

# semiconductor **TODAY**

COMPOUNDS & ADVANCED SILICON

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## Navitas partners with TSMC and Amkor

GaN

Veeco ships EPIK 868 MOCVD system • Skorprios acquires Novati  
• Source Photonics doubling InP laser capacity



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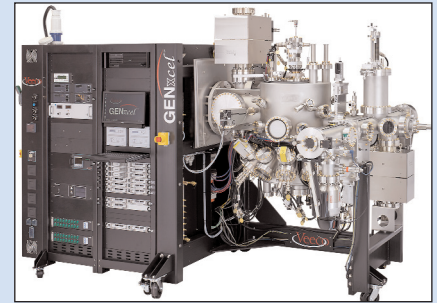
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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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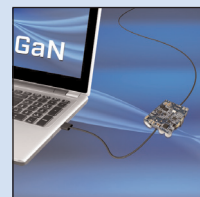
**p34** Veeco has shipped its first GENxcel MBE system, which will be received by China's Acken Optoelectronics Ltd.



**p56** Lithuania's Brolis has established a new R&D division in Ghent, Belgium for the design and development of novel integrated photonic systems.



**p72** Germany's Fraunhofer Institute for Solar Energy Systems ISE has laid the cornerstone of its new Center for High-Efficiency Solar Cells. Construction should be completed by end 2019.



Cover: GaN power IC firm Navitas Semiconductor has formed manufacturing partnerships with Taiwan Semiconductor Manufacturing Corp (TSMC) and contract assembly, packaging & test service provider Amkor Technology to support customer demand for 2018 and beyond. **p27**

## Technology scale-up and integration

October saw news of Veeco shipping its new TurboDisc EPIK 868 gallium nitride (GaN) metal-organic chemical vapor deposition (MOCVD) system (which — due to its four-chamber configuration — has 2.3x the throughput of the existing EPIK 700 system) to several Chinese manufacturers of LEDs for solid-state lighting applications (see page 34).

According to market research firm LEDinside, in 2017 global LED chip production capacity has entered a new expansion phase in response to rising demand from Chinese LED package suppliers that began raising their production capacities earlier in 2016 (see page 6). With major Chinese LED chip makers including San'an Optoelectronics, HC SemiTek and Aucksun recommencing significant capacity building, the number of MOCVD chambers installed worldwide in 2017 (based on the equivalent of Veeco's standard K465i design) will be 401 (the largest chip capacity increase since 2011), forecasts LEDinside, driving China's share of global MOCVD capacity from 49% in 2016 to 54% in 2017.

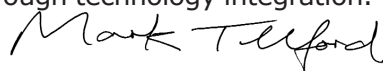
IHS Market says that, in Q2/2017, China's MLS rose to the world's 4th biggest LED packager (up from 6th in 2016) and will double full-year revenue from 2013 to 2017). Also, China's Nationstar entered the top 10 (see page 7). It adds that Chinese MOCVD system makers AMEC and TOPEC have seen a sharp increase in sales, becoming "the first companies to seriously challenge the long-standing dominance of Aixtron and Veeco".

After its sale to China's Grand Chip Investments was thwarted by the Committee on Foreign Investment in the United States (CFIUS), Germany-based deposition equipment maker Aixtron's subsequent sale of its US-based ALD/CVD memory product line to South Korea's Eugene Technology has now been approved by CFIUS (page 36) as part of its refocusing on its core MOCVD technology. In its Q3/2017 results (see [www.semiconductor-today.com/news\\_items/2017/oct/aixtron\\_271017.shtml](http://www.semiconductor-today.com/news_items/2017/oct/aixtron_271017.shtml)) Aixtron is seeing sustained demand for MOCVD systems for producing VCSELs and other lasers, red-orange-yellow and specialty LEDs, and power electronics, leading it to again raise its full-year 2017 order guidance.

As well as the growth in gallium arsenide-based VCSELs, the transition to 100Gb/s and emerging 400Gb/s data-rate optical communications is driving growth in indium phosphide-based lasers. US-based Source Photonics has more than doubled its capacity for producing InP lasers at its fab in Taiwan over the last three years, and will more than double its capacity again by establishing a new fab in China (see page 63). Product developments in 100–400G and beyond on show at September's European Conference on Optical Communications (ECOC) are reported on pages 60–70. Meanwhile, MACOM has opened an Optoelectronics Customer Innovation Lab in China, and PHIX Photonics Assembly has raised its first funds to scale up its new PIC module assembly & packaging production line at the University of Twente, The Netherlands. Also, driven by burgeoning silicon photonics applications, fabless firm Skorpios has acquired manufacturing partner Novati to advance the integration of III-V gain materials on silicon, and Lithuania's Brolis has established an R&D division in Belgium to combine its gallium antimonide-based long-wave infrared lasers with UGent-imec's CMOS-compatible silicon-on-insulator PICs (see pages 56–59).

So, while many applications and volume manufacturing developments are increasingly China-focused, other geographic regions continue to contribute much innovation, increasingly through technology integration.

**Mark Telford, Editor**



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# Chinese LED chip suppliers to comprise 54% of global production capacity in 2017

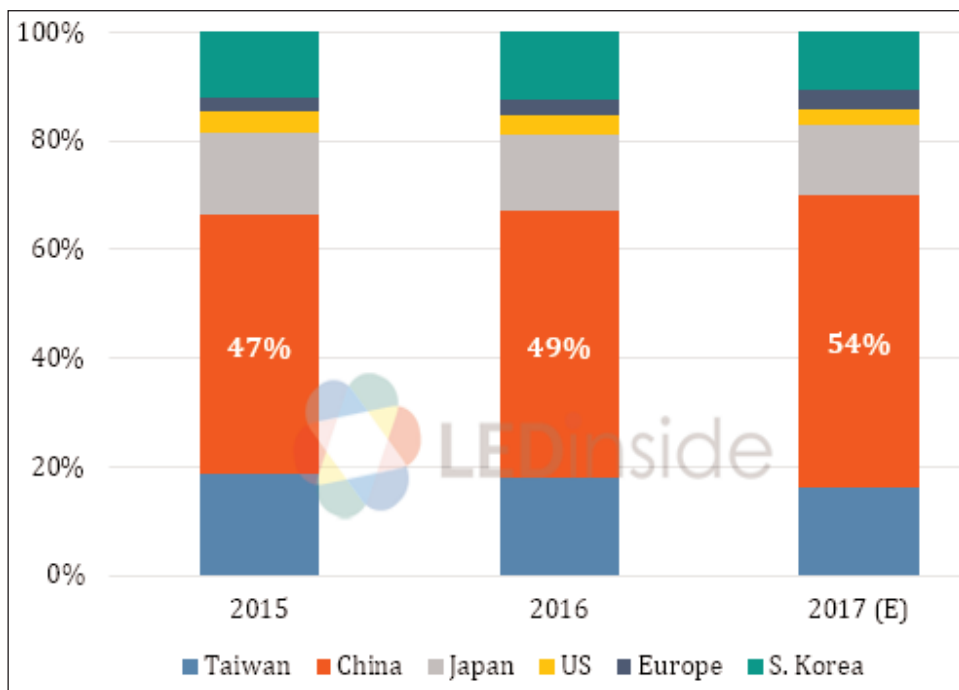
## Local subsidies for LED packagers driving demand, squeezing major international chip makers to downsize or outsource manufacturing

Total global LED chip production capacity has entered a new peak expansionary phase in 2017, according to the latest LED market supply and demand analysis by LEDinside (a division of TrendForce). This recent surge of capacity expansion has been a response to the rising demand from Chinese LED package suppliers that began raising their production capacities earlier in 2016.

With Chinese LED chip suppliers recommencing their capacity building activities, LEDinside estimates that the number of metal-organic chemical vapor deposition (MOCVD) chambers (based on the standard K465i design) installed worldwide in 2017 will be 401, representing the largest chip capacity increase since 2011.

"At the start of 2017, major Chinese LED chip makers including San'an Optoelectronics, HC SemiTek and Aucksun revealed that during the year they will be carrying out major capacity expansion plans," says LEDinside research director Roger Chu. "The new processing operations set up by the domestic chip makers will push China's representation in the global MOCVD capacity to 54%," he estimates.

This wave of capacity building for LED chips in China has been to meet the growing demand from the LED package suppliers downstream, Chu adds. Furthermore, domestic package suppliers in recent years have been relocating their operations to second-tier cities due to the rising costs of labor and land in the traditional industry clusters of Guangdong Province and the Pearl River Delta. Local governments in the smaller cities have



Distribution of MOCVD systems installed by country/region, 2015–2017.

offered various incentives to get LED companies to build factories in their domains. Consequently, China's LED industry in 2017 saw another capacity growth spurt comparable to the one during the 2010–2011 period.

There have also been changes in China's subsidy policy, LEDinside notes. In the past, small- or mid-size domestic LED companies were in a rush to build chip fabrication plants because local governments' subsidies mainly targeted the upstream of the supply chain.

**This wave of capacity building for LED chips in China has been to meet the growing demand from the LED package suppliers downstream**

In contrast, the latest round of subsidies targets the LED package industry and its related businesses. China this time wants to generate demand for the upstream by helping the downstream in opening up market channels. Hence, major domestic package suppliers this year have also been expanding their capacities together with the first-tier domestic chip makers.

The rapid and subsidized capacity expansions that is taking place in China is now heavily squeezing the profit margins of long-established LED companies on the global market, LEDinside believes. These international majors in turn have scaled down their own manufacturing or increased the proportion of outsourcing. Either way, Chinese LED companies will benefit and become even larger, concludes LEDinside.

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

# China's Nationstar enters top 10 ranking of packaged LED firms in Q2/2017, as MLS rises to 4th Chinese MOCVD system suppliers AMEC and TOPEC see sales surge

After narrowly missing out on entering IHS Markit's top 10 for 2016 and first-quarter 2017, Nationstar (whose primary markets are lighting and signage) has broken into the top-10 ranking for packaged LED firms for Q2/2017, according to the latest 'LED Supply & Demand Market Tracker' of market research firm IHS Markit. Located in Foshan in Guangdong province in southern China near Guangzhou, Shenzhen, and Hong Kong, Nationstar's packaged LED revenue was \$112m in Q2/2017, up 48% on Q1. While strong Q2 growth is common from Chinese companies (given the low Q1 due to Chinese New Year), Nationstar's Q2 revenue was also 48% above Q2/2016. It now appears likely that Nationstar will also finish full-year 2017 inside the top 10.

## MLS growth fueled by lighting and signage

Nationstar joins MLS in the top 10, which was the first company from mainland China to enter the top 10 in 2013. After its very strong 2013, MLS saw only modest growth from 2013 to 2015, but grew very strongly in 2016 to reach a new high of 6th place. Like Nationstar, MLS does not have much business in backlighting or automotive, but is seeing growth fueled by lighting and signage sales. In Q2/2017 it recorded \$247m in revenue, and was ranked 4th.

| Packaged LEDs revenue Q2'17 |      |
|-----------------------------|------|
| Company Name                | Rank |
| Nichia                      | 1    |
| Osram Opto                  | 2    |
| Lumileds                    | 3    |
| MLS                         | 4    |
| Seoul Semiconductor         | 5    |
| Samsung                     | 6    |
| Cree                        | 7    |
| Everlight                   | 8    |
| LG Innotek                  | 9    |
| Nationstar                  | 10   |

MLS's 2017 revenue is now set to roughly double its 2013 revenue. Furthermore, it has a chance this year to become only the fifth supplier in history to achieve \$1bn in packaged LED sales in a single year (the others being Nichia, Osram Opto, Lumileds, and Samsung).

## Rise of Chinese companies

In addition to MLS and Nationstar, many other players are active in the China market. Hongli, Jufei, Shenzhen MTC and Refond are estimated to be the next largest. There are also many smaller LED suppliers in China.

The rise of Chinese vendors in the LED market is not limited to the LED vendors themselves. This year, metal-organic chemical vapor deposition (MOCVD) suppliers AMEC and TOPEC have seen a sharp increase in sales to become the first companies to seriously challenge the long-standing dominance of

Germany-based Aixtron and USA-based Veeco. The current IHS Markit quarterly report tracking the LED market (issued in September) also includes the MOCVD rankings and shares for 2016 and 2017 (annual and quarterly).

New production equipment continues to be added in China, showing that the Chinese competition is here for the long term and will continue to grow in the future, says IHS Markit.

