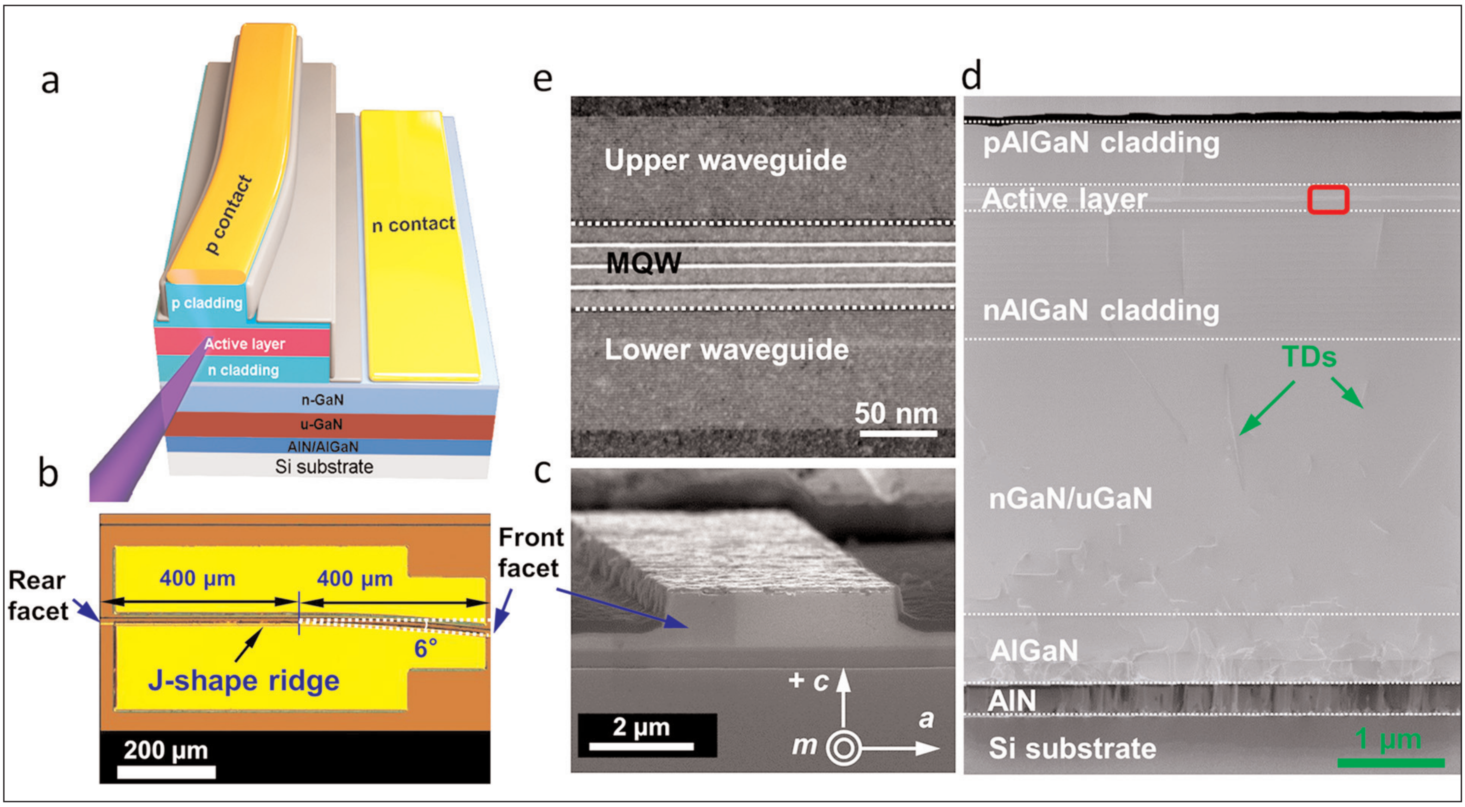



**Figure 4. (a) Three-dimensional illustration of InGaN-based SLDs grown on silicon with J-shaped ridge waveguide. (b) Top-view optical microscopy image of bar of InGaN-based SLDs after facet cleavage. (c) Scanning electron microscope image of cleavage facet. (d) Cross-sectional scanning transmission electron microscope (STEM) image. Total thickness of epitaxial layer was 5.8μm. (e) Enlarged STEM image of marked zone in (d).**

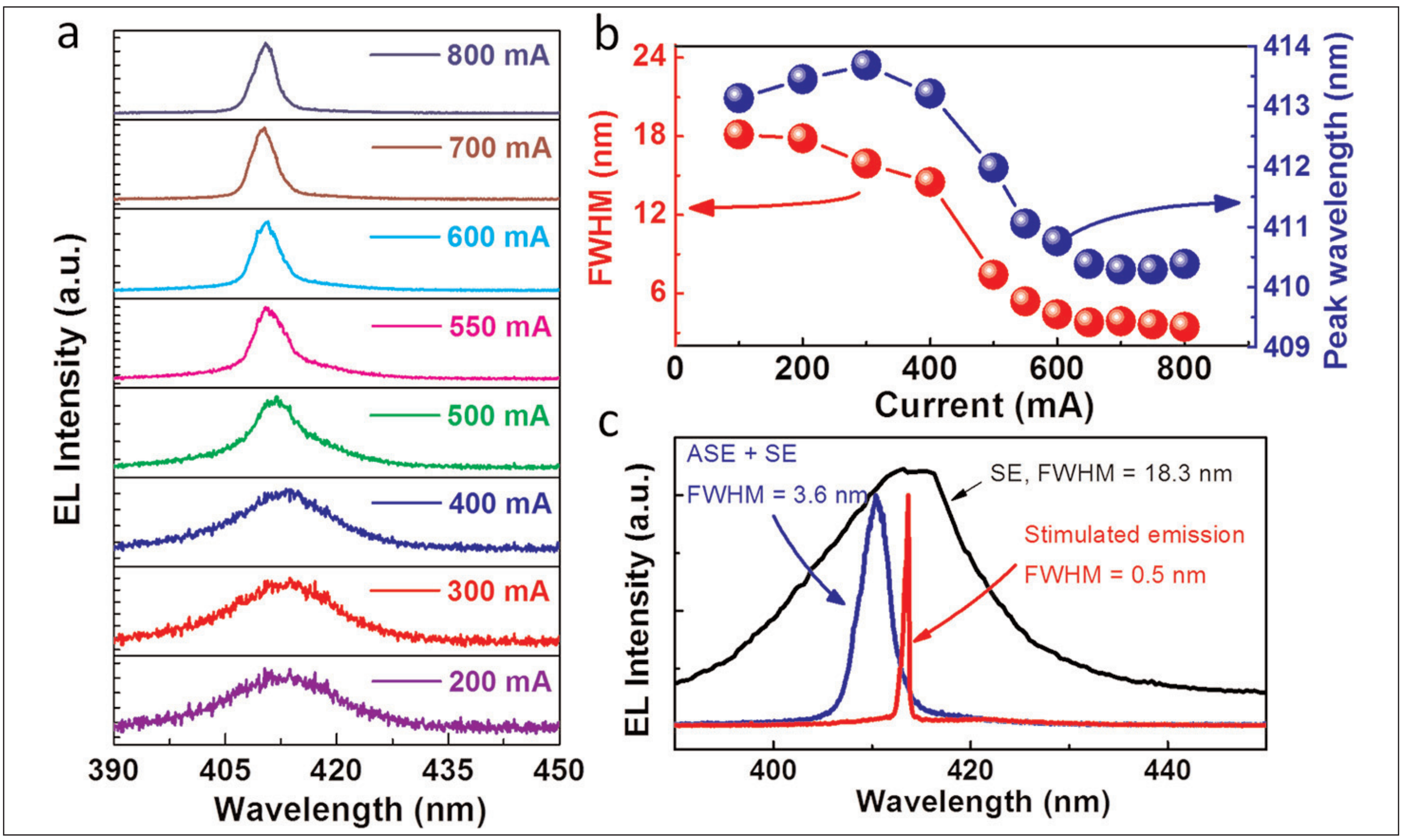



**Figure 5. (a) EL spectra of SLD under various pulsed injection current at room temperature. (b) Peak wavelength and FWHM as function of injection current. (c) Comparison of EL spectra for SLD below threshold (100mA), above threshold (800mA), and stimulated emission from laser diode (250mA) with identical epitaxial design.**

nescence (EL) peak wavelength. The researchers comment: "The observed red-shift under a low injection current can be attributed to the bandgap narrowing resulting from many-body effects. While the blue-shift of the EL peak under a high injection current can be explained by combined effects of the band-filling effect and the carrier-induced screening of the quantum-confined Stark effect." The quantum-confined Stark effect refers to the electric field that arises in III–nitride semiconductor heterostructures due to the charge-polarization of the chemical bonds. The effect tends to shift electron energy levels and to negatively impact electron-hole recombination into photons.

The transition from spontaneous emission to amplified spontaneous emission was also reflected in optical polarization measurements. Even below threshold, the emissions were dominated by the transverse electric (TE) modes of the waveguide structure. The degree of polarization, as expressed by the difference in TE and transverse magnetic (TM) emission relative to the total emission, increased from 84% to 97.6% between 400mA and 600mA injection. The 97.6% value is said to correspond to 20dB polarization extinction ratio (I make it 19dB, but I may have worked from a different definition).

Comparing SLD and comparison laser diode threshold currents, the former occurred around 550mA while the latter achieved lasing around 230mA, less than half the value of the SLD.

The SLD light output power began to saturate at 1100mA injection, and rolled off at 1400mA when about 2.5mW. Although the power was measured under pulsed injection, the saturation and roll-off was attributed to heating effects. "A significant improvement in optical output power is expected for the SLDs by applying anti-reflection coating to the cavity facets and adopting proper packaging with good heat dissipation," the team writes.