## Threat to others

Many Western and Japanese LED companies do not yet encounter Nationstar as a major competitor, because most of its sales are within China. However, the rise of Chinese companies is, in general, making the competitive environment tougher for other suppliers that are struggling to match the low pricing in lighting and other applications, says IHS Markit.

Western, Korean and other vendors are now increasingly looking to alternative markets such as automotive, horticulture and ultra-violet (UV) LEDs, the report adds. Alternatively, tier-1 vendors are able to differentiate themselves with intellectual property, product quality, or specific technology (such as chip-scale packaging).

<https://technology.ihs.com/589407/led-supply-demand-market-tracker-q3-2017>

## HB-LED market growing at 10% CAGR to 2023

The high-brightness LED market will rise at a compound annual growth rate (CAGR) of 10% during 2016–2023, forecasts Occams Business Research and Consulting in its report 'Global High Brightness LED Market Research Report Insights, Opportunity Analysis, Market Shares and Forecast, 2017 – 2023'. The key factors driving growth are increasing lighting applications, large-scale replacement

of traditional luminaires, the falling cost of LED components, and the growing need for energy-efficient lighting products to save energy.

Asia-Pacific is the largest market region in terms of revenue share. Key factors are the large market for LEDs in China and the on-going technical advances in LED technology. Furthermore, according to the US Department of Energy (DOE), the Chinese LED market grew at a

CAGR of 15.3% in 2015 (up from 13% in 2014 and 10.7% in 2013).

Further, the presence of leading LED makers in the Asia-Pacific region such as Epistar, LG Innotek, Moritex and Nichia is driving growth.

However, North America is expected to emerge as the fastest-growing region over the forecast period due to increased adoption of high-brightness LEDs for energy conservation.

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

# HB-LED chip production to grow 2.8% to \$13.179bn in 2017, then 2–5% annually during 2018–2022

Global production of high-brightness LED chips is expected to grow 2.8% year-on-year to US\$13.179bn in 2017, then at 2–5% annually during 2018–2022, forecasts Digitimes Research.

The production value for automotive and display applications will rise at a compound annual growth rate (CAGR) of 13–15% and 8–11%, respectively, in 2018–2022, while lighting will see a CAGR below 10% because LED lighting penetration will approach saturation, the firm adds. The production value for backlighting applications for TVs, notebooks, monitors and tablets

will continue to decline slightly in 2018–2022, while backlighting applications for handsets will drop significantly due to the increasing adoption of AMOLED panels for smartphones.

LED chip makers have developed infrared (IR) and ultraviolet (UV) LED chips as well as mini LEDs, and they are also developing micro LEDs. IR LED chips have been widely used in sensing for biometrics (fingerprint, face and iris recognition), ADAS (advanced driver assistance systems) and IoT (Internet of Things) applications. LED chips have been used emitting at wavelength of

320–400nm (UV-A) for industrial and nail curing applications; at 290–320nm (UV-B) for skin medical care applications; and at 240–290nm (UV-C) for water and air purification applications.

Mini LED chips have begun to be adopted for fine-pixel-pitch displays, automotive displays and backlighting of high-contrast displays. However, micro LEDs still see technological bottlenecks, and commercial applications may not appear until 2018, concludes Digitimes Research.

[www.digitimes.com/news/a20171004PD204.html](http://www.digitimes.com/news/a20171004PD204.html)

## Automotive and signage segments growing as much as lighting in 2017

Strong growth in packaged LED lighting revenue from 2007 to 2014 was the result of consumers replacing incandescent and fluorescent lighting with LED lighting. However, price erosion due to competition and the trend toward less robust, inexpensive 2835 packages caused revenues to decline by 9% in 2015 and only 1% in 2016, according Jamie Fox, principal analyst, lighting and LEDs group, IHS Markit.

Starting in 2017, revenue growth is expected to increase by 3% as prices settle. In 2017, automotive and signage segments are growing as much as lighting, with each of the three applications forecast to be \$200m higher than packaged LED revenue in 2016. Furthermore, horticulture is projected to see the fastest growth in 2017 although the absolute increase in dollars will be lower compared with automotive, lighting and signage.

### If not lighting, then what?

Automotive is boosted by increasing LED use on vehicle exteriors, in headlamps and other areas such as daytime running lights, rear lighting, turning lights and interior vehicle

illumination for both cars and heavy vehicles such as trucks and buses. Automotive packaged LED revenue is forecast to grow 9.2% in 2017, from \$1.9bn to \$2.1bn.

Signage use is boosted by the trend towards finer pitch displays and the fact that LED displays are not a mature market; growth is possible by finding new business, not only replacement. Signage markets include large full-color displays known as videowalls, as well as road signs, traffic lights and building lettering. Signage is forecast to grow 11.5% from \$1.8bn to \$2bn.

Horticulture is a smaller market but in percentage terms will grow even faster in 2017 than signage and automotive.

### Lighting growth should resume after 2017

Lighting growth from 2018 to 2022 is forecast to increase 6–7% per year due to a strong forecast for LED lamp shipments and reduced price erosion at the packaged LED component level. Due to basic material costs, company overheads and the slow reduction of subsidies

in China, it will not be possible for prices to fall as quickly as they did from 2007 to 2014. In terms of compound annual growth rate (CAGR), lighting still is forecast to have a slightly lower 2016–2022 CAGR (6.1%) than automotive exterior (7.9%) and signage (8.5%).

### How LED manufacturers are reacting

LED manufacturers are no longer focused on only packaged LEDs for lighting for growth. Now most companies have entered automotive, signage or horticulture segments, or are considering doing so. The era of specialists is over; now, everyone does everything.

To deal with reduced growth in visible LEDs, LED manufacturers are increasingly producing more infrared and ultraviolet LEDs to create new revenue streams. In addition, in a slow trend that already started some years before, LED manufacturers are now more vertically integrated, selling complete modules and light engines, and sometimes complete LED lamps.

<https://technology.ihs.com>



# RF GaN market growing at CAAGR of 14.1% to \$733m in 2021, maintained by defense applications

## As China LTE base-station deployments wind down, industry needs to take advantage of other applications and emerging 5G opportunities

RF gallium nitride (GaN) device revenue rose by slightly more than 23% in 2016, and will increase at a compound annual average growth rate (CAAGR) of 14.1% to \$733m in 2021, forecasts the Strategy Analytics Strategic Component Applications (SCA) group report 'RF GaN Market Update: 2016–2021'.

The largest application sector is currently wireless infrastructure, for which Sumitomo Electric Device Innovations (SEDI) is the dominant supplier (giving it the greatest share of the overall RF GaN device market in 2016). Wolfspeed is second largest, due to strength in both defense and commercial applications. Qorvo is third, due to its strength in defense. These top three suppliers account for nearly 82% of the RF GaN market.

The wireless infrastructure segment is expected to flatten. However, overall market growth will be maintained by rapid growth in defense, so that the overall RF GaN device market will almost double by 2021.

In particular, trends across radar, electronic warfare (EW) and communications — driven by a move towards broadband performance, higher frequencies and digitization — will cause the defense sector to grow at a faster rate than the commercial segment, to more than 51% of the total RF GaN device market in 2021.

"LTE base-station deployments in China have been the obvious growth driver for RF GaN revenue these past three years," comments Eric Higham, service director, Advanced Semiconductor Applications service. "As this activity winds down, infrastructure will remain a large and important segment, but the industry will need to position to take advantage of other applications and emerging 5G opportunities for growth."

Key questions that the RF GaN device supply base needs to understand are listed as:

- How will the GaN equipment/supplier landscape change over time?
- What product platforms will be

important?

- What are the technology/product differentiators?
- Where is the next big commercial application for RF GaN?

"While the GaN supply chain looks for guidance on these future commercial opportunities, fast growth in defense applications will keep the overall market growth for GaN on an upwards trajectory," notes Asif Anwar, director of the Advanced Defense Systems service. "The question is, can companies focused exclusively on domestic defense sectors take advantage of this growing global demand? These companies will need to understand how to better compete against commercial manufacturers as well explore strategic options including partnerships or secondary manufacturing options."

[www.strategyanalytics.com/access-services/components/defense/market-data/report-detail/rf-gan-market-update-2016---2021-ADS](http://www.strategyanalytics.com/access-services/components/defense/market-data/report-detail/rf-gan-market-update-2016---2021-ADS)

# RF GaAs device revenue growth slowed to 0.9% in 2016, but will rise from \$7.5bn to \$9.2bn in 2021

## Adoption of gigabit LTE and emerging 5G applications to drive growth

Although the market for RF gallium arsenide (GaAs) devices (merchant and captive, but excluding foundry) rose by just 0.9% in 2016 as an anticipated drop in cellular revenue nearly offset gains in other market segments, revenue still managed to surpass \$7.5bn for the first time, and gigabit LTE and emerging 5G applications will drive revenue past \$9.2bn in 2021, forecasts the Strategy Analytics' Advanced Semiconductor Applications (ASA) service in its report 'RF GaAs Device Forecast and Outlook: 2016–2021'.

Wireless applications (especially cellular terminals) continue to be

the dominant segment and the driving force for the entire GaAs market. "The RF GaAs device market is so dependent on cellular terminals that declining growth rates in smartphone sales has put the brakes on total revenue growth," says Eric Higham, director of the Advanced Semiconductor Applications (ASA) service. "The good news for the industry is that growing adoption of gigabit LTE networks and devices, coupled with emerging 5G opportunities, will restart the GaAs growth engine." The added complexity of gigabit LTE cellular terminals will offset

slowing smartphone growth and price erosion, resulting in additional revenue growth in the GaAs device market, adds the report.

"We are seeing new platforms and major program upgrades starting to ramp toward production, and these developments will maintain the growth of GaAs device revenue in the defense sector," adds Asif Anwar, director of the Advanced Defense Systems (ADS) service.

[www.strategyanalytics.com/access-services/components/advanced-semiconductors/reports/report-detail/rf-gaas-device-forecast-and-outlook-2016---2021](http://www.strategyanalytics.com/access-services/components/advanced-semiconductors/reports/report-detail/rf-gaas-device-forecast-and-outlook-2016---2021)

## WIN enables fully integrated single-chip GaAs solutions for 5G RF front-end modules

### PIH1-10 platform provides monolithic PIN Tx/Rx switches with power and low-noise pHEMT technology to realize single-chip front ends operating at 28–40GHz

WIN Semiconductors Corp of Taoyuan City, Taiwan — the largest pure-play compound semiconductor wafer foundry — says that its PIH1-10 gallium arsenide (GaAs) platform enables fully integrated single-chip solutions for 5G front-end modules. The PIH1-10 process integrates monolithic PIN diodes, capable of power switching through 50GHz, into a 100GHz  $f_T$  pHEMT (pseudomorphic high-electron-mobility transistor) platform, providing the transmit power performance and lower receiver noise figure required for 5G systems.

WIN says the versatile technology provides users with multiple pathways to add on-chip functionality and higher integration. In addition to monolithic PIN diodes and high-performance pHEMT devices, the PIH1-10 platform offers linear Schottky diodes for mixers or

detectors, as well as enhancement and depletion transistors optimized for logic functionality and bias controls. When combined with RF isolated through-wafer vias, the humidity-resistant technology enables a wafer-level package option for compact chip integration in MIMO functions where available board space is limited.

“The PIH-10 technology leverages WIN’s qualified production techniques and industry-leading manufacturing scale to provide a new platform that can be extended and optimized to address rapidly evolving market requirements,” says senior VP David Danzilio. “Compound semiconductors, and particularly GaAs, remain the technology of choice for demanding amplifier functions from 500MHz through 100GHz and above. This advantage comes from higher gain, linearity and power-added

efficiency provided by GaAs devices as compared to RF CMOS or SiGe [silicon germanium]. This performance advantage will be critical in the 28–40GHz bands envisioned for 5G, where gain and efficiency at 6–10dB back-off will determine system-level performance,” he adds. “WIN’s GaAs pseudomorphic HEMT is the foundation for many of today’s high-performance amplifiers operating in the 20–100GHz range, and incorporating low-loss PIN switch functionality enables our customers to field unique single-chip 5G solutions without sacrificing performance.”

WIN showcased its compound semiconductor RF and mm-wave solutions at European Microwave Week (EuMW 2017) in Nurnberg, Germany (8–13 October).

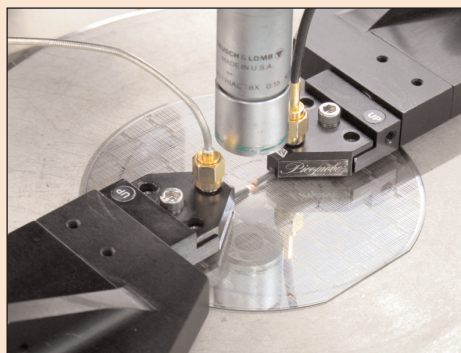
[www.eumweek.com](http://www.eumweek.com)  
[www.winfoundry.com](http://www.winfoundry.com)

## WIN enhances 0.25 $\mu$ m GaN power process

### NP25 provides 28V operation with better power density and efficiency for demanding power applications through Ku-band

WIN Semiconductors has released an optimized version of its 0.25 $\mu$ m gallium nitride technology, NP25, that provides what is claimed to be superior DC and RF transistor performance.

In production since 2014, NP25 is a 0.25 $\mu$ m-gate gallium nitride on silicon carbide (GaN-on-SiC) process, and offers the flexibility to produce both fully integrated amplifier products and custom discrete transistors. The optimized 0.25 $\mu$ m process offers enhanced RF performance with fast switching time, higher gain and increased power-added efficiency (PAE) for demanding power applications through Ku-band.



Optimized NP25 transistors exhibit better DC and RF current-voltage (IV) characteristics and provide 2dB higher maximum stable gain. Increased gain leads directly to higher power density and PAE under a range of tuning and bias conditions. This performance-optimized

process is fully qualified and supported with a comprehensive design kit and transistor models.

WIN’s NP25 technology is fabricated on 4” silicon carbide substrates and operates at a drain bias of 28V. At 10GHz, NP25 provides saturated output power of 5W/mm with 19dB linear gain and over 65% PAE. These performance metrics make the NP25 process suitable for a variety of high-power, broad-bandwidth and linear transmit functions in the radar, satellite communications and wireless infrastructure markets.

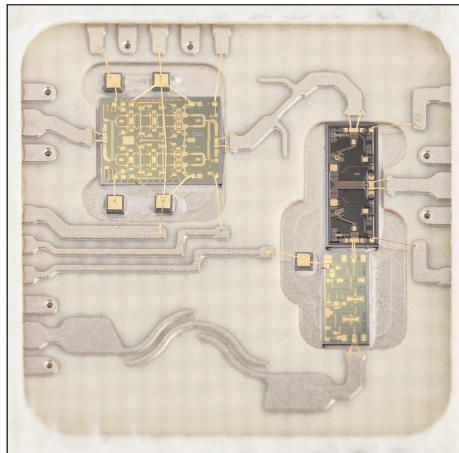
NP25 sample kits are available and can be obtained by contacting WIN’s regional sales managers.

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

## Plextek RFI and Filtronic Broadband develop 26GHz SMT front-end multi-chip module addressing lack of components for European 5G 'Pioneer Band'

Plextek RFI Ltd of Cambridge, UK (which designs RFICs, MMICs and microwave/millimeter-wave modules) has developed a multi-chip module (MCM) to cover the recently designated European 'Pioneer Band' for mmWave 5G around 26GHz. The development of the front-end module (FEM) was carried out in collaboration with Filtronic Broadband, which designs and makes RF, microwave and mm-wave products for telecoms and aerospace/defence OEMs.

"The band 24.25–27.5GHz was designated at the end of last year by the EU Radio Spectrum Policy Group (RSPG) as the preferred band, or 'Pioneer Band', for mmWave 5G," says Plextek RFI's CEO Liam Devlin. "We welcome the opening up of this spectrum band for 5G, but we identified early on that there was a lack of components available at this frequency, and that led us to define this joint FEM development project."



**A 26GHz 5G SMT front-end module.**

The FEM comprises a gallium arsenide (GaAs) low-noise amplifier (LNA), power amplifier (PA) and transmit/receive switch housed in a custom laminate surface-mount (SMT) package measuring 10mm x 10mm. The receive-path gain is 20dB across the full band, with a noise figure of 3.5dB. The

transmit-path gain is 19dB, and the output referred third-order intermodulation (IP3) is +36dBm. Low-loss RF filtering has been integrated into the package structure, with a band-pass filter after the LNA and a harmonic rejection filter after the PA. Insertion-loss figures are 0.7dB for the band-pass filter and 0.2dB for the harmonic rejection filter.

"This development has demonstrated that we can overcome the manufacturing challenges of integrating filters along with multiple die into an SMT package," says Filtronic Broadband's managing director Mike Weaver. "This is not easy at mmWave frequencies, and will give us a crucial head start towards eventual production when the market demand for 5G components at 26GHz begins to ramp up."

[www.plextekrfi.com](http://www.plextekrfi.com)  
[www.filtronic.com](http://www.filtronic.com)

## Anokiwave's chief systems architect presents at IWPC's '5G mmWave Opportunities and Challenges' Interactive Workshop

At the International Wireless Industry Consortium (IWPC) Interactive Workshop '5G mmWave Opportunities and Challenges' in Austin, TX, USA (16–18 October), chief systems architect David W. Corman of Anokiwave Inc of San Diego, CA, USA — which provides highly integrated silicon core chips and III-V front-end integrated circuits for millimeter-wave (mmW) markets and active antenna based solutions — gave a presentation in the Technology Enablers session on 18 October.

In the interactive workshop (which addresses the fundamental issues that the industry faces approaching the first release of the 5G standards), Corman discussed



**David Corman.**

High Performance, All-Silicon Arrays'.

"Beam-forming in active antennas is not new technology and has been around for decades," says chief engineer Shmuel Ravid. "The revolutionary change is that we are able to industrialize these beam-forming active antennas now for 5G," he adds. "All-silicon arrays are very

how silicon-based arrays are the path to mass industrialization of active antennas during his presentation

'Industrializing 5G mmW Radio Front Ends with

power efficient because we can place the IC directly at the radiating elements. In addition, the ICs allow for self-testing, eliminating the need to calibrate the array, thus offering a path to high-volume manufacturing."

Corman, a 37-year veteran in the mmW industry with 48 patents worldwide, has been the main systems architect for Anokiwave's portfolio of silicon beam-forming ICs, and believes that increased integration and the elimination of array calibration are primary enablers for cost-competitive, high-volume 5G systems.

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

# Infineon demos autonomous driving technology using new RF radar single-chip transceiver with 77/79GHz MMIC

At its OktoberTech 2017 Technology Collaboration Forum in Palo Alto, CA, USA, Infineon Technologies AG of Munich, Germany demonstrated the latest semiconductor solutions underlying autonomous driving, including new radar sensors.

The firm recently made available to early adopters a complete radar chipset that includes a 77/79GHz monolithic microwave integrated circuit (MMIC), a high-performance multicore microcontroller with a dedicated sensor processing unit and a safety power supply to accelerate the development of advanced radar systems.

"Over the recent years, we have seen the pace of innovation in the automotive industry accelerate to a level we have not experienced previously. Companies in Silicon Valley have taken a strong interest in taking a leading position for automotive innovation," says Ritesh Tyagi, head of the Silicon Valley Automotive Innovation Center (SVIC) at Infineon. "Infineon has more than a decade of radar experience and is a preferred chip partner of the automotive industry," he adds. "Our SVIC team connects the development forces of established and disruptive companies with latest technologies of Infineon, thus accelerating the advancement of the fully automated car."

## Complete radar chipset: new RF radar transceiver, micro-controller and power supply

Infineon says that its concept of a monolithic highly integrated radio frequency (RF) radar transceiver was well received with major design-wins at industry-leading system suppliers to the automotive industry. The new RF radar single-chip transceiver replaces three previous components: the RF transmitter, the RF receiver and a companion phase-locked loop (PLL) device. The RF radar transceiver together with a second-generation AURIX radar-specific microcontroller and a fail-safe power supply is the basis for a scalable radar chipset.

All three products are fully compliant with ISO26262 specifications. To support new designs at established automotive system suppliers and disruptive companies, in first-quarter 2018 Infineon will make available a radar module starter kit including the three ICs (RF radar transceiver, AURIX radar-specific microcontroller and fail-safe power supply) and an integrated software package to take advantage of the dedicated signal processing hardware accelerator in the chipset (intended as an evaluation starter kit for developing radar sensors using the Infineon chipset).

## More road safety with radar chips for vehicles and infrastructure

Infineon says that it is currently the leading supplier of 77/79GHz radar chips. With a total of over 50 million radar sensor chips sold, the firm claims that it is the standard in radar-based driver assistance systems in all car segments (premium, mid-range and compact), and that with the new radar chipset it will boost its market position over the next years. The growth of radar applications in vehicles is further fueled by the voluntary commitment of the USA automotive industry and a mandatory requirement by Euro NCAP for the use of radar-based driver assistance systems to achieve a five stars safety rating in a new car.

Infineon will equip the three key sensor technologies for semi-automated and fully automated cars: radar, camera (with 3D image sensor chips based on the time-of-flight (ToF) principle), and lidar. Infineon has also developed other sensing technologies for automotive safety sensor applications: Hall, magnetic and pressure sensor chips for airbags and tire pressure monitoring systems (TPMS) as well as gear sticks and steering column controls, for example.

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

## AWR Design Forum 2017 visits Russia

RF/microwave electronic design automation (EDA) software provider NI (formerly AWR Corp) of El Segundo, CA, USA has held the Russia leg of AWR Design Forum (ADF) 2017, an open forum bringing together NI AWR Design Environment customers, partners and engineering professionals to learn, network and collaborate on the design of RF/microwave circuits and systems. ADF 2017 visited three cities in Russia: St Petersburg, Moscow and

Zelenograd on 3–5 October.

Presentation highlights included:

- multi-technology low-temperature co-fired ceramic (LTCC) module design flow;
- system-level simulation and analysis of active phased-array systems;
- RF integrated circuit (RFIC) design flow;
- IHP Microelectronics' multi-project wafer (MPW) offerings and PDK features;

- PeterSoft Engineering's GaAs digital phase shifter monolithic microwave IC (MMIC);
- OMMIC's process roadmap, products and design tools;
- design bureau Robototekhnika's design of a low-noise amplifier (LNA) at Moscow Unit of OOO IRZ; and
- Planeta-IRMIS's nonlinear stability analysis.

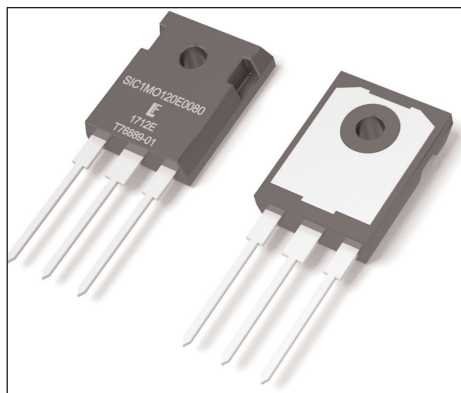
ADF was free to attend and included simultaneous Russian interpretation.

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

## First Littelfuse SiC MOSFET provides ultra-fast switching in power electronics

Littelfuse Inc of Chicago, IL, USA,, which provides circuit protection technologies (including fuses, semiconductors, polymers, ceramics, relays and sensors), has launched its first series of silicon carbide (SiC) MOSFETs as the latest addition to its growing power semiconductor line.

In March, Littelfuse took another step in the power semiconductor industry through a majority investment in silicon carbide technology development company Monolith Semiconductor Inc of Round Rock, TX, USA. With a voltage rating of 1200V and ultra-low on-resistance of 80m $\Omega$ , the LSIC1MO120E0080 Series is the first organically designed, developed and manufactured silicon carbide MOSFETs to be released by this partnership. The device is optimized for high-frequency switching applications, providing a combination of ultra-low switching losses and ultra-fast switching speeds that is said to be unavailable with traditional power transistor solutions.



**Littelfuse's 80m $\Omega$  1200V LSIC1MO120E0080 SiC MOSFET.**

Compared with silicon devices that have the same rating, the SiC MOSFET Series enables substantially greater energy efficiency, reduced system size/weight, and increased power density in power electronics systems, says Littelfuse. It also offers

**Our SiC MOSFET application support network is prepared to help customers enhance the performance of their existing designs**

superior robustness and performance, even at high operating temperatures (150°C), the firm adds.

Typical applications for the new SiC MOSFETs include power conversion systems such as solar inverters, switch mode power supplies (SMPS), uninterruptible power supply (UPS) systems, motor drives, high-voltage DC/DC converters, battery chargers, and induction heating.