Current–voltage and capacitance–voltage measurements were used to assess the resistance–capacitance (RC) bandwidth of the devices. The series resistance was estimated at 2.8Ω for the SLD, on the basis of the linear section of the current–voltage plot between 150mA and 400mA injection. A similar estimate for the laser diode gave 2.6Ω series resistance. A 1MHz modulated signal with the diode biased between −8V and +2V gave a capacitance estimate of 32.5pF at −4V bias, representing deep depletion in the diode (34.4pF for the laser diode). The RC time constant for the SLD was 90ps, representing a frequency of 1.77GHz. This opens up VLC opportunities.

## Vertical light-emitting diodes

A different group of researchers in China have integrated high-power, reliable vertical InGaN light-emitting diodes on 4-inch silicon substrates using wafer bonding methods [Shengjun Zhou et al, Optics Express, vol27, pA1506, 2019]. The team from Wuhan University, Changchun Institute of Optics, Fine Mechanics and Physics, and Xiamen Changelight Co Ltd used a number of measures to improve the performance of the final LEDs by reducing current crowding and protecting the device structure from humidity.

The device layers were grown on patterned sapphire substrates using MOCVD (Figure 6). The LED fabrication began with inductively coupled plasma (ICP) etch into 1mmx1mm mesas for electrical isolation. A $SiO_2$ current-blocking layer (CBL) was applied using plasma-enhanced CVD and patterning into 15μm-wide strips via photolithography and buffered-oxide wet etch (Figure 7).

Ion-beam sputtering applied a 100nm silver film as reflector, followed by titanium/tungsten as a diffusion barrier. After electron-beam deposition of a platinum/titanium cap, rapid thermal annealing at 600ºC was used to improve the GaN/silver ohmic contact.

The 4"-diameter p-Si final device substrate was prepared by adding multi-layers of titanium/platinum/gold and a titanium/platinum cap. A 2.5μm layer of indium was applied to the p-Si substrate before thermal compression bonding at 230ºC. One feature of the titanium adhesion layer was that it also acted as a barrier against poisoning of the p-Si with gold. Platinum contamination of the p-Si was also avoided, according to energy-dispersive x-ray analysis.

A 248nm krypton-fluoride excimer laser was used to perform lift-off separation of the sapphire growth substrate.

| | | |
|---|---|---|
| Contact | p-GaN | 110nm |
| Electron blocking | p-AlGaN/GaN superlattice | 48nm |
| Multiple quantum well | 12x(InGaN/GaN) | 12x(3nm/10nm) |
| Strain release | InGaN/GaN superlattice | 200nm |
| Contact | n-GaN | 3μm |
| Buffer | GaN | 2.5μm |
| Nucleation | GaN | 30nm |
| Substrate | Sapphire | |

**Figure 6. Vertical LED device layer MOCVD growth sequence.**

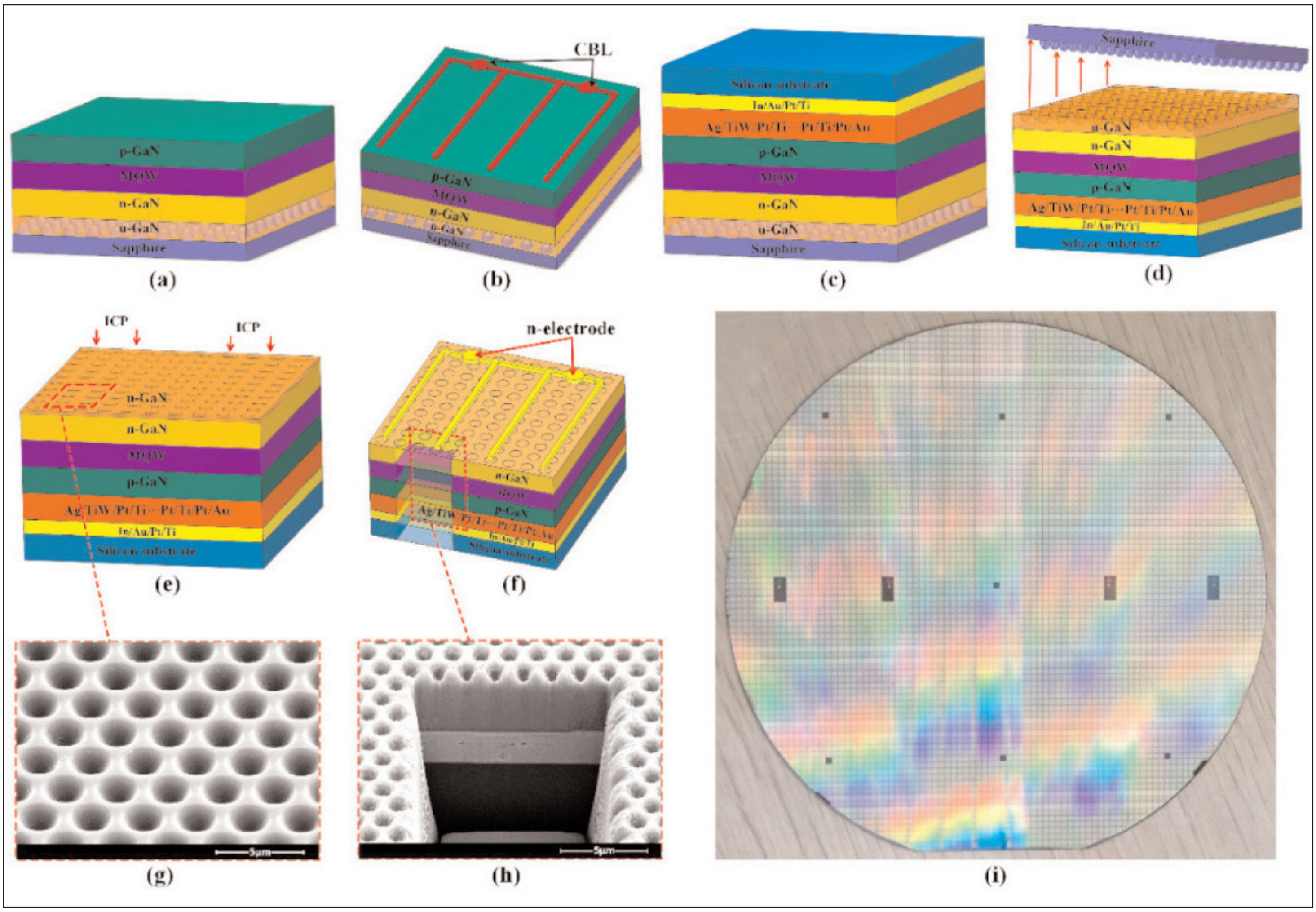



**Figure 7. Fabrication process of LEDs: (a) MOCVD growth; (b) defining $SiO_2$ CBL; (c) metal deposition and bonding to silicon wafer; (d) laser lift-off (LLO) removal of sapphire substrate; (e) ICP etch to n-GaN contact; (f) deposition of p- and n- electrodes. (g) Scanning electron microscope (SEM) image of exposed n-GaN surface with hemispherical dimples after LLO and ICP etching. (h) Cross-section SEM image of LEDs bonded to silicon wafer. (i) Photograph of LEDs on 4" silicon wafer; colors arise from thin-film interference effects.**

This was followed by ICP etch down to the n-GaN contact layer.

The n-GaN was treated with potassium hydroxide (KOH) or phosphoric acid ($H_3PO_4$) solution to texture the surface for improved light extraction. Chromium/platinum/gold was used to form the p- and n-electrodes for the LED. The n-contact metals were formed into 12μm-wide fingers.

The $SiO_2$ CBL around the opaque electrodes directed current away from this region and made for more uniform current density in the light-emitting areas, according to simulations. Along with the vertical structure, it was hoped the CBL would reduce self-heating, making for more efficient performance over lateral structure devices. Current crowding leading to self-heating is a major problem in conventional lateral structure LEDs.

The vertical LED structure enabled much lower forward voltages for a given current injection — 2.87V at 350mA, compared with 3.52V with a conventional lateral LED structure (Figure 8). Lower forward voltage indicates lower input power and hence higher power efficiency. The light output power (LOP) for a given current injection was also higher in the vertical LED: the lateral LED output saturated at ~320mA, while the vertical device increased in light power up to 1300mA. "The absence of premature LOP saturation in V-LEDs was attributed to reduced current crowding and enhanced heat dissipating compared to L-LEDs," the team writes.

With 350mA, the vertical LED output power was 501mW, beating a previous report of a GaN vertical blue LED of ~450mW at the same injection. The researchers comment: "The higher LOP demonstrated in this work confirmed that integrating the optimized metallization scheme, $SiO_2$ CBL and surface texturing by KOH wet etching is an effective approach to higher performance V-LEDs."

[I get a crude output/input power efficiency value of 50% (501mW/(2.87Vx350mA).]