"Our SiC MOSFET application support network is prepared to help customers enhance the performance of their existing designs, as well as assist those developing new power converter products," says Michael Ketterer, product marketing manager for Power Semiconductors in Littelfuse's Electronics business unit.

The LSIC1MO120E0080 Series SiC MOSFET is available in TO-247-3L packaging and provided in tubes in quantities of 450. Sample requests may be placed through authorized Littelfuse distributors worldwide. [www.littelfuse.com/products/power-semiconductors/silicon-carbide/silicon-carbide-mosfets](http://www.littelfuse.com/products/power-semiconductors/silicon-carbide/silicon-carbide-mosfets)

## Infineon launches sixth generation of CoolSiC Schottky diodes for fast switching

As the latest development in its CoolSiC diode family, Infineon Technologies AG of Munich, Germany has launched the CoolSiC Schottky diode 650V G6, which builds on the characteristics of the G5 to provide reliability, quality and increased efficiency. Complementing the 600V and 650V CoolMOS 7 families, the CoolSiC G6 diodes target applications in server and PC power, telecom equipment power, and photovoltaic (PV) inverters.

The G6 has a new layout, new cell structure, and a new proprietary Schottky metal system. The result is what is claimed to be an industry benchmark forward voltage ( $V_F$ ) of



1.25V, and a  $Q_C \times V_F$  figure of merit (FOM) that is 17% lower than the previous generation. In addition, the new G6 diode makes use of silicon carbide's strong characteristics of temperature-independent switching behavior and no reverse recovery charge.

The design of the device is said to provide improved efficiency over all load conditions along with increased system power density. The CoolSiC Schottky diode 650V G6 hence features reduced cooling requirements, increased system reliability, and extremely fast switching.

[www.infineon.com/cool-sic-g6](http://www.infineon.com/cool-sic-g6)

# Kyoto University professor Hiroyuki Matsunami awarded Honda Prize for research on SiC power devices

Honda Foundation (a public-interest incorporated foundation created by Honda Motor Co Ltd's founder Soichiro Honda and his younger brother Benjiro Honda) says that the Honda Prize 2017 will be awarded to Kyoto University professor emeritus Dr Hiroyuki Matsunami for his contributions to pioneering research on silicon carbide (SiC) power devices and their practical applications.

The award ceremony will be held at the Imperial Hotel in Tokyo, Japan on 16 November. In addition to the prize medal and diploma, the laureate will be awarded 10m yen.

Matsunami is the 38th Honda Prize laureate. Established in 1980, the Honda Prize is Japan's first international award in the field of science & technology. It is awarded annually to an individual or group in order to recognize accomplishments in the field of ecotechnology (advancing human achievement while concurrently preserving the natural environment). Through Matsunami's research, SiC power devices have been put into practical use and are contributing to reducing power loss in the control of power supplies.

Research on SiC began in the USA in the mid-1950s. Matsunami had an interest in SiC from early on, and started basic research in the late 1960s to develop electronic devices utilizing SiC's excellent physical properties of high-temperature operability and radiation resistance.

While silicon has the characteristics of a single crystal with a regular diamond structure, SiC is a hard-to-handle material, as achiev-



**Dr Hiroyuki Matsunami**

ing crystal growth with few defects is difficult. Also, SiC has 200 different types of crystal structure (polymorphism), so the most appropriate crystal polymorphism for commercialization was difficult to determine. Furthermore, with a robust structure as hard as diamond, processing SiC is extremely difficult and challenging. Although many research institutes attempted to realize the practical application of SiC, none overcame the processing difficulties and most of them withdrew from the project.

Matsunami continued basic research on SiC and, about 20 years after starting his research, in 1987 he published a method 'Step-Controlled Epitaxy', enabling the production of a homogeneous SiC thin membrane with uniform crystal polymorphism by tilting the surface of the substrate a few degrees. Around 1990, as silicon power devices were approaching their performance limit, due to his discovery the use of SiC came under the spot light and the development of SiC power devices progressed dramatically.

Around 2010, the practical application of SiC power devices began. Using SiC in power devices led to a tremendous reduction in power loss, enabling high-speed, high-efficiency power control. Likewise, as SiC has high-voltage resistance and high-temperature resistance

characteristics, cooling systems became more compact, leading to the downsizing of power control mechanisms. In 2013, SiC power devices were introduced to the Tokyo Metro subway, yielding a 30% energy reduction compared to the energy required by conventional train cars. In recent years, SiC power devices have been installed on suburban trains, high-speed elevators, power conditioners for solar batteries, and fuel-cell vehicles. Also, experiments for installation on hybrid cars and the Tokaido Shinkansen bullet train have begun.

Although there are still some challenges to the wider adoption of SiC power devices (including the establishment of mass-production technology, cost reduction, etc), its application to electric vehicles is also anticipated, after a further reduction in power consumption, space-saving through downsizing of the devices, and cost reduction are achieved.

Beginning with Step-Controlled Epitaxy, SiC production methods and the technologies enabling practical applications to power devices have paved the way for new possibilities for SiC as a novel material. As realization of the practical uses of SiC power devices can also lead to mitigating the rapid increase in fossil fuel consumption and the amount of waste from power generation accompanied by a surge in consumption globally, Matsunami's accomplishments were hence considered appropriate for recognition with the Honda Prize.

[www.hondafoundation.jp/en](http://www.hondafoundation.jp/en)

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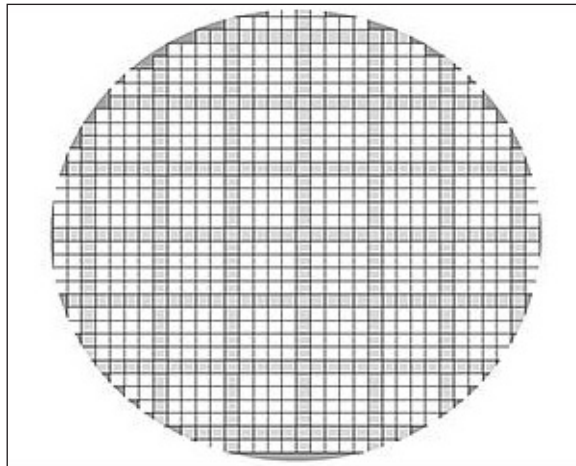
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[www.semiconductor-today.com](http://www.semiconductor-today.com)

## Sumitomo Electric launches EpiEra SiC epiwafer, achieving 99% defect-free area

After being showcased at the International Conference on Silicon Carbide & Related Materials (ICSCRM 2017) in Washington DC, USA (17–22 September), Tokyo-based Sumitomo Electric Industries Ltd (SEI) has launched the EpiEra high-quality SiC epitaxial wafer, which has now entered mass-production.

Demand for SiC-based devices is growing rapidly as a key component of energy-efficient solutions. However, to satisfy this demand and to compete with the yields and reliability of silicon-based devices, material improvements are necessary, says SEI.

Sumitomo Electric has developed EpiEra by using its multi-parameter and zone (MPZ)-controlled SiC growth technology, which adjusts various parameters (including temperature, pressure, gas reactions



**Sumitomo Electric Industries' new EpiEra silicon carbide epitaxial wafers.**

etc) depending on the area and time zone by utilizing simulation and monitoring techniques.

EpiEra has achieved what is claimed to be an industry-leading 99% defect-free area (DFA), eliminating surface defects and basal plane dislocations (BPD) and hence improving quality stability and reliability, the firm adds.

[www.mrs.org/icscrm-2017](http://www.mrs.org/icscrm-2017)  
<http://global-sei.com/products/semiconductor.html>

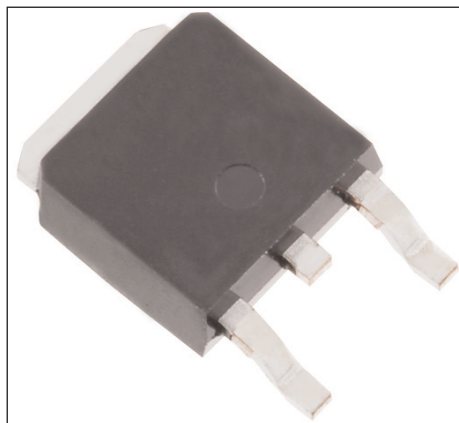
**Basal plane dislocations (BPD) map for SEI's 4-inch EpiEra epiwafer .**

## Toshiba adds second-generation 650V SiC Schottky barrier diodes in DPAK surface-mount package

Toshiba Electronic Devices & Storage Corp (TDSC) — spun off from Toshiba Corp in July — has enhanced its diode portfolio with the addition of six Schottky barrier diodes (SBDs) fabricated with silicon carbide (SiC) and housed in surface-mount packages (shipping in volume now).

Up to now, TDSC has focused on SiC SBDs in through-hole packages. The addition of its first SiC SBDs in DPAK surface-mount packages meets what the firm says are customer requirements to reduce system size and thickness.

The new SiC SBDs incorporate Toshiba's latest second-generation chip, which delivers improvements in both surge peak forward current IFSM (to about 7–9.5 times the current rating,  $I_{F(DC)}$ ) and in figure of merit  $V_F \times Q_C$  (to about 1/3 lower than first-generation products, indicating high efficiency). The devices



**Second-generation 650V SiC Schottky barrier diodes in DPAK surface-mount type package.**

offer enhanced ruggedness and low loss, which helps to improve system efficiency and simplify thermal design.

The new SiC SBDs are suitable for a wide range of commercial and industrial applications, including:

- power factor correction (PFC) circuitry for high-efficiency power supplies, micro inverter circuits, chopper circuits (various power supplies of hundreds of watts or more), and free-wheel diodes for switching devices;
- consumer products and OA equipment: power supplies for large-screen 4K LCD and OLED TV sets, projectors, multi-function copiers, etc; and
- industrial equipment: power supplies for telecom base stations, PC servers, solar micro-inverters, etc.

TDSC says that it will continue to expand its product portfolio in order to help improve the efficiency and reduce the size of communications equipment, servers, inverters and other products.

<https://toshiba.semicon-storage.com/ap-en/product/diode/sic.html>

# SUNY Poly professor awarded DOE grant as part of \$750,000 project to develop more efficient, cost-effective SiC power electronics chips

## MOSFETs & diodes with 600V rating for power supplies, PV inverters, and electric vehicles; 3.3kV and 6.5kV for heavy-duty vehicles and wind turbines; and 10kV for circuit breakers and electrical grid

State University of New York (SUNY) Polytechnic Institute says that associate professor of nano-engineering Dr Woongje Sung has been selected to receive \$375,000 in federal funding as part of an overall \$750,000 project from the US Department of Energy (DOE) to develop silicon carbide (SiC) power electronics chips that are smaller and more efficient than existing power electronics chips. Sung's research efforts could also lead to the development of a more cost-effective manufacturing process for making the chips, enabling more robust chips for application ranging from solar energy, electric vehicles, and the electric grid.

"This effort paves the way for hands-on student research opportunities in an area of critical importance to our country's energy future," comments SUNY Poly's provost Dr William Durgin.

"SUNY Poly is playing a role in the technologies of the future and making the chips utilized in our electrical grid, for example, more energy efficient, in addition to being cheaper to manufacture," says associate professor of nanoengineering Dr Michael Carpenter, SUNY Poly's interim dean of the College of Nanoscale Engineering



**Dr Woongje Sung.**

and Technology Innovation.

Supported by the DOE grant, Sung's research will utilize the material properties of SiC, which allow metal-oxide-semiconductor

field-effect transistors (MOSFETs) to be designed ten times smaller than silicon-based counterpart. Coupled with an expected move from 4" to 6" wafers, the anticipated economies of scale could lead to vastly more cost-effective production of power electronics chips via Sung's innovative design concepts and the establishment of a more efficient manufacturing process flow.

The research could lead to improved performance for a wide variety of applications, it is reckoned. Sung and his research team will focus on developing SiC MOSFETs and diodes with voltage ratings of 600V for power supplies, photovoltaic inverters, and electric vehicles; 3.3kV and 6.5kV for heavy-duty vehicles and wind turbines; and 10kV for circuit breakers and electrical grid applications, for example.

"This work, leading to chips that consume less energy, could save significant amounts of energy once they are produced in a way that makes them even easier to adopt," says Sung.

The power electronics-focused research will support SUNY Poly graduate and undergraduate students, who will gain first-hand experience optimizing the device structure, designing the process flow, and characterizing fabricated devices.

The new grant also follows a recent award of \$720,000 in funding from the DOE for the further development of gallium nitride (GaN)-based power electronics at SUNY Poly, in which Sung received a portion of the funds for research in partnership with interim dean of graduate studies Dr Fatemeh (Shadi) Shahedipour-Sandvik, the Army Research Lab, Drexel University, and Gyrotron Technology Inc. That DOE Advanced Research Projects Agency-Energy (ARPA-E) funding will be used to develop new ways to fabricate semiconductors for high-performance, high-powered applications such as electric vehicles and the grid.

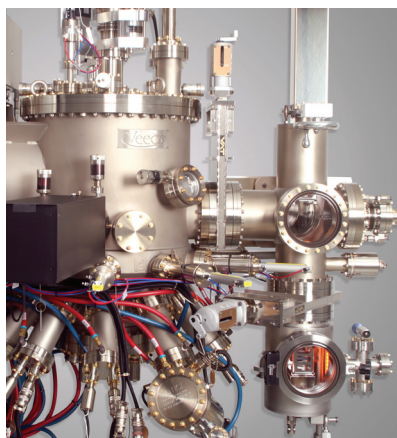
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## PowerAmerica gains Dr Jon Zhang as director of Power Device Technology

PowerAmerica — a manufacturing institute consisting of public and private partners from the semiconductor industry, the US Department of Energy (DoE), national laboratories and academia — says that Dr Jon Zhang has joined it as director of Power Device Technology.

Zhang received his PhD in 2001 from the University of South Carolina and has spent the last 16 years innovating in silicon carbide (SiC) power devices. His record of achievement includes writing a book chapter on SiC devices; coauthoring more than 75 technical

papers and conference presentations; and being the first inventor on 64 US and numerous international patents (with more applications pending).

Milestones also include demonstrating the industry's first reported trench MOSFET with dual buffer layers on SiC (2005), the first reported 12kV insulated-gate bipolar transistor (IGBT) on SiC (2007), the first reported trench Schottky diode on SiC (2009), the first reported bipolar junction transistor (BJT) with high current gain of >100 on SiC (2010), the first

reported 12kV gate turn-off thyristor on SiC (2011), and the first reported 12kV optically triggered gate turn-off thyristor on SiC (2012).

Zhang has "an outstanding track record of accomplishment in power semiconductor devices and will play a key role in supporting the PowerAmerica goal of creating US manufacturing jobs through accelerated adoption of SiC and GaN power electronics," says deputy executive director & chief technology officer Dr Victor Veliadis.

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

## Leti-coordinated EU project ModuLED launches to develop drive-trains for third-generation electric vehicles

October saw the launch in Grenoble, France of the three-year, €7.2m European Union 'Horizon 2020' project ModuLED, which brings together 10 European research institutes, key members of the automotive-industry value chain and universities to develop electric drive-trains for third-generation electric vehicles.

The project will focus on boosting drive-train performance to meet vehicle-owner requirements, to make manufacturing more efficient and to reduce environmental impact and vehicle cost.

The ModuLED team will leverage recent innovations from diverse industries, including integrating the frequency, voltage and high-temperature benefits of wide-bandgap semiconductors like gallium nitride (GaN). Such devices allow the electronic circuitry that changes direct current to alternating current (DC-AC) to be integrated directly into the motor.

Coordinated by Grenoble-based Leti — a research institute of CEA Tech, the technology research branch of France's Alternative Energies and Atomic Energy Commis-



sion (CEA) — ModuLED involves the companies BRUSA Elektronik AG (Switzerland), Punch Powertrain NV (Belgium), ZG GmbH (Germany), Siemens (France), Efficient Innovation (France); universities RTWH Aachen University, Chalmers University and Eindhoven University of Technology, and Leti's sister CEA Tech research institute Liten. The project leverages Leti's expertise in wide-bandgap semiconductors along with Liten's know-how in magnetic materials and simulation.

Other recent innovations that the project will develop for the new drive-trains include:

- processes for manufacturing magnetic materials for the mag-

netic part of the motor (lowering the density of the rare-earth element);

- a motor architecture that allows modularity in production;

- transmission and cooling systems that are compatible with hybrid vehicles; and
- the optimization of

braking systems to recover energy in the braking phase.

"Electric vehicles are a key component of the EU's commitment to limit climate change, but current electric vehicles face challenges preventing large market acceptance, including consumer resistance due to cost and limited driving ranges," says Bernard Strée, project coordinator at Leti. "ModuLED will target these challenges via the manufacturing process, including the mass-production context, increased value-chain involvement and lifecycle analysis for optimized duration and minimized environmental impact."

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

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## Wolfspeed highlights GaN RF technology and GaN-on-SiC foundry services at CSICS

At the 2017 IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS) in Miami, FL (22–25 October), Wolfspeed of Raleigh, NC, USA — a Cree Company that makes silicon carbide (SiC) power products and GaN-on-SiC high-electron-mobility transistors (HEMTs) and monolithic microwave integrated circuits (MMICs) — exhibited its GaN RF amplifier technology and showcased its GaN-on-SiC commercial foundry services, enabling RF design engineers to build more efficient broadband power amplifiers for commercial and military wireless communications and radar applications.

Wolfspeed engineers showcased the firm's commercial open GaN-on-SiC foundry services, as well as demonstrating their

latest GaN-on-SiC power devices for an extensive range of RF power amplifier applications for military communications systems, radar equipment, electronic warfare (EW) and electronic counter-measure (ECM) systems, as well as commercial RF applications in the industrial, medical & scientific (ISM) band. Wolfspeed claims that its GaN RF technology leads the industry in reliability with a failure-in-time (FIT) rate of <10 after billions of device hours of field operation.

"As GaN-on-SiC RF technology has entered the mainstream in commercial wireless infrastructure, our industry-leading open RF foundry and components business continues to innovate to meet the changing cost, efficiency and performance demands needed for upcoming

5G systems," says Jim Milligan, vice president, RF and Microwave Products.

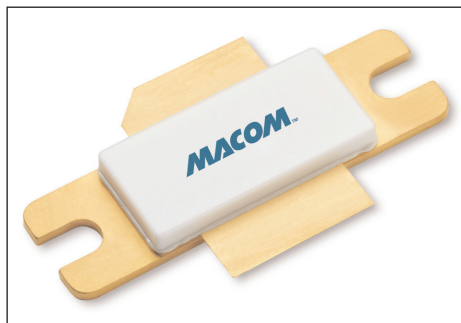
Wolfspeed's RF business development manager Simon Wood served as the exhibition chair of the CSICS conference, and Wolfspeed personnel presented one of the CSICS 2017 conference technical sessions. RF applications engineer Kasyap Patel delivered a presentation 'Current Contours-Based Input Matching Network (IMN) Design Methodology for Broadband GaN Doherty Power Amplifiers'. Co-presenters for this session were H. Golestaneh (RF/mmWave design engineer at Peraso Technologies) and S. Boumaiza (professor, ECE at University of Waterloo, Canada).

<https://csics.org>  
[www.wolfspeed.com/csics-17](http://www.wolfspeed.com/csics-17)

## MACOM launches 500W GaN-on-Si power transistor for L-band airport surveillance radar

MACOM has launched the newest entry in its gallium nitride on silicon (GaN-on-Si) power transistor portfolio for pulsed L-band radar systems targeted for airport surveillance radar (ASR) applications at 1.2–1.4GHz. Delivering high efficiency at peak pulse power levels up to 500W, the MAGX-101214-500 is expected to outperform premium-priced GaN-on-SiC-based transistors, and far exceed the performance, efficiency and power density of legacy silicon LD MOS-based devices.

The new MAGX-101214-500 enables customers to scale to higher power levels across a host of ASR applications, delivering 500W output power and greater than 70% power efficiency under pulsed conditions at 50V operation. Supplied in a small-footprint ceramic flanged package and supporting matching structures that minimize circuit size, the transistors help to



**MACOM's new MAGX-101214-500 GaN-on-SiC-based transistor.**

enable rugged, compact radar systems underpinned with efficient, simplified cooling and power supply architectures, says MACOM.

The MAGX-101214-500 builds on MACOM's portfolio of GaN-on-Si power transistors, which have demonstrated field-proven reliability in harsh environmental conditions. To date, over 1 million MACOM GaN-on-Si devices have been shipped to customers around the world.

"The continued expansion of MACOM's GaN-on-Si product portfolio enables customers to address an ever-widening range of RF power requirements while achieving performance profiles that meet and exceed GaN-on-SiC, at significantly less cost at scaled volume production levels," claims Greg French, senior product manager, RF Power. "Our proven technology leadership in GaN-on-Si combined with our decades-long heritage in civil and defense radar are among the many factors fueling our innovation in these important markets."

MACOM showcased the MAGX-101214-500 at European Microwave Week (EuMW 2017) in Nuremberg, Germany (10–12 October). Products are sampling to customers now, with production release targeted for first-half 2018.

[www.eumweek.com](http://www.eumweek.com)  
[www.macom.com/gan](http://www.macom.com/gan)  
[www.macom.com/products/product-](http://www.macom.com/products/product-)

# MACOM showcases GaN-on-Si portfolio and high-performance MMICs and diodes at EuMW

At European Microwave Week (EuMW 2017) in Nürnberg Convention Center, Germany (10–12 October), M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) showcased its gallium nitride-on-silicon (GaN-on-Si) portfolio and other high-performance monolithic microwave integrated circuits (MMICs) and diode products.

The booth featured new products optimized for base-station, aerospace and defense, RF energy, commercial, and industrial, scientific & medical RF applications,

namely:

- high-power GaN-on-Si (RF Energy Toolkit enabling faster and easier solid-state RF system development, and a 500W GaN-on-Si device with high efficiency and power at elevated temperature, suitable for rugged aerospace & defense applications);
- RF small-signal portfolio (featuring high-performance MMICs and base-station and mobile backhaul devices);
- high-performance diodes (diode design and application-specific solutions); and
- high-reliability (hi-rel) and component devices (the latest screened products for mission-

critical aerospace applications).

Also, MACOM experts participated in various sessions throughout EuMW, including:

- Technical Session EuMIC02-1: 'GaN-on-Silicon — Present Challenges and Future Opportunities' — presenter Tim Boles;
- Poster Session EuMIC05-03: 'Rugged AlGaAs PIN Diode Switches' — presenter James Brogle; and
- Defence, Security & Space Forum — MWJ Industry Panel Session: Internet of Space, Past, Present & Future — presenter Tim Boles.

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

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

## MACOM's RF Energy Toolkit now available for commercial OEMs seeking fast path to revenue for GaN-on-Si-based RF systems

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) says that its RF Energy Toolkits are now available for order, meeting surging demand for a flexible and cost-effective development platform that helps to accelerate time to market with high-performance, power-efficient solid-state RF systems. Targeted for use in commercial markets ranging from cooking, lighting and industrial heating/drying to medical/pharmaceutical, automotive ignition systems and beyond, the RF Energy Toolkits enable engineers to quickly and easily take advantage of GaN-on-Si as a high-precision, high-efficiency energy source, says MACOM.

The firm says that the all-in-one versatility and ease-of-use of its RF Energy Toolkit streamlines development cycles and costs for GaN-on-Si-based RF systems, equipping engineers to overcome the limitations of legacy mag-



netron power sources while achieving significantly higher efficiency than silicon LDMOS-based systems, at comparable cost structures. Designers can fine-tune RF energy output for any application requirements, with push-button ease and an intuitive display interface. OEMs designing for more complex RF energy applications can tap MACOM and its partner network for custom applicator and algorithm development, plus expert engineering support.

The RF Energy Toolkits can scale power output up to 300W leveraging the onboard MACOM GaN-on-Si power transistor, and can be paralleled for higher-power applications. The Toolkits support pulsed and continuous-wave

operation at the 2.45GHz frequency band. Future Toolkits will support the 915MHz frequency band.

"Commercial OEMs have awakened to the massive market opportunity for GaN-on-Si-based solid-state RF systems which essentially remove most of the limitations of magnetron-based systems, but they are new to this technology, and design and development challenges have slowed their time to market — until now," says Mark Murphy, senior director, RF Power. "The RF Energy Toolkit affords them an all-in-one, adaptable 'Swiss army knife' solution that removes the engineering barriers that have impeded OEMs' adoption of RF energy, liberating them to take giant strides forward on the path to mainstream commercialization," he adds.