The researchers also developed a platinum/titanium protective wrap-around layer for the silver/titanium-

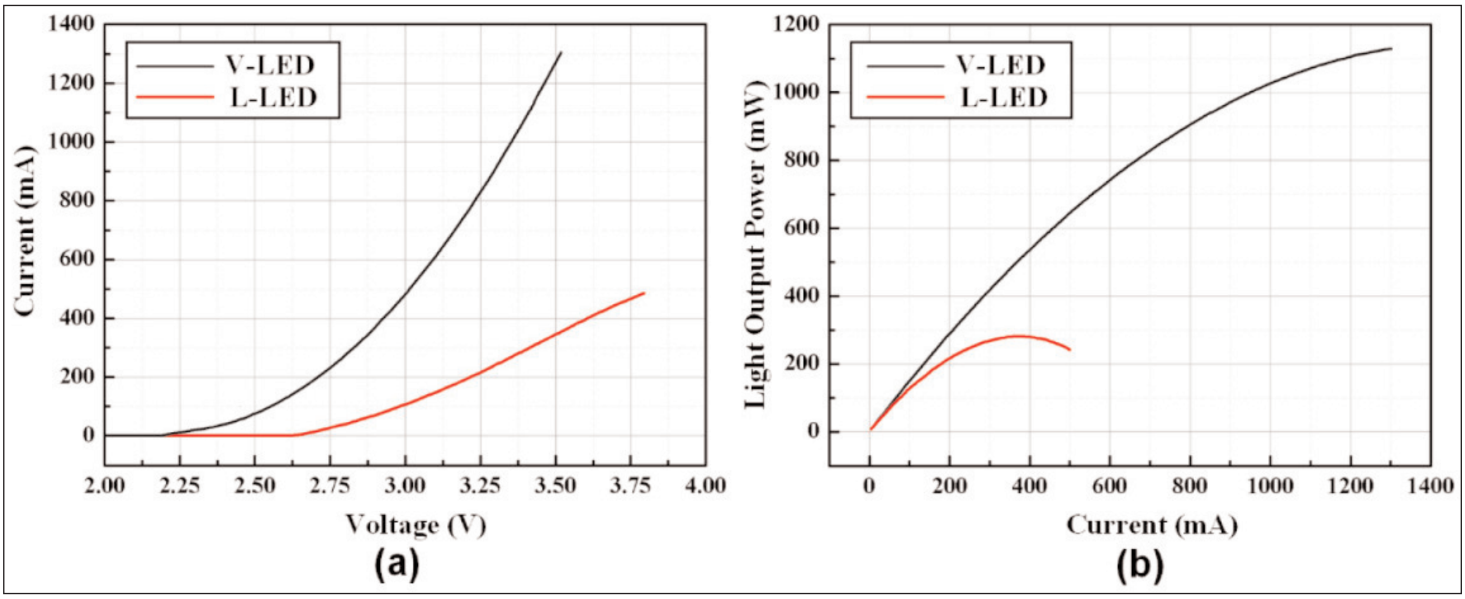



**Figure 8. (a) Current–voltage profiles of lateral (L-) and vertical (V-)LEDs. (b) Light output power–current characteristics.**

tungsten alloy structure. The wrap-around structure protected the mirror contact from humidity degradation. Operation at 85ºC and 85% relative humidity degraded the performance of LEDs without lateral wrap-around protection over 1000 hours. By contrast, the LEDs with wrap-around platinum/titanium showed "negligible optical degradation even after an aging time of 1008h," according to the researchers. ■

*The author Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.*

# High-frequency InAlN barrier transistors on silicon

**Researchers claim record 16GHz-µm cut-off-gate-length product for gallium nitride channel HEMTs.**

University of Delaware in the USA claims a record for radio frequency (RF) performance of indium aluminium nitride (InAlN)-barrier gallium nitride (GaN) high-electron-mobility transistors (HEMTs) on silicon [Peng Cui et al, Appl. Phys. Express, vol12, p104001, 2019]. The device also demonstrates records for direct current (DC) characteristics such as low gate leakage, high on/off current ratio, and subthreshold swing, according to the researchers.

Usually for high performance, GaN HEMTs are produced on very expensive silicon carbide (SiC) substrates. Growth on low-cost, large-diameter silicon should open up more economic opportunities for high-power and high-frequency GaN-based devices.

Metal-organic chemical vapor deposition (MOCVD) on (111) resulted in an epitaxial structure with a 2µm undoped GaN buffer, a 4nm $In_{0.12}Ga_{0.88}N$ back-barrier, a 15nm GaN channel, a 1nm AlN interlayer, an 8nm lattice-matched $In_{0.17}Al_{0.83}N$ barrier, and a 2nm GaN cap. Hall measurements gave sheet electron concentration and electron mobility values in the two-dimensional electron gas (2DEG) channel of $2.28x10^{13}/cm^2$ and $1205cm^2/V\text{-}s$, respectively.

Device fabrication included plasma reactive-ion etch of isolation mesas, and alloying of titanium/aluminium/nickel/gold ohmic source-drain contacts at 850°C. The source–drain distance was 2µm. The researchers used an oxygen plasma treatment to oxidize the surface between the source and drain with the aim of reducing gate leakage current ($I_g$) and improve RF performance. The 80nm-long nickel/gold gate was centered in the source-drain gap.

The oxygen plasma treatment increased the on/off current ratio ($I_{on}/I_{off}$) by a factor of around two to reach $1.58x10^6$. Another benefit was a reduction in subthreshold swing (SS) from 76mV/decade to 65mV/decade.

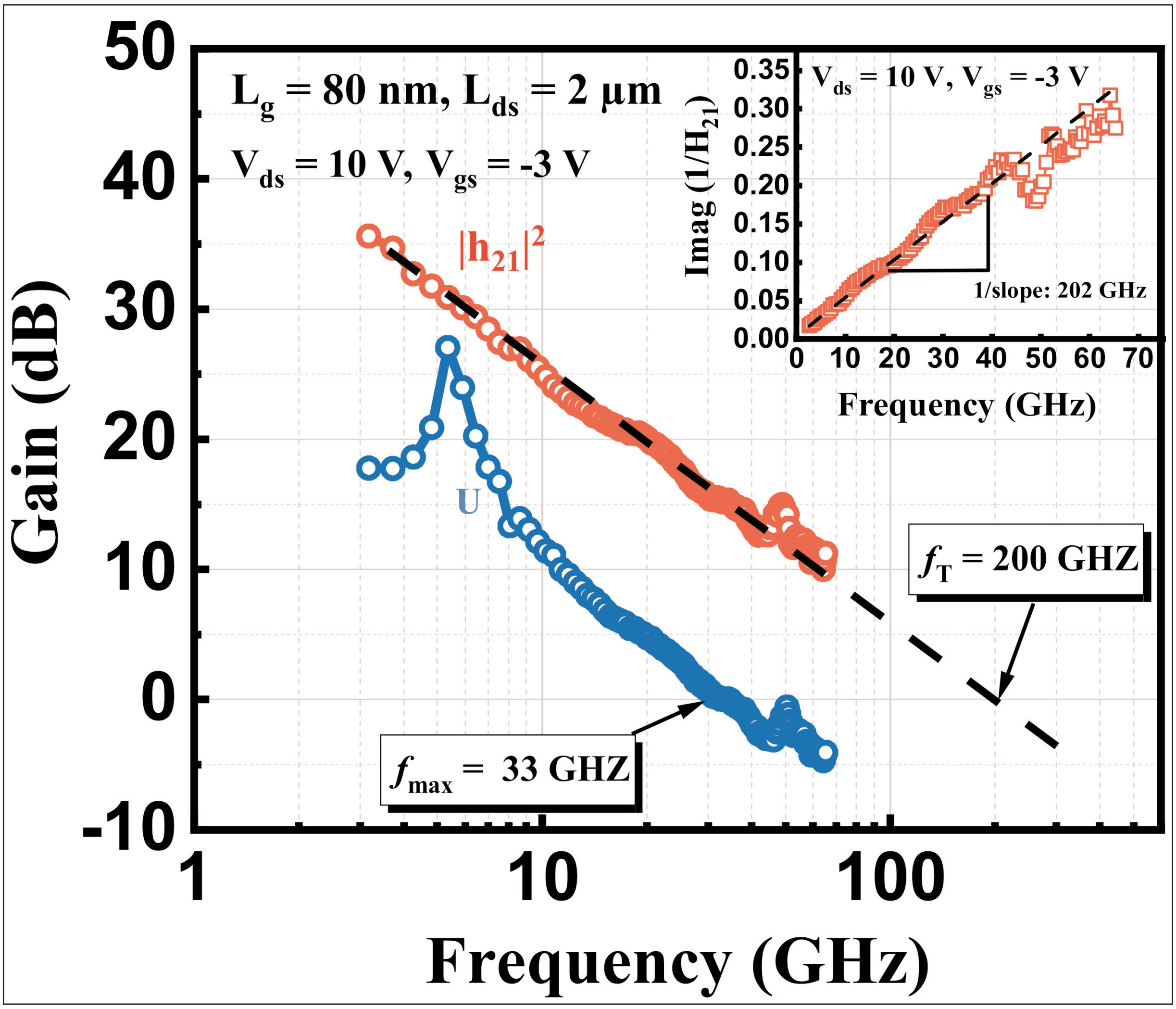



**Figure 1. RF performance of 80nm-gate-length InAlN/GaN HEMTs with 200/33GHz $f_T/f_{max}$. Inset: Gummel's method showing 202GHz $f_T$ estimate.**

The team comments: "To the best of our knowledge, these DC measurement results all show record values among those reported InAlN/GaN HEMTs on silicon to-date ($I_g$ of $7x10^{-6}$A/mm, $I_{off}$ of $7x10^{-6}$A/mm, $I_{on}/I_{off}$ ratio of $1.78x10_5$, and SS of 82mV/decade are the best values that have been reported in InAlN/GaN HEMTs)."

The researchers admit that better values have been obtained for $I_g$ and $I_{off}$ with 20nm aluminium gallium nitride (AlGaN) barrier HEMTs on silicon — of order $10^{-12}$A/mm for both. The resulting $I_{on}/I_{off}$ was $2.5x10^{11}$.

However, one benefit of the thinner InAlN-based barrier was better electrostatic control of current flow in the channel, reducing short-channel effects (SCEs). The InGaN back barrier reduces losses from current leaking into the buffer layer and improves confinement of charge carriers to the GaN-channel region.

The peak transconductance of the InAlN-HEMT was 391mS/mm with 10V drain bias, beating a 75nm-gate 11.4nm-barrrier AlGaN-HEMT's 374mS/mm that has been reported. An 80nm-gate AlN-HEMT on silicon has been presented with 580mS/mm peak transconductance, enabled by a very thin 6nm barrier.

The 1.26A/mm maximum drain current of the team's InAlN-HEMT has also been bettered by a similar device on silicon with a very small 300nm source-drain gap (2.66A/mm). The wider 2μm gap of the team's HEMT naturally increased the on-resistance. One would expect, although the paper does not report on this, that the wider gap would lead to a higher breakdown voltage performance.