MACOM showcased its RF Energy Toolkit at European Microwave Week (EuMW 2017) in Nuremberg, Germany (10–12 October). RF Energy Toolkits are available for order now.

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

# Peregrine's new PE29102 FET driver brings fastest switching speeds to GaN class-D audio

Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has launched the UltraCMOS PE29102 high-speed FET driver.

With a switching frequency up to 40MHz, the PE29102 delivers what is claimed to be the industry's fastest switching speeds, empowering design engineers to extract the full performance and switching-speed advantages from gallium nitride (GaN) transistors. In class-D audio amplifiers, the new high-speed FET driver enables GaN technology to deliver what is claimed to be superior audio performance with low jitter.

The PE29102 integrates resistor-settable, internal dead-time control and is implemented so that it preserves the integrity of the incoming audio signal. When used in conjunction with GaN FETs, low dead times minimize crossover distortion in class-D applications. The PE29102's unique set of phase-control pins enable the same part to be used for both phases in bridge-tied load (BTL) configurations — a technique used in audio amplifiers. It has an output source current of 2A and an output sink current of 4A. The PE29102 handles voltages up to 60V and supports a gate drive up to 6V.

"Our customers have validated the improved sound quality with GaN-based circuits, and we see the pairing of Peregrine's driver and GaN Systems' transistors as the superior solution in applications such as class-D audio, bi-directional DC-DC, and push-pull DC-AC power supplies," comments Paul Wiener, VP of strategic marketing at GaN Systems.

Audio systems are challenged to both minimize size and deliver exceptional audio quality. At the system-design level, better audio performance and sound quality



occur when distortion is reduced. MOSFET components have parasitic diodes and gate capacitance that creates jitter and distortion in class-D audio systems, whereas GaN FETs have much smaller gate capacitance and lower parasitics. GaN transistors can beat MOSFET jitter performance by a factor of ten and deliver reduced distortion and smooth sound, Peregrine says. However, to reach this performance potential, GaN transistors need an optimized gate driver. The PE29102 is designed specifically for this purpose. Its high switching speeds result in smaller peripheral components and enable innovative designs for applications like class-D audio.

"GaN is disrupting traditional power MOSFET markets," notes Alex Lidow, CEO & co-founder of Efficient Power Conversion Corp (EPC). "In class-D audio systems, the audio performance is impacted by the FET characteristics," he adds. "Our enhancement-mode GaN (eGaN) transistors enable a significant increase in the sonic quality and higher efficiency. High-speed FET drivers, like Peregrine's PE29102, are critical to unlocking the performance potential of eGaN FET technology in applications like class-D audio."

Peregrine says that its UltraCMOS technology platform is the driving force behind the PE29102's speed, enabling integrated circuits to operate at much faster speeds than

conventional CMOS technologies. This speed advantage results in significantly smaller power converters, benefitting the design engineer with increased power density.

"By enabling GaN to reach its performance potential, UltraCMOS technology and Peregrine are playing a role in GaN's disruption into more

mainstream applications," says Mark Moffat, director of Peregrine's power management product line. "In the case of audio, GaN technology is enabling the next generation of class-D audio advancements."

To showcase the GaN-enabling capabilities of the new UltraCMOS PE29102 driver (which is suitable for either half-bridge or full-bridge configurations), Peregrine has developed evaluation kits with two leading GaN transistor providers (GaN Systems and EPC):

- The GaN Systems GS61004B evaluation board allows the user to evaluate the PE29102 gate driver in a full-bridge configuration. The board is assembled with two PE29102 FET drivers and four GS61004B GaN transistors. The full-bridge board is available from Peregrine as EK29102-03, GaN Systems as GS61004B-EVBCD, and distributor Richardson RFPD under both part numbers.
- The EPC9086 is a half-bridge board that uses one PE29102 to drive the 30V, 15A EPC2111 eGaN half bridge. This board is available from EPC via its distributor Digi-Key.

Offered as a 2mm x 1.6mm flip-chip die, PE29102 volume-production parts, samples and evaluation kits are available now.

[www.psemi.com/products/gan-fet-driver/pe29102](http://www.psemi.com/products/gan-fet-driver/pe29102)  
[www.gansystems.com/gs61004b.php](http://www.gansystems.com/gs61004b.php)  
[www.epc-co.com/epc/Products/DemoBoards/EPC9086.aspx](http://www.epc-co.com/epc/Products/DemoBoards/EPC9086.aspx)

## EPC launches high-efficiency half-bridge development board operating up to 10MHz for point-of-load DC–DC conversion

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 made available the EPC9086 development board, a high-efficiency half-bridge development board that can operate up to 10MHz.

The EPC9086 board is 2" x 2" and contains a 30V, 15A EPC2111 eGaN half bridge in combination with the recently introduced PE29102 high-speed gate driver from Peregrine Semiconductor Corp of San Diego, CA, USA, a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI).

The purpose of the development board is to reduce time to market by simplifying the evaluation

process of the EPC2111 eGaN by including all the critical components, such as Peregrine's PE29102 high-speed gate driver, on a single board that can be easily connected into any existing converter. "The PE29102 is an integrated high-speed driver specifically designed to control the gates of high-switching-speed external power devices, such as eGaN FETs," says Mark Moffat, director of Peregrine's power management product line.

The outputs of this driver can provide switching transition speeds in the sub-nanosecond range with optimized matched dead time. It offers what is claimed to be best-in-class propagation delay for hard switching applications up to 40MHz, enabling the high performance of GaN power transistors. The PE29102 provides minimum pulse

widths of 5ns and is offered as a 2mm x 1.6mm flip-chip die, enabling a small-form-factor power stage for high-duty-cycle power conversion at high frequency.

The board may be used for applications where high frequency can enable a significant size and height reduction, such as in notebook and tablet computing.

The EPC9086 has been evaluated in a 12V to point-of-load DC–DC converter application and achieved efficiency levels of 86% at 10A when switching at 5MHz and over 80% when switching at 10MHz.

The EPC9086 half-bridge development boards are priced at \$118.75 each, available via Digi-Key.

[www.epc-co.com/epc/Products/DemoBoards/EPC9086.aspx](http://www.epc-co.com/epc/Products/DemoBoards/EPC9086.aspx)  
[www.psemi.com/products/gan-fet-driver/pe29102](http://www.psemi.com/products/gan-fet-driver/pe29102)

## GaN Systems launches evaluation board combining GaN power transistors with Peregrine's E-HEMT drivers

GaN Systems has made available the GS61004B-EVBDC evaluation board, which combines what are claimed to be best-in-class GaN power transistors with the fastest commercially available GaN transistor driver.

The GS61004B-EVBDC evaluation platform is now available with the latest high-speed GaN E-HEMT drivers from Peregrine Semiconductor Corp of San Diego, CA, USA, a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI). The evaluation kit combines four of GaN Systems' GS61004B GaN power transistors with two of Peregrine's PE29102 E-HEMT drivers, providing power design engineers with benefits including: GaN transistors operable up to 100MHz; a transistor driver operable up to

40MHz; what is claimed to be a best-in-class propagation delay; optimized, Vcc independent, for matched dead time; and integrated dead-time control, resistor-adjustable.

The GS61004B GaN E-HEMTs generate low dead times to minimize crossover distortion in class-D applications. The PE29102's unique set of phase-control pins enables the same part to be used for both phases in bridge-tied load (BTL) configurations — a technique used in audio amplifiers.

"By providing an evaluation kit with GaN Systems' world's-best power transistors and Peregrine Semiconductor's fastest-ever GaN transistor driver, design engineers have an easy-to-use platform for optimizing their system's performance and gaining a competitive

advantage," says Paul Wiener, VP strategic marketing for GaN Systems.

"By enabling GaN to reach its performance potential, UltraCMOS technology and Peregrine are playing a role in GaN's disruption into more mainstream applications," reckons Mark Moffat, director of Peregrine's power management product line. "In the case of audio, GaN technology is enabling the next-generation of class-D audio advancements."

The GS61004B-EVBDC evaluation platform includes a GaN E-HEMT driver GS61004B full-bridge evaluation board assembly and detailed user's guide, and is available worldwide through distribution channels, priced at \$99 each.

[www.psemi.com](http://www.psemi.com)  
[www.gansystems.com/gs61004b.php](http://www.gansystems.com/gs61004b.php)

# EPC launches wireless power demonstration kits

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 the availability of two new demonstration kits: the EPC9127 (a complete wireless power kit including a 10W, class 2 amplifier, category 3 receiver device) and the EPC9128 (consisting of a 16W, class 3 amplifier and two receiver devices — categories 3 & 4).

Coupled with the existing EPC9120 (33W class 4) and the EPC9121 multi-mode kit (capable of operating to either an AirFuel Class 2 standard with a category 3 device or a Qi (A6)/PMA standard with a compatible receiving device), these systems provide a full range of wireless power demonstration kits to allow for complete, wide-spread implementation.

EPC hence now covers a wide range of the AirFuel resonant technology standard. The popularity of resonant wireless power transfer is increasing rapidly, with end applications evolving quickly from mere cell-phone battery charging to the powering of large surface areas where handheld tablets, laptops and computers — and, soon TV sets, lamps and other electrically powered appliances — can simultaneously charge anywhere on the surface.

The purpose of the demonstration kits is to simplify the evaluation process of using eGaN FETs and ICs

for highly efficient wireless power transfer. Operating at 6.78MHz (the lowest ISM band), the kits utilize the high-frequency switching capability of EPC's GaN transistors to facilitate wireless power systems. The system efficiency is about 87% from input to the amplifier to the output of the receiver (end-to-end). With future improvements in architecture and GaN IC technology, this can reach the 95% range, says EPC.

The EPC9127 wireless power system consists of three boards:

- a source board (transmitter or power Amplifier) EPC9510;
- a Class 2 AirFuel Alliance-compliant source coil (transmit coil); and
- a Category 3 AirFuel Alliance-compliant receiving device EPC9513.

The EPC9128 wireless power system consists of four boards:

- a source board (transmitter or power amplifier) EPC9509;
- a Class 3 AirFuel Alliance-compliant source coil (transmit coil);
- a Category 3 AirFuel Alliance-compliant receiving device EPC9513; and
- a Category 4 AirFuel Alliance-compliant receiving device EPC9515.

Source (amplifier) and receiving device boards available separately

The source (amplifier) boards included in these kits are highly efficient zero voltage switching (ZVS), Class-D amplifiers configured in an optional half-bridge topology (for single-ended configuration) or default full-bridge topology (for differential configuration).

They include the gate driver(s), oscillator and feedback controller for the pre-regulator. This allows for compliance testing operating to the AirFuel standard over a wide load range. The amplifier boards are available separately as EPC9509 and EPC9510 for evaluation in existing customer systems.

The receiving device boards include the category 3 EPC9513 (5V, 5W) and category 4 EPC9515 (5V, 10W). They are also available separately for customers that have their own source boards or for those who want to design wireless power systems powering multiple devices simultaneously. The boards allow customers to bring various wirelessly powered consumer electronic products quickly to market, says EPC.

With the wide range of efficient receivers that can be used to power anything from lamps to laptops to tablets, while remaining compatible with cell-phone charging, the system designer now has all the tools needed to create an entire wireless power, large-area efficient system, says the firm.

The EPC9127 and EPC9128 wireless power transfer demonstration systems are priced at \$907.20 each. The EPC9513 and EPC9115 device receive boards can also be purchased separately and are priced at \$168.75 each. All the products are available via Digi-Key.

[www.epc-co.com/epc/Products/DemoBoards/EPC9127.aspx](http://www.epc-co.com/epc/Products/DemoBoards/EPC9127.aspx)

## MIGVAN sales, marketing and technical support partner for Israel

To support its accelerating growth throughout Israel, EPC has appointed MIGVAN Technologies & Engineering Ltd as its sales, marketing and technical support representative.

Founded in 1988, MIGVAN is a representative/distributor that promotes and sells electronic components and subsystems to the Israeli electronics industry. "MIGVAN has extensive reach and

experience throughout Israel in making leading-edge electronics available to designers and engineers," comments EPC's senior VP of sales & marketing Nick Cataldo. "The company's professional and dedicated staff of employees provides full, high-quality technical support to customers while focusing on timely, efficient service," he adds. "Our new partnership with EPC is

an exciting addition to our Power & Control portfolio of products and will allow us to bring leading-edge gallium nitride power semiconductors to Israel," says MIGVAN's VP of sales Erez Shahrabany. "GaN technologies are an exciting innovation and will enable Israeli system design houses to produce really exciting, high-performance products," he believes.