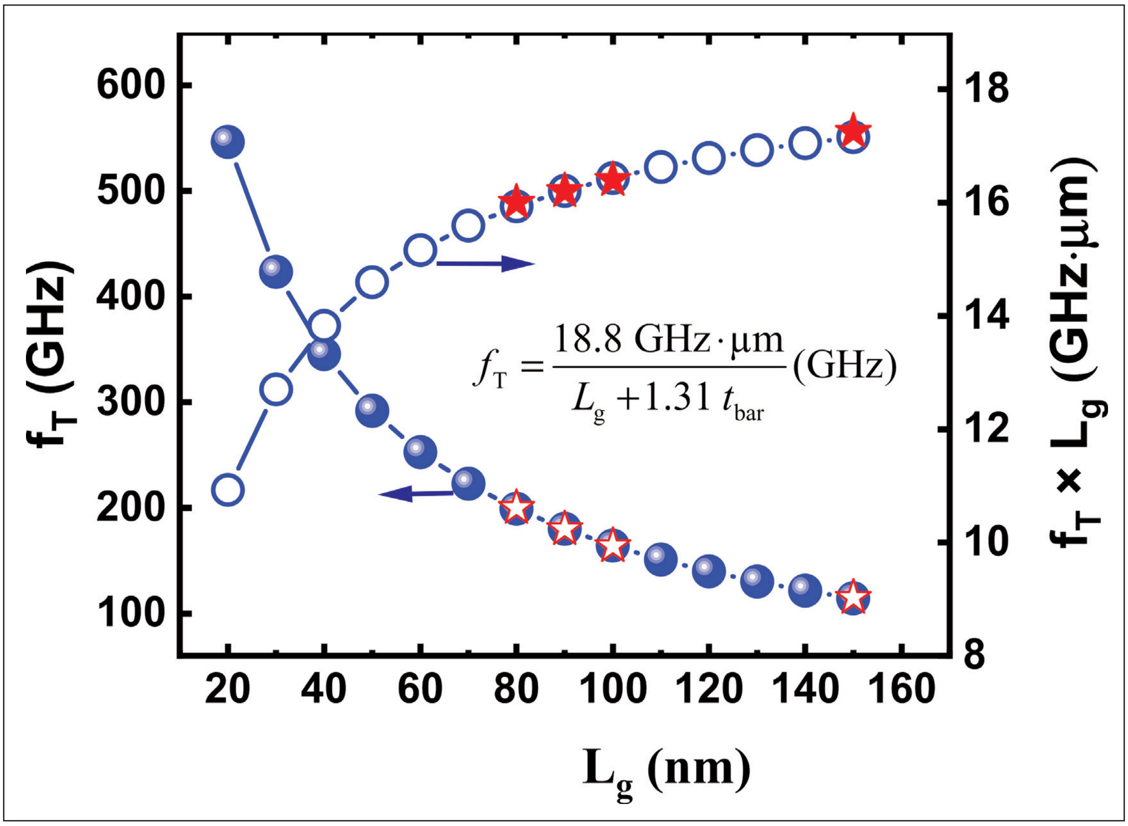



**Figure 2. Predicted $f_T$ (left) and $f_TxL_g$ (right) as a function of $L_g$ — stars represent experimental results.**

**The team comments: "To the best of our knowledge, the $f_TxL_g$ in our study achieves the highest value among all reported GaN HEMTs on silicon, and set a new record among GaN HEMTs on SiC/Si with $L_g$ <<100nm."**

**Using an empirical model that relates $f_T$ to $L_g$, barrier thickness, the effective electron velocity and one fitting parameter, the researchers project that an $f_T$ of 546GHz could be achieved with 20nm $L_g$, giving a $f_TxL_g$ value of 10.9GHz-μm**

RF measurements were made in the 1–65GHz range (Figure 1). With parasitic elements accounted for ('de-embedded'), the current gain cut-off ($f_T$) was extracted as 200GHz, using a −20dB/decade extrapolation. The drain bias was 10V and the gate potential was set at −3V. The maximum oscillation/power gain ($f_{max}$) was 33GHz, suffering due to losses from the high resistance of the rectangular gate.

The cut-off-gate-length product ($f_TxL_g$) was 16GHz-μm. The researchers compare this with best result obtained on SiC — 17.8GHz-μm from 162GHz $f_T$ and 110nm $L_g$. The team comments: "To the best of our knowledge, the $f_TxL_g$ in our study achieves the highest value among all reported GaN HEMTs on silicon, and set a new record among GaN HEMTs on SiC/Si with $L_g$ <<100nm."

Using an empirical model that relates $f_T$ to $L_g$, barrier thickness, the effective electron velocity and one fitting parameter, the researchers project that an $f_T$ of 546GHz could be achieved with 20nm $L_g$, giving a $f_TxL_g$ value of 10.9GHz-μm (Figure 2). ■

**https://iopscience.iop.org/article/10.7567/1882-0786/ab3e29**

*Author: Mike Cooke*

# Gadolinium oxide gate insulation for gallium nitride channel transistors

**Use of single-crystalline material reduces current leakage by up to six orders of magnitude compared with a Schottky junction.**

Researchers from India, Finland and Germany are proposing epitaxial gadolinium oxide ($Gd_2O_3$) as a gate insulator for gallium nitride (GaN)-channel metal-oxide-semiconductor high-electron-mobility transistors (MOSHEMTs) [Ritam Sarkar et al, Appl. Phys. Lett.,vol115, p063502, 2019].

The team from the Indian Institute of Technology Bombay, Finland's Aalto University and Leibniz University in Hannover suggest that the crystalline $Gd_2O_3$ should be better able to withstand high-temperature post-deposition treatments than the more usual amorphous oxide gate insulators. At high temperature, amorphous atomic structures tend to become polycrystalline, creating current-leakage paths at grain boundaries, negatively impacting transistor performance. Single-crystal material is more resilient against structural changes at high temperature.

With a view to low-cost high-volume manufacturing, the substrate was 1mm-thick 150mm-diameter (111) silicon. Low-pressure metal organic vapor phase epitaxy (MOVPE) produced a step-graded series of AlGaN layers to enable a 1μm (0001) GaN buffer and channel layer (Figure 1). The top aluminium gallium nitride (AlGaN) barrier layers consisted of 1.5nm AlN, 26nm $Al_{0.27}Ga_{0.73}N$, and 2nm GaN cap.

The $Gd_2O_3$ gate oxide was grown by 650°C molecular beam epitaxy (MBE). The sources were $Gd_2O_3$ granules evaporated using an electron beam, along with extra molecular oxygen to make up for oxygen depletion from the evaporation process. The III-nitride surface was prepared for the $Gd_2O_3$ by heating to 630°C for 30 minutes.

The crystalline nature of the $Gd_2O_3$ varied according to the layer thickness: at ~2.8nm the structure was hexagonal, according to high-resolution x-ray diffraction, by 15nm the structure transforms to monoclinic. A mixed state of hexagonal and monoclinic structures was found for 5.5nm thickness.

The x-ray analysis also suggested that the $Gd_2O_3$ put the underlying AlGaN under compressive strain along the c-axis of the crystal structure. Hall measurements of sheet carrier density and mobility of the two-dimensional electron gas (2DEG) channel near the AlGaN/GaN interface gave values in the ranges 5–6x$10^{12}$/$cm^2$ and 1400–1500$cm^2$/V-s, respectively. "The small variation in the mobility and electron concentration could be attributed to a minute fluctuation

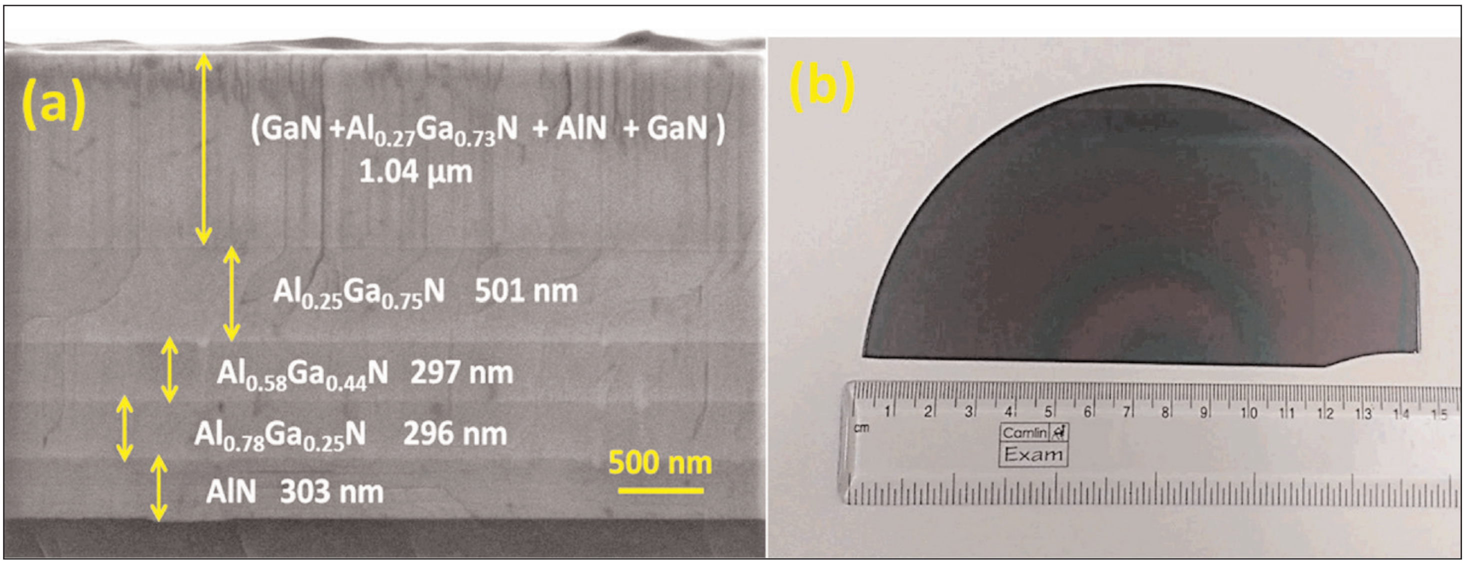



**Figure 1. (a) Cross-sectional scanning electron microscope image of AlGaN/GaN heterostructure. (b) Picture of wafer after epitaxial HEMT growth.**

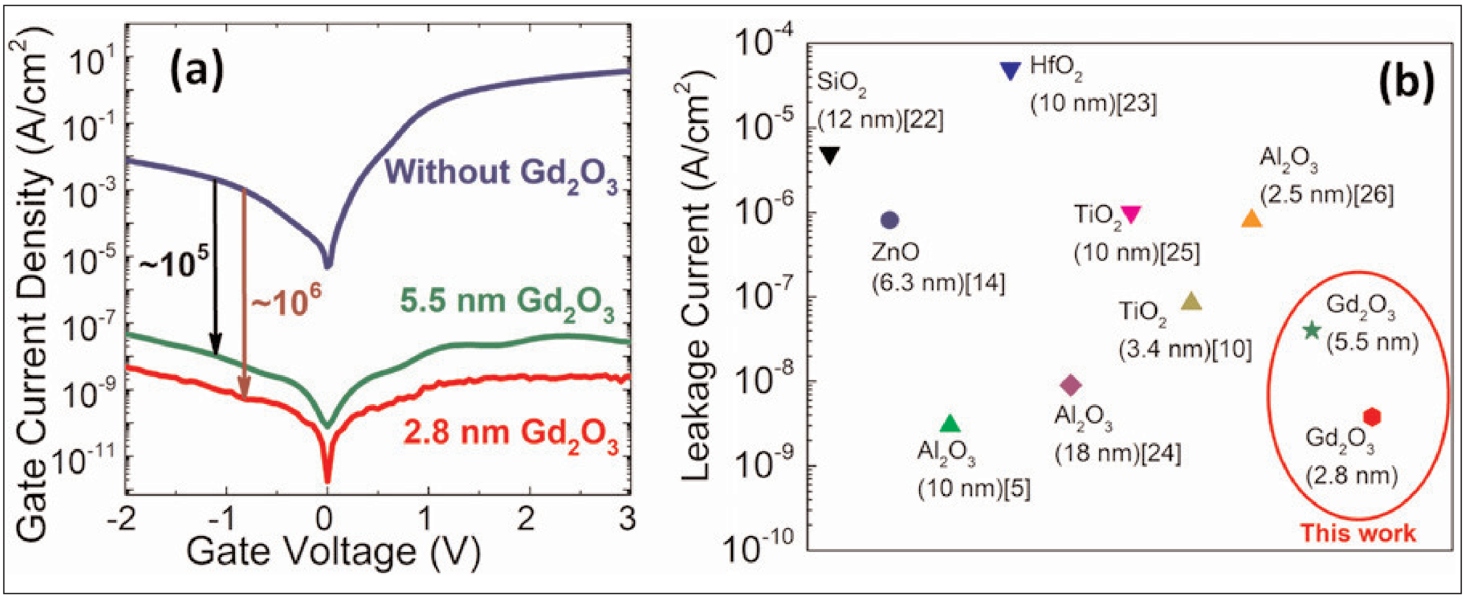



**Figure 2. (a) Gate leakage current versus gate voltage for control HEMT and MOSHEMTs with 2.8nm and 5.5nm $Gd_2O_3$ thickness. (b) Comparison of leakage current density with earlier reported data on various dielectric-based MOSHEMTs.**

of Al concentration across the large-diameter wafer," the researchers comment.

The III–nitride epitaxial material was used to fabricate circular HEMTs with annealed titanium/aluminium/nickel/gold ohmic source/drain contacts. A Schottky gate contact was constructed from nickel/gold.

The maximum drain current was 175mA/mm with 4.5V drain bias and the gate potential at 1V. "The relatively low drain saturation current compared to earlier reported results may be attributed to the large perimeter of the devices (source drain distance ~20μm)," the team explains. The threshold of the HEMT device was −2.7V; the peak transconductance was 60mS/mm. The on/off current ratio was $5x10^3$.

Epitaxial material with $Gd_2O_3$ allowed fabrication of MOSHEMTs. The gate electrode was tungsten. The insulating $Gd_2O_3$ naturally reduced the gate leakage current compared with the Schottky gate on AlGaN of the pure HEMTs by around five orders of magnitude (Figure 2). With 5.5nm $Gd_2O_3$, the leakage was $\sim 5x10^{-8}$A/cm$^2$ with the gate at -2V.

Reducing the $Gd_2O_3$ to 2.8nm perhaps surprisingly reduced the leakage to $\sim 4x10^{-9}$A/cm$^2$, six orders of magnitude lower than the Schottky HEMT control. The researchers suggest that, unlike thicker layers of $Gd_2O_3$, the 2.8nm device benefits from "a single phase (hexagonal) with no domain boundaries, and hence behaves as an ideal oxide with no leakage path". The 2.8nm $Gd_2O_3$ also had the lowest interface trap density ($D_{it}$) of $\sim 2.98x10^{12}$/cm$^2$-eV, according to capacitance–voltage analysis. The dielectric constant of 2.8nm $Gd_2O_3$was ~15.

The Hall sheet carrier density with 2.8nm $Gd_2O_3$ was also enhanced by ~40%. The researchers attribute the boost to in-plane tensile strain from the pseudomorphic $Gd_2O_3$ that balances the c-direction compression. ■

https://doi.org/10.1063/1.5109861

*Author: Mike Cooke*

# Indium gallium arsenide one-transistor dynamic random access memory

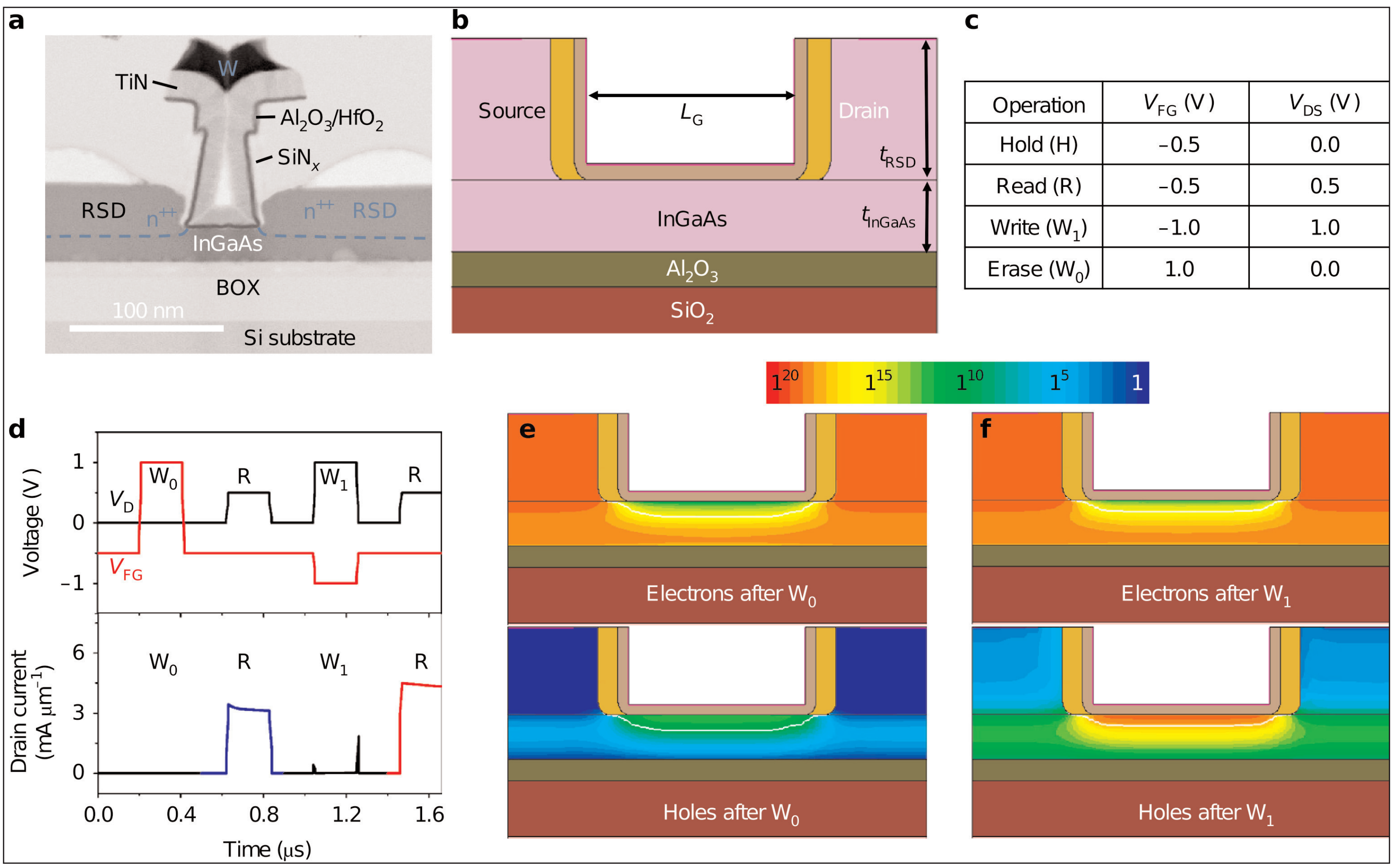
**Researchers hope for devices with lower operating voltages and lower energy consumption.**

Spain's University of Granada and IBM Research Zürich in Switzerland have been developing III–V on silicon technology for dynamic random access memory (DRAM) based on one transistor (1T) and without a capacitor structure [Carlos Navarro et al, Nature Electronics, 2 (2019), p412]. The team comments: "Such capacitor-less DRAM has been demonstrated in silicon, but the use of other materials, including III–V compound semiconductors, remains relatively unexplored, despite the fact that they could lead to enhanced performance."