[www.mte.co.il](http://www.mte.co.il)



## GaN Systems and Taiwan's Ministry of Economic Affairs collaborate to meet global power challenges

GaN Systems Inc of Ottawa, Ontario, Canada — a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control — and Taiwan's Ministry of Economic Affairs (MOEA) have entered into a Letter of Intent to collaborate on expanding the economic and technical benefits of GaN technology to Taiwan's electronics manufacturers. The aim is to meet the global challenges of unsustainable increases in power consumption, combating climate change, implementing cleantech technologies, and meeting green CO<sub>2</sub>-reduction initiatives.

To further advance Taiwan's role in the electronics industry, recognizing the importance and benefits of GaN, the MOEA will provide assistance to GaN Systems to extend its in-country business and representation. This agreement brings together the GaN transistor manufacturer with the government body that oversees



**GaN Systems and Taiwan's Ministry of Economic Affairs sign Letter of Intent.**

Taiwan's electronics industry. Working together, the alliance will collaborate to help solve global power challenges.

"As Taiwan plays a preeminent role in the Asian electronics industry, we are pleased to provide GaN Systems with the resources to continue their success with our leading manufacturers," says Mei-Hua Wang, Vice Minister of Taiwan's Ministry of Economic Affairs (MOEA). "This

Letter of Intent strengthens the bonds between GaN Systems and Taiwan's electronics industry," she adds.

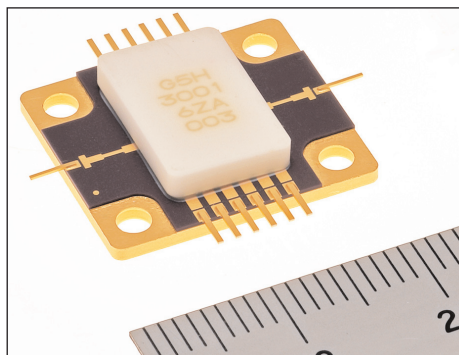
"We see this as an important demonstration of how companies and government work together to reinforce partnerships amongst industry leaders and across industry segments," comments GaN Systems' CEO Jim Witham.

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

## Mitsubishi Electric launching Ka-band GaN-HEMT MMIC to downsize satellite earth-station power transmitters

Following development that was partially supported by Japan's New Energy and Industrial Technology Development Organization (NEDO), Tokyo-based Mitsubishi Electric Corp is to launch the MGFG5H3001, a Ka-band (26–40GHz) 8W gallium nitride (GaN) high-electron-mobility transistor (HEMT) monolithic microwave integrated circuit (MMIC) amplifier for satellite earth stations.

Satellite networks (used for high-speed communication during natural disasters and in areas where ground networks are difficult to construct) are currently implemented mainly in the C-band (4–8GHz) and Ku-band (12–18GHz), but higher frequencies are increasingly being used. Also,



**The new MGFG5H3001 Ka-band GaN-HEMT MMIC.**

market demand for deployments in the higher-frequency Ka-band are increasing.

The new Ka-band GaN-HEMT MMIC is targeted at helping to meet the growing demand for higher-frequency deployments,

as well as facilitating the development of satellite communications equipment capable of extra-high output power and efficiency.

With an optimized transistor configuration on one chip that integrates amplifier transistor circuits, matching circuits and distortion-reducing linearizer, the MGFG5H3001 offers what are claimed to be industry-best low distortion and saturated output power rating ( $P_{out}$  typical) of 39.0dBm (8W). The reduced number of parts yields a small footprint that can help to downsize satellite earth-station power transmitters.

Mitsubishi says that samples of the MGFG5H3001 are shipping from 1 November.

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

## Navitas' co-founder delivers keynote on GaN power ICs

Navitas Semiconductor Inc of El Segundo, CA, USA says that, at the 5th IEEE Workshop on Wide Bandgap Power Devices and Applications (WiPDA 2017) in Albuquerque, NM, USA, co-founder & VP of engineering Dr Nick Fichtenbaum delivered a keynote address 'GaN Power ICs: Device Integration Delivers Application Performance' on 1 November.

Fichtenbaum also provided real-world insights in a panel discussion 'Commercialization of GaN Devices in High-Frequency Power Electronic Applications' on 31 October.

"WiPDA is an influential forum as it brings together many of the best minds in power devices," comments Fichtenbaum, who has been pioneering GaN materials and devices for nearly 15 years. "It is a great honor to present the latest in GaN technology including advances in the monolithic integration of ana-

log, digital and power circuits all in GaN to solve fundamental challenges in high-speed, high density applications," he adds.

Founded in 2013, Navitas introduced what it claimed to be the first commercial GaN power ICs. The firm says that its proprietary 'AllGaN' 650V platform process design kit (PDK) monolithically integrates GaN power field-effect transistors (FETs) with logic and analog circuits, enabling smaller, higher-energy-efficiency and lower-cost power for mobile, consumer, enterprise and new energy markets.

"Navitas has developed high-performance, easy-to-use GaN power ICs for next-generation applications in advanced mobile, industrial and consumer markets," says VP of sales & marketing Stephen Oliver. "Fichtenbaum's presentation highlights advanced research, practical

development and real-world commercial implementation of this new GaN material," he adds. "We look forward to discussing these GaN innovations as GaN adoption accelerates throughout the power industry."

In September, Navitas introduced what is claimed to be the smallest 65W USB-PD laptop adapter reference design in support of the dramatic size and weight reductions driven by market demand. The NVE028A uses Navitas high-frequency, high-efficiency AllGaN GaN Power ICs to deliver 65W in a package up to five times smaller and lighter than traditional silicon-based designs. Since introducing the AllGaN platform at APEC'16, Navitas has announced single and half-bridge GaN power ICs, plus the smallest 150W adapter.

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

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

## Navitas' GaN power ICs enable smallest 65W USB-PD laptop adapter

To keep pace with the dramatic size and weight reductions in laptop designs over the last 10 years, Navitas Semiconductor Inc of El Segundo, CA, USA has launched what it claims is the smallest 65W USB-PD (Type C) adapter reference design.

High-frequency, high-efficiency AllGaN Power ICs have been used to deliver 65W in only 45cc/2.7in<sup>3</sup> and only 60g in weight by minimizing the size, weight and cost of transformers, filters and heat-sinks. By contrast, existing silicon-based designs can require 6–7in<sup>3</sup> and weigh over 300g, says the firm.

"Finally, a laptop adapter is thin and light — like the laptop it charges — and at a great price," says VP of sales & marketing Stephen Oliver. "Power designers have been faced with several, conflicting industry challenges, from new USB Type C connectivity and USB PD (Power Delivery) output compliance to statutory

energy-efficiency standards and the ever-present issue of cost," he adds. "Navitas' GaN power ICs deliver the simultaneous achievements of high-speed operation and high efficiency to enable a single system design that meets all of those challenges — at the same or lower cost than old, slow silicon designs".

The new NVE028A reference design uses GaN power ICs in an active clamp flyback (ACF) topology running 3–4x faster and with 40% lower loss than typical adapter designs, to deliver smaller size and reduced costs. The design is fully compliant with European CoC Tier 2 and US DoE Level VI efficiency standards, in addition to reaching peak efficiencies of over 94% at full load.

"China power supply manufacturers have been looking for wide-bandgap components like this, to further increase the power supply's efficiency and power density to satisfy the requirement of customers," comments Mark Dehong Xu,

president of the China Power Supply Society (CPSS) and director of Zhejiang University's Institute of Power Electronics.

Unlike earlier attempts at high-density adapters, the NVE028A achieves small size (51mm x 43mm x 20.5mm cased) and what is claimed to be breakthrough power density (1.5W/cc, 24W/in<sup>3</sup> cased) using simple, standard, low-cost manufacturing techniques.

"Since we introduced the AllGaN platform at APEC'16, Navitas has announced single and half-bridge GaN power ICs, the world's smallest 150W adapter, and now the world's smallest, fully compliant 65W USB-PD design," says Navitas' CEO Gene Sheridan. "This is the flexible, high-performance, cost-effective platform that meets and exceeds the targets of the mobile and consumer charger markets".

[www.cpss.org.cn](http://www.cpss.org.cn)

[/cn/about/xuehuijianjie](http://cn/about/xuehuijianjie)

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

## Navitas partners with TSMC & Amkor on manufacturing

Navitas Semiconductor Inc of El Segundo, CA, USA has formed manufacturing partnerships with Taiwan Semiconductor Manufacturing Corp (TSMC, the world's biggest semiconductor wafer foundry) and contract assembly, packaging & test service provider Amkor Technology Inc to support significant customer demand for 2018 and beyond.

Founded in 2013, Navitas introduced what it claimed to be the first commercial gallium nitride (GaN) power ICs. The firm says that its proprietary 'AllGaN' 650V platform process design kit (PDK) monolithically integrates GaN power field-effect transistors (FETs) with logic and analog circuits, enabling smaller, higher-energy-efficiency and lower-cost power for mobile, consumer, enterprise and new energy markets.

Since the introduction of its GaN power IC platform last year, customers have moved quickly to

adopt the technology, says Navitas. The products are said to enable major size, efficiency and charge-rate improvements in next-generation mobile fast chargers, miniaturized consumer adapters and other density-driven power electronics applications.

TSMC provides what is said to be the largest GaN-on-silicon wafer manufacturing capability for Navitas' proprietary GaN power IC platform. "TSMC has made significant capital and engineering investment in GaN manufacturing capability, and this platform is well suited to support Navitas and its customers' high-volume needs," believes Bradford Paulsen, TSMC's senior VP business management.

"Utilizing our high-volume and low-cost QFN packaging platform, Amkor will provide packaging, test and logistics services," says John Stone, Amkor's executive VP, worldwide sales & marketing.

Navitas' GaN power ICs integrate power, analog and digital circuits all in GaN for what is claimed to be the first time in the industry, enabling dramatic improvement in application power density, efficiency and cost. Performance is achieved using standard processes and equipment, allowing fast and capital-efficient expansion of manufacturing capacity. The firm says that this capability is critical to support the high-volume and fast-paced needs of mobile charger and consumer adapter markets, which are shipping billions of units per year.

"These manufacturing partnerships allow Navitas to ramp capacity very quickly," says Navitas' chief operating officer Dan Kinzer. TSMC and Amkor are "world-class supply-chain partners, and I am confident in their ability and commitment to support the dramatic growth expectations we have for our GaN power ICs."

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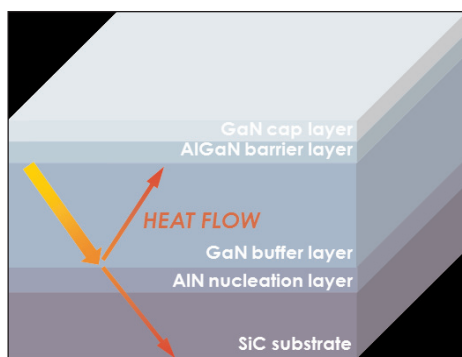
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# Nitride epiwafer firm SweGaN raises \$750,000 in new share issue

## Funds to be used to scale up production and speed development of new epitaxial materials

In a new share issue between June and August, custom III-nitride epiwafer maker SweGaN of Linköping, Sweden has raised SEK6m (\$750,000) from existing investors US-based Mount Wilson Ventures, Almi Invest and Linköping University's LiU Invest together with several private angel investors.

Founded in 2014, SweGaN has developed patented nitride-based epitaxial structures aimed at meeting the challenges of high-performance and high-frequency gallium nitride devices, targeting a wide range of applications including telecoms for 5G networks, satellite communications and defense or civilian sensors.



**SweGaN's ultra-low thermal boundary resistance (TBR) technique.**

"The investment is further supplemented by a loan that gives us a great opportunity to grow rapidly," says CEO Olof Kordina. "The funds

raised will be used to increase production and accelerate the development of our new materials," he adds.

The strategy is to increase and improve production to meet the growing demand for high-quality epitaxial wafers. Production capacity is to be increased by a factor of five, and by the beginning of 2018 the firm will start producing on 6-inch substrates instead of the existing 4-inch substrates. By the end of 2017 SweGaN expects to see revenue growth of 300%, the employment of three new staff, and the launch of a new product range.