Removing the capacitor used in traditional '1T1C' DRAM allows simpler processing and should enable smaller cell sizes.

The increased carrier mobility in III–V compound semiconductors such as indium gallium arsenide (InGaAs) offers the prospect of lower operating voltages and lower energy consumption.

The researchers describe their structure as being related to the meta-stable dip RAM (MSDRAM) concept that uses parasitic floating-body effects (FBEs) to store information. FBEs arise in semiconductor-on-insulator




| Operation | $V_{FG}$ (V) | $V_{DS}$ (V) |
|---|---|---|
| Hold (H) | −0.5 | 0.0 |
| Read (R) | −0.5 | 0.5 |
| Write ($W_1$) | −1.0 | 1.0 |
| Erase ($W_0$) | 1.0 | 0.0 |

**Figure 1. a, Transmission electron microscope image of III–V cell. b, Corresponding 2-dimensional structure used in simulations. c, Default front-gate ($V_{FG}$) and drain ($V_D$) voltages for memory operation. d, Readout drain current, demonstrating memory operation. Inset: drain and front-gate bias pattern. e,f, Electron and hole densities, after $W_0$ (e) and $W_1$ (f), respectively, demonstrating MSDRAM memory operation in structures similar to experimental devices with 5V on back gate. Simulated device dimensions: 90nm $L_G$, 1µm width.**

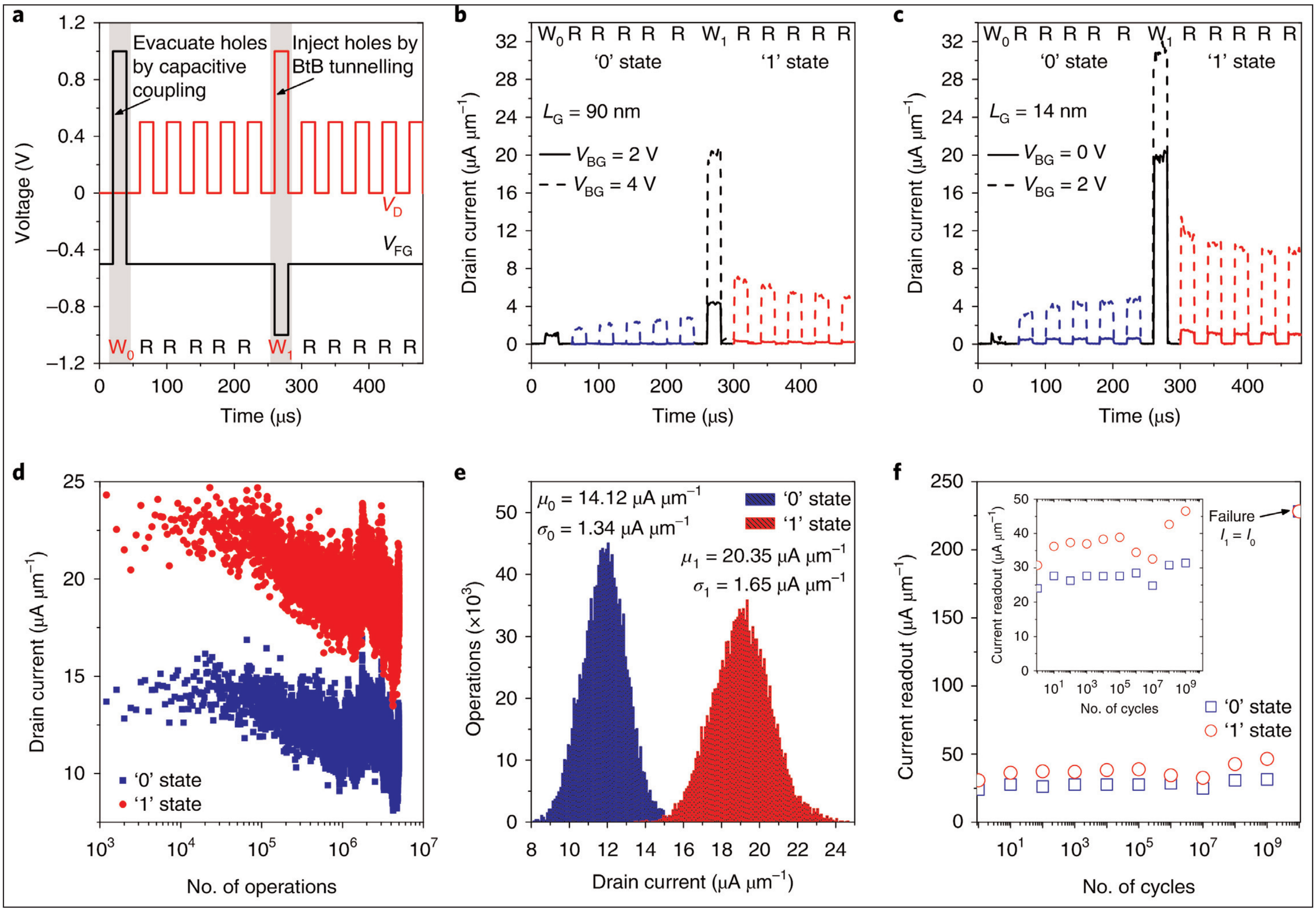


**Figure 2. a, Default $W_0$–5xR–$W_1$_5xR sequence bias pattern to test memory operation. b,c, Readout drain current, successfully probing the memory behavior for 90nm (b) and 14nm $L_G$ (c) at room temperature (300K). d,e, Endurance test on 50nm $L_G$ device at high temperature (360K), showing continuous '0'- and '1'-state readout currents for the first $5x10^6$ cycles (one in every 100 points) (d), together with Gaussian-shaped histograms (e). f, Longer cycling test showing memory operation up to between $10^9$ and $10^{10}$ cycles when successive '1'-state writing steps are carried out at 50MHz. State current readouts characterized every decade. Inset: magnified view of memory operation**

(-OI) structures where the potential in the semiconductor depends on biasing history and carrier recombination processes. The charge in the body of the device modulates current flow in the reading operation.

The team sees potential uses of the device coming from demands for higher performance and scalability, along with III–V optoelectronics and high-power circuitry.

The devices were based on InGaAs-OI transistors fabricated on silicon at IBM's Zurich facility (Figure 1). The InGaAs channel layer was 20nm thick. The indium mole fraction was 53%, which provides a good trade-off between the on- and off-current performance through a high electron mobility and a relatively wide bandgap.

InGaAs-OI on silicon wafers were direct bonded structures using metal-organic chemical vapor deposition (MOCVD) heterostructures grown on indium phosphide (InP) transferred to (001) silicon. The buried oxide layers (BOX) were added by atomic layer deposition (ALD) onto the InP growth wafer, which was then flipped onto the silicon for initial bonding, followed by annealing. The InP growth substrate, and etch stop layers, were then removed.

The aluminium/silicon BOX layers (10nm/25nm $Al_2O_3/SiO_2$) prevents charge leaked into the p-Si substrate. The back-side of the wafer served as a back gate electrode. A front gate was implemented with 4nm-total high-k aluminium/hafnium oxide ($Al_2O_3/HfO_2$) bilayer, giving a 1nm equivalent oxide thickness (relative to the traditional $SiO_2$).

The MSDRAM principle uses coupling between the front- and back-gates, along with floating-body and non-equilibrium effects. The gates create front- and back-channels. Holes accumulate in the front-channel, while the back-channel is driven into inversion by the back-gate. The accumulated holes modulate the electron density in the inverted back-channel. Larger hole density in the front-channel enables increased current flow in the inversion layer.

The '0' state is written ($W_0$ or 'erase') by applying a positive potential to the front-gate, expelling holes from the front-channel through capacitive coupling. The '1' state ($W_1$ or 'write') is created through band-to-band tunneling to inject holes from the drain edge with a negative front-gate potential and positive drain bias.

The MOCVD regrown n-type source/drain regions were raised 25nm and isolated from the gate stack with 9nm plasma-enhanced ALD silicon nitride spacers. The doping of the source/drain with tin was $2x10^{19}/cm^3$. The channel body suffered in performance due to some residual n-type doping of the order $2x10^{16}/cm^3$. This factor modified the desired MSDRAM behavior, to give something more approaching what is described as an 'A2RAM'.

Final devices with various gate lengths ($L_G$) were fabricated with a 0.5μm width. The subthreshold swings with the back-gate at 0V were ~150mV/decade and ~200mV/decade for 90nm and 14nm gate length, respectively. The relatively high swings were attributed to "interface defects at the gate/channel interface". The higher value for the 14nm device also indicated the presence of short-channel effects in the highly scaled device.

Putting a positive voltage on the back-gate switches the channel for current flow from the top to the back interface. This flattens the control of current flow by the top-gate. Due to the thick BOX layer, the current control by the back-gate is limited. However, the current in the back channel is modulated by charge trapped in the front channel, creating the prospect of 1T-DRAM performance (Figure 2).

The reading of the memory state was through a drain bias. Due to the residual body n-type doping, there was still a significant current flow for the '0' state, although the '1' state did demonstrate a higher value. Write and erase processes involved specific front-gate voltage pulses.

To test the endurance of the cell, a 50nm-gate device was subjected to $5x10^6$ cycles of a sequence of $W_0$–R–$W_1$–R operations at 360K without bit failure. The back gate was set at 5V. The various front-gate potentials were −0.3 V (R), −0.8V ($W_1$), and +0.8V ($W_0$). The pulse widths were 20μs. The researchers comment that basic calculations suggest that endurance of $5x10^9$ operations could be envisaged with nanosecond-order operations. Another test at 360K with 50MHz $W_1$ operations, considered the most damaging, only failed after $10^9$–$10^{10}$ cycles. ■

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*Author: Mike Cooke*

# Vertical gallium oxide Schottky barrier diodes with improved performance

**Small-angle beveled field plate increases power electronics Baliga figure of merit to 0.6GW/cm², matching gallium nitride and silicon carbide devices.**

Researchers based in the USA and Japan claim the highest Baliga figure of merit (FOM) of 0.6GW/cm² so far for β-phase gallium oxide ($Ga_2O_3$) vertical Schottky barrier diodes (SBDs) [Noah Allen et al, IEEE Electron Device Letters, vol40, issue 9 (September 2019), p1399]. The breakdown voltage was 1100V.

The Baliga FOM measures the trade-off between breakdown voltage (BV) and on-resistance. The reported value is competitive with state-of-the-art gallium nitride (GaN) and silicon carbide (SiC) SBDs. One previous report of a $Ga_2O_3$ SBD gave a Baliga FOM of 0.39GW/cm² with a 2.44kV breakdown voltage.

The team from Virginia Polytechnic Institute and State University and the University of Southern California in the USA, Novel Crystal Technology Inc in Japan, and the US Naval Research Laboratory used a small-angle beveled field plate (SABFP) and non-punch-through (NPT) design to achieve the high FOM.

Field plates (FPs) are used to massage electric fields, reducing peak values for a given bias. The NPT design consists of a lightly doped drift layer, which contains all of the space-charge region even at breakdown. In punch-through (PT) designs, by contrast, the space-charge region begins to encroach on the more heavily doped lower region of the device. PT designs enable higher breakdown voltages, but at the cost of higher on-resistance.

The researchers comment: "The NPT design is particularly critical for $Ga_2O_3$ devices as it makes them competitive with vertical GaN and SiC devices despite the higher bulk electron mobility in GaN and SiC."

$Ga_2O_3$ is being explored for high-power and high-voltage application due to its high expected critical field of order 8MV/cm, resulting from its ultra-wide bandgap of 4.8eV, compared with 3.3–3.4eV for GaN and SiC. The electron mobility of $Ga_2O_3$ is over 200cm²/V-s. Another attractive feature is the availability of large-diameter $Ga_2O_3$ substrates. Novel Crystal Technology has spec sheets for 2-inch diameter and 10mmx15mm substrates.

The $Ga_2O_3$ drift layer was grown by halide vapor phase epitaxy (HVPE) on 2-inch tin-doped $n^+$-$Ga_2O_3$ substrates (Figure 1). The doping donor concentration (ND) of the drift layer was in the range 3.0–3.5x10$^{16}$/cm³.

Device fabrication was initiated with thinning the substrate from 652μm to 400μm, using mechanical grinding and polishing/chemical mechanical planarization (CMP). The aim of this step was to reduce series resistance.

Spin-on-glass (SOG) served both as a hard mask for mesa etching and as the field-plate dielectric/support. A 45°-bevel was achieved by hydrofluoric acid wet etching of the SOG hard mask through patterned photoresist (PR), and then inductively coupled plasma etch of the $Ga_2O_3$ with boron trichloride reactive ions. The bevel/mesa etch depth was ~1μm.

The shallower bevel structure was obtained using a bilayer mask that consisted of 450nm SOG followed by 200nm of plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide ($SiO_2$). The $SiO_2$ layer speeded up the lateral wet etch under the photoresist through diffusion along the PR/$SiO_2$/SOG interfaces. This enabled reduction of the bevel angle from 45° to 1°.

The devices were completed with the deposition of SOG for the field-plate dielectric, backside annealed titanium/gold Ohmic contact formation, and creation of the Schottky contact/FP with wet etch of an opening in the SOG and nickel/gold deposition.

The 45° (BFP) and 1° SABFP devices were compared against Schottky barrier diodes (SBDs) with no FP and with a standard surface FP (Figure 2).

The SABFP SBD demonstrated an on–off current ratio of almost $10^9$. The ideality was 1.2 — the excess over unity is attributed to lateral inhomogeneity of the Schottky barrier height. The effective barrier height was ~1.2eV. The differential on-resistance ($R_{on}$) was ~2mΩ-cm² normalized according to the Schottky anode area. The comparison devices delivered similar on-resistance performance. The low value was enabled by the reduced substrate thickness.

Destructive breakdown (BV) under reverse bias occurred at 1100V, which compared with 650V, 400V and 200V for the BFP, SFP and no FP SBDs, respectively. Traces of burning were observed at the Schottky contact edges. ►

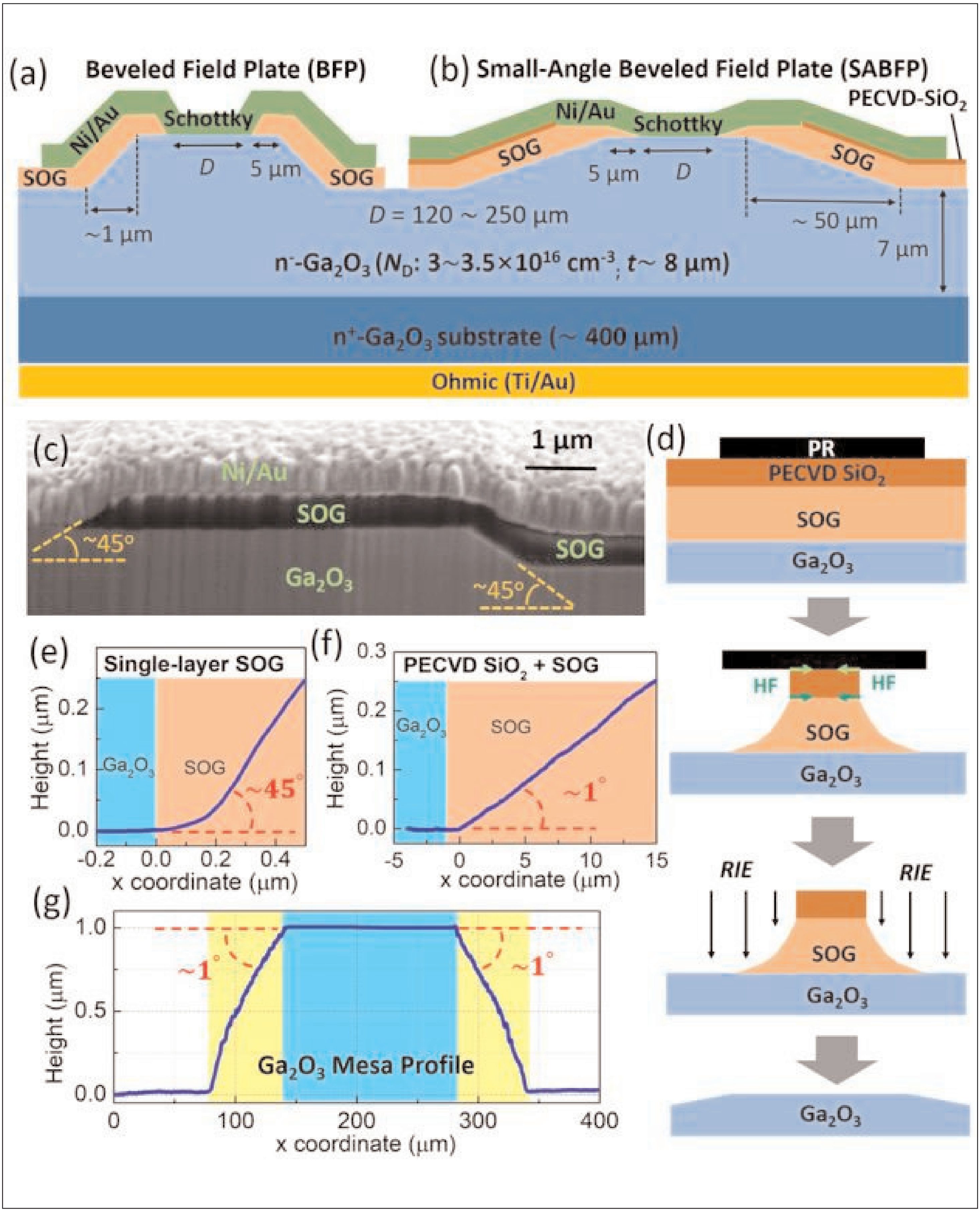


**Figure 1. Schematics of vertical $Ga_2O_3$ SBDs with (a) BFPs and (b) SABFPs. (c) Cross-sectional scanning electron microscope images of BFP structure. (d) Key process steps for fabricating SABFP structure using $SiO_2$/SOG bilayer mask. SOG surface profiles after wet etch (e) without and (f) with a $SiO_2$ interlayer. (g) Surface profile of $Ga_2O_3$ mesa after dry etch using small-angle bilayer mask.**

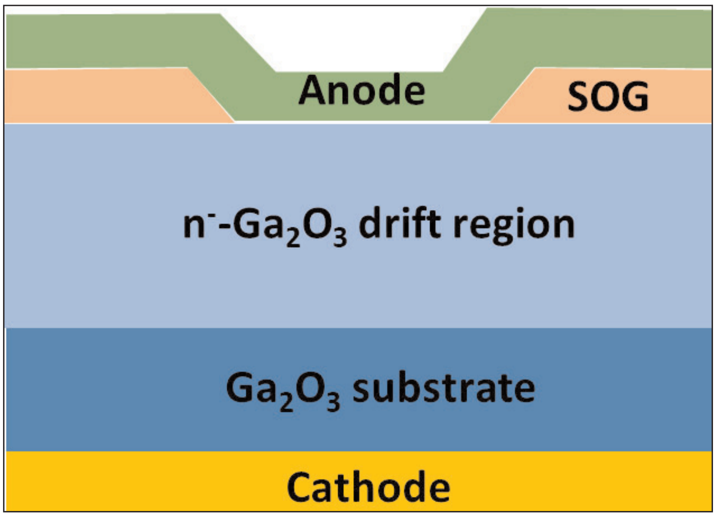


**Figure 2. SFP structure.**

Simulations of the SABFP device suggested that the peak electric fields at 1100V reverse bias were 3.5MV/cm in the $Ga_2O_3$ and 9MV/cm in the SOG. Experiments on SOG suggested that 9MV/cm was the field point where exponential leakage begins.

The simulations also suggested that, since the depletion region only reached around 7μm into the structure, some reduction in on-resistance could be achieved by reducing the drift layer from 8μm to around 7μm without compromising the NPT design.

The team reports (Figure 3): "Our SABFP-SBDs shows a FOM [figure of merit ($BV^2/R_{on}$)] of 0.6GW/cm$^2$, which is the highest in all $Ga_2O_3$ SBDs reported and is comparable to the state-of-the-art vertical GaN SBDs." The researchers also point out that their simulated peak field of 3.5MV/cm in the $Ga_2O_3$ exceeds the critical field in GaN or SiC. Indeed, state-of-the-art vertical GaN SBDs have only achieved under 3MV/cm. ■

https://doi.org/10.1109/LED.2019.2931697

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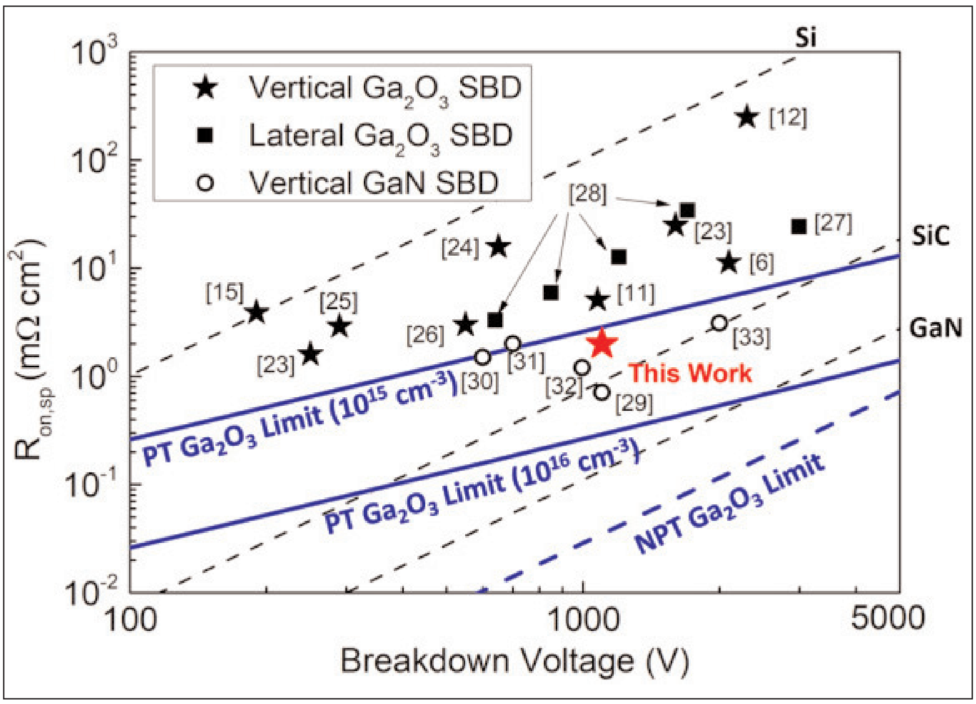


**Figure 3. $R_{on}$ against BV for reported vertical and lateral $Ga_2O_3$ SBDs and vertical GaN SBDs. Theoretical limits of Si, SiC, GaN and $Ga_2O_3$ NPT, and $Ga_2O_3$ PT designs with ND values of $10^{15}$/cm$^3$ and $10^{16}$/cm$^3$ are plotted. ($Ga_2O_3$ limits assume 300cm$^2$/V-s electron mobility and 8MV/cm critical field.)**

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**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**

**3–6 November 2019**

**2019 IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS)**

Loew's Vanderbilt Hotel,
Nashville, TN, USA
**E-mail**: bruce.green@nxp.com
**www.bcicts.org**

**5–8 November 2019**

**5th International Conference on Advanced Electromaterials (ICAE 2019) — Symposium 8, 'Materials and Devices for Power Electronics'**

Ramada Plaza Jeju Hotel,
Jeju Korea
**E-mail**: secretary@icae.kr
**www.icae.kr**

**7 November 2019**

**Interlligent UK's 2019 RF & Microwave Design Seminar**

Møller Centre, Cambridge, UK
**E-mail**: info@interlligent.co.uk
**www.eventbrite.co.uk/e/interlligent-uks-2019-rf-microwave-design-seminar-tickets-59049393325**

**7–8 November 2019**

**EPIC Meeting on Wafer Level Optics**

hosted by SUSS MicroOptics, Neuchatel,
Switzerland
**E-mail**: neringa.norbutaite@epic-assoc.com
**www.epic-assoc.com/epic-meeting-on-wafer-level-optics-at-suss-microoptics**

**12–13 November 2019**

**SEMI Strategic Materials Conference: 'Strategic Materials – Enabling Industry Roadmaps'**

ICM Munich, Munich, Germany
**E-mail**: SEMICONEuropa@semi.org
**www.semiconeuropa.org/strategic-materials-conference**

**12–15 November 2019**

**SEMICON Europa 2019**

Munich, Germany
**E-mail**: SEMICONEuropa@semi.org
**www.semiconeuropa.org**

**13–15 November 2019**

**PowerAmerica's 2019 Wide Bandgap Devices and Applications Short Course**

PowerAmerica Office at North Carolina State University,
Raleigh, NC, USA
**E-mail**: poweramerica@ncsu.edu
**www.poweramericainstitute.org/shortcourse**

**9–11 December 2019**

**65th IEEE International Electron Devices Meeting (IEDM 2019)**

San Francisco, CA USA
**E-mail**: info@ieee-iedm.org
**www.ieee-iedm.org**

**11–13 December 2019**

**SEMICON Japan 2019**

Tokyo Big Sight, Tokyo, Japan
**E-mail**: semicon@sakurain.co.jp
**www.semiconjapan.org/en**

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**11–14 December 2019**
**2019 IEEE 50th IEEE Semiconductor Interface Specialists Conference (SISC)**
Bahia Resort Hotel, San Diego, CA, USA
**E-mail**: wzhu@ieeesisc.org
**www.ieeesisc.org**

**28–30 January 2020**
**OPTRO 2020 (9th International Symposium on Optronics in Defence Security)**
Paris, France
**E-mail**: optro2020.exhibition@3af.fr
**www.optro2020.com**

**30 January 2020**
**EPIC Roundtable on Quantum Optronics at OPTRO**
Paris, France
**E-mail**: neringa.norbutaite@epic-assoc.com
**www.epic-assoc.com/epic-roundtable-on-quantum-optronics-at-optro**

**1–6 February 2020**
**Photonics West 2020**
The Moscone Center, San Francisco, CA, USA
**E-mail**: customerservice@spie.org
**https://spie.org/conferences-and-exhibitions/photonics-west**

**2–6 February 2020**
**IEEE International Solid- State Circuits Conference (ISSCC 2020)**
San Francisco, CA, USA
**E-mail**: Issccinfo@yesevents.com
**www.isscc.org**

**3 February 2020**
**EPIC World Photonics Technology Summit**
St. Regis San Francisco Hotel, San Francisco, CA, USA
**E-mail**: neringa.norbutaite@epic-assoc.com
**www.epic-assoc.com/epic-world-photonics-technology-summit-2020**

**5–7 February 2020**
**SEMICON Korea 2020**
COEX Convention & Exhibition Center, Seoul, South Korea
**E-mail**: semiconkorea@semi.org
**www.semiconkorea.org/en**

**11–13 February 2020**
**Strategies in Light**
San Diego Convention Center, San Diego, CA, USA
**E-mail**: SIL@american-tradeshow.com
**www.strategiesinlight.com**

**8–12 March 2020**
**OFC: The Optical Networking and Communication Conference & Exhibition**
San Diego Convention Center, San Diego, CA, USA
**E-mail**: OFC@compusystems.com
**www.ofcconference.org**

**12–14 March 2020**
**International Conference on Nano Research and Development (ICNRD-2020) – Breakthrough and Innovation in Nano Science and Technology**
Grand Copthorne Waterfront Hotel, Singapore
**E-mail**: laura@icnrd.com
**www.istci.org/ICNRD2020/Program.asp**

**15–19 March 2020**
**IEEE Applied Power Electronics Conference and Exposition (APEC 2020)**
Ernest N. Morial Convention Center, New Orleans, LA, USA
**E-mail**: apec@apec-conf.org
**www.apec-conf.org**

**15–17 April 2020**
**EPIC Annual General Meeting 2020**
Radisson Blu Hotel Lietuva, Vilnius, Lithuania
**E-mail**: neringa.norbutaite@epic-assoc.com
**www.epic-assoc.com/epic-annual-general-meeting-2020**

**21–23 April 2020**
**24th Annual Components for Military & Space Electronics Conference & Exhibition (CMSE 2020)**
Four Points by Sheraton (LAX), Los Angeles, CA, USA
**E-mail**: info@tjgreenllc.com
**www.tjgreenllc.com/cmse**

**26–29 April 2020**
**2nd International Conference on UV LED Technologies & Applications (ICULTA 2020)**
MELIÃ Hotel, Berlin, Germany
Abstract deadline: 30 November 2019
**E-mail**: contact@iculta.com
**www.ICULTA.com**

**7–8 May 2020**
**EPIC Meeting on Nanophotonics for Communication, Sensing and Data Processing at Nanoscribe**
Karlsruhe, Germany
**E-mail**: neringa.norbutaite@epic-assoc.com
**www.epic-assoc.com/epic-events**

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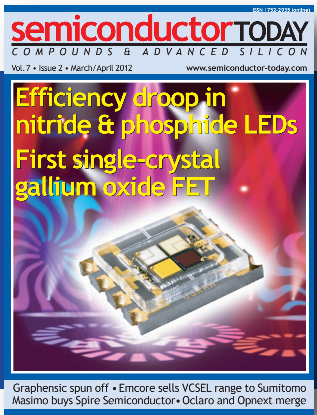


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