[www.swegan.se](http://www.swegan.se)

# EpiGaN to supply OMMIC with GaN/Si material for new 150mm RF power product line

## Firms partner on GaN/Si epi for RF power products targeting 5G wireless communications

EpiGaN nv of Hasselt, near Antwerp, Belgium — which supplies gallium nitride on silicon (GaN-on-Si) and gallium nitride on silicon carbide (GaN-on-SiC) epitaxial wafers for power switching and RF power devices as well as sensors — and OMMIC of Limeil-Brévannes, France, which provides compound semiconductor monolithic microwave integrated circuits (MMICs) and foundry services, are collaborating to develop RF GaN/Si technology on 150mm-diameter wafers. OMMIC recently inaugurated what is reckoned to be Europe's first 150mm GaN production line.

The firms have jointly collaborated on establishing a production process based on EpiGaN's GaN/Si material technology with in-situ grown silicon nitride (SiN) passivation. They will also cooperate directly to move this technology to

150mm-diameter wafers, targeting future 5G wireless communication standards, for which OMMIC last week announced a large project with a 5G equipment supplier.

The advent of the 5G era about to revolutionize long-distance communications, says EpiGaN. In order to provide users with exceptionally high-speed wireless connections, ultra-low latency and enhanced mobile broadband, gallium nitride is required — in applications such as multimedia streaming, autonomous driving, machine-to-machine communication with billions of interconnected sensors or Internet-of-Things (IoT) — to transmit and receive RF signals in the utmost efficient way, add the firm.

"We offer many attractive USPs for RF power, which add value to device designers, such as in-situ SiN passivation for enhanced

device robustness, or very low RF losses up to 100GHz," says EpiGaN's CEO Dr Marianne Germain. The high-frequency capability of the firm's material "enables a very cost-efficient and energy-efficient GaN technology for the higher frequency bands targeted by 5G," she adds.

"The next-generation 5G standard will require GaN as an enabling semiconductor technology to provide a step-up in performance," states OMMIC's CEO Dr Marc Rocchi. "Only then will the experience for the end user be superb," he adds. "Teaming up with EpiGaN is an essential element of our growth strategy and it enables us to meet the required volume and quality levels for our 5G GaN MMICs," Rocchi concludes.

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

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

# Reedholm signs joint marketing and support agreement with Taiwan's STAr Technologies

## Turn-key test system, prober/handler and load board/probe card targets wide-bandgap power device market

Reedholm Systems of Georgetown, TX, USA has signed a joint marketing and support agreement with STAr Technologies of Hsinchu City, Taiwan to provide a turn-key offering consisting of a test system, prober/handler, and load board/probe card, with characterized, assured performance of all three items.

Founded in 1983, Reedholm provides new and fully refurbished parametric and wafer-level reliability (WLR) test systems, high-power wide-bandgap test systems, and support and service agreements.

Established in 2000, STAr provides intellectual property, software, hardware, consumables, service and expertise to the semiconductor industry, spanning parametric electrical test (E-test), wafer-level and package-level reliability (WLR & PLR), mixed-signal tests, assembly & packaging services, probe cards, load boards, test interfaces and

sockets, to top-tier players such as TSMC, UMC, Global Foundries, SMIC, KYEC, ASE, Samsung, Hynix, Elpida, Toshiba, Renesas, Maxim, and OmniVision.

The combined offerings will be under the Reedholm Systems brand (regardless of where the products are sold) for activities such as: process control monitoring (PCM), wafer-level die sort, packaged part/final test, and reliability (packaged and wafer level).

For the burgeoning wide-bandgap power device market, customers are demanding newly designed products with safety requirements in mind for applications that involve measuring voltages of 10kV and currents of 50A or more. Reedholm and STAr are striving to develop the supply of such tools on a broader basis and share details about evolving customer needs.

Reedholm's products include a series of parametric test systems

(RI-40, RI-75, RI-EG) that are used for the gamut of dc parametric test requirements. The latest system — the RI-10kV/50A model — addresses both vertical and lateral GaN and SiC device test requirements.

STAr's range includes the Virgo series parametric and reliability probe cards, Aries series wafer-sort/function tests probe cards, and the Magic A-series, P-series and X-series Probe Station.

STAr will have primary market responsibility in the Pacific Rim markets (Taiwan, Korea, China, Japan, Singapore, Malaysia, along with access to Thailand and Philippines), while Reedholm will have primary responsibility for North American markets. The parties will work together to address how to best serve customers in Europe and markets outside of North America and the Pacific Rim.

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

[www.star-quest.com](http://www.star-quest.com)

# StratEdge's molded ceramic packages meet GaN Mil-Std packaging requirements up to 18GHz

StratEdge of San Diego, CA, USA (which designs and produces packages for microwave, millimeter-wave, and high-speed digital devices) says that its off-the-shelf line of molded ceramic packages can be configured to meet the requirements for chips with frequencies up to 18GHz, including gallium nitride (GaN) devices. The firm's molded ceramic packages come in over 200 standard outlines, dramatically increasing the packaging options for GaN devices. StratEdge also offers complete automated assembly & test services for these packages, including gold-tin solder die attach.

GaN devices are traditionally

packaged in StratEdge's LL family of high-power laminate copper-moly-copper (CMC) base packages with a ratio of 1:3:1 CMC, accommodating frequencies up to 63GHz. In the molded ceramic package, the standard Kovar base can be replaced with CMC. For frequencies of 18GHz or less, using a molded ceramic package provides the advantages of hermeticity, a broad array of outline packages and lower cost, while the CMC provides the heat dissipation needed for GaN devices to meet requirements for aerospace applications. For surface-mount (SMT) applications, the packages can be manufactured with gull-wing formed leads, offer-

ing flexibility since it is inexpensive to change the lead design to match an existing footprint.

"StratEdge has hundreds of molded ceramic MC Series packages in standard, open-tooled configurations, which are all Mil-Std hermetic," says president Tim Going. "By swapping out their bases with CMC, you get a low-cost, high-power, fully hermetic packaging solution."

StratEdge exhibited at the 2017 IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS) in Miami, FL, USA (22–25 October).

<https://csics.org>

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

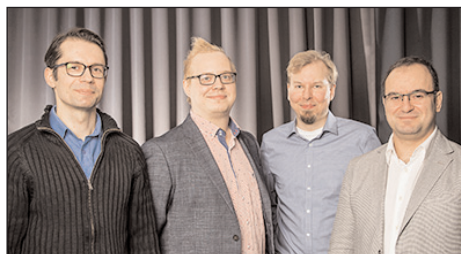
# Comptek raises €450,000 for Kontrox technology to passivate oxidized III–V surfaces

## Atomic-level surface engineering reduces defects by up to 98%, increasing yields

Comptek Solutions Oy (which was spun off from Finland's University of Turku) recently raised €450,000 in a pre-seed funding round, led by Nordic venture capital fund Inventure and joined by Timo Toikkanen and other business angels and industry experts. Previously, in February, Comptek was awarded a €140,000 funding grant from Microsoft.

Despite having superior electrical characteristics to silicon, compound semiconductor materials tend to oxidize very quickly during the manufacturing process, leading to a much lower performance level than what could be achieved, says Comptek. The firm targets tackling this problem by using a quantum (atomic-level) surface engineering process (discovered and patented by the founders) that is claimed to yield a crystalline surface with up to 98% fewer defects, providing a new tool for boosting the efficiency and manufacturing yield of III–V-based compound semiconductor devices.

Direct benefits are said to be higher gate voltages, better quantum efficiency and lower leak currents.



**Comptek Solutions' team.**

The crystalline structures formed on Kontrox-treated surfaces are inert to ambient air, so additional passivation processes are no longer needed, the firm adds. Also, the implementation of Kontrox into existing manufacturing steps — such as, for example, growth in molecular beam epitaxy (MBE) reactors — is claimed to be simple and does not require extensive equipment modification.

"With our technology, branded as Kontrox, we are giving compound semiconductor producers the means to push the boundaries of power efficiency much further," claims CEO Vicente Calvo Alonso. "This is of extreme importance in booming markets, such as electric

cars, self-driving cars, or VR/AR [virtual reality/augmented reality], where the demands for functionality optimization and power savings are critical. We have already achieved unprecedented levels of performance for some materials and raised the interest of some of the biggest companies in the space worldwide," he adds.

"The proprietary technology developed by Comptek shows a tremendous increase in performance and quality in the compound semiconductor process," comments Inventure partner Timo Tirkkonen. "The technology will be a crucial part of the next-generation semiconductor products," he believes.

With the new capital, Comptek is opening a laboratory with a new cleanroom and equipment to further develop the technology and to produce customer samples.

Comptek aims to expand its activities and offerings globally and to see its technology implemented in manufacturing worldwide, in markets such as China and the USA.

[www.comptek-solutions.com](http://www.comptek-solutions.com)

## IQE wins Best Technology title at 2017 AIM Awards

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has won the Best Technology title at the AIM Awards 2017, presented during a gala ceremony at Old Billingsgate in London.

Sponsored by Allenby Capital, the Best Technology award is in recognition of IQE's technology leadership in the supply of advanced compound semiconductor wafers for a wide range of products that enable technologies as diverse as mobile phones, high-speed optical communications, ultra-efficient solar cells, low-energy lighting, autonomous drive vehicles, and

power switching applications.

Working in collaboration with the Welsh and UK Governments, Cardiff University and other partners, IQE is progressing with its vision to establish the world's first Compound Semiconductor Cluster in Wales.

"Compound semiconductors are front and centre of the 21st century technologies and IQE has developed an unparalleled breath of materials IP, which is enabling us to differentiate ourselves in the marketplace," says president & CEO Dr Drew Nelson.

"To help capitalize on the opportu-

nities ahead, we have entered into two joint venture arrangements: in Singapore — jointly owned by IQE, WIN Semiconductor and Singapore's National Technology University — and in the United Kingdom — jointly owned by IQE and Cardiff University," he adds. "The UK joint venture was a catalyst to securing committed investments totalling £300m towards the continued development of a UK compound semiconductor cluster, and the Singapore JV has been selected as a partner in a major program for CS on silicon technology."

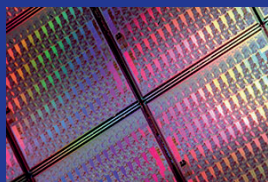
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## AXT's revenue grows 19.5%, driven by record InP sales

### Multi-million dollar long-term InP order received as capacity boosted

For third-quarter 2017, AXT Inc of Fremont, CA, USA — which makes GaAs, InP and Ge substrates and raw materials — has reported revenue of \$28.2m, up 19.5% on \$23.6m last quarter and up 29% on \$21.9m a year ago (exceeding the forecasted 14% growth to \$26.5–27.5m).

"The third quarter was another solid quarter in which we posted revenue growth in all of our product categories, including record revenue in indium phosphide," says CEO Morris Young. Also, germanium substrate business grew again sequentially as the satellite industry continues its positive trend.

Revenue from substrates rose by 17.3% from \$19.1m last quarter to \$22.4m (79.4% of sales).

Revenue from raw material joint ventures rose by 28.9% from \$4.5m last quarter to \$5.8m (20.6% of total sales).

Of total revenue, Asia-Pacific comprised 68%, while North America comprised 8% and Europe 24%. Again, two customers generated over 10% of revenue, while the top five customers generated about 39% of revenue, again reflecting the continuing diversification of both products and customers.

"We also achieved strong gross margin improvement and outperformed our profitability expectations for the quarter," says Young.

Gross margin was 39.5%, up from 30.8% last quarter, due mainly to favorable product mix (due to the record InP revenue plus the better-than-expected Ge revenue), higher sales volume (across all substrate types), and greater manufacturing efficiency (including improvement in overall yields and crystal growth, consistently high product quality, and good raw material cost).

Operating expenses (OpEx) have risen from the regular \$5m to \$5.9m, although this includes one-time expenses of \$500,000 (\$250,000 in special R&D expenses for the InP development program plus fees related to AXT's new facility in China).

Net income was \$4.4m (\$0.11 per diluted share, exceeding the \$0.08–0.10 guidance), up from \$1.9m (\$0.05 per diluted share) last quarter and \$2.2m (\$0.07 per diluted share) a year ago.

"These results demonstrate that our products are well positioned in strategic growing markets, and that we are seeing the benefit of the operational efficiencies and improvements that we began successfully implementing more than a year ago," reckons Young.

During the third quarter, net cash generated from operations was \$4.3m. Depreciation & amortization was steady at \$1.1m. However, capital expenditure (CapEx) has leapt from just \$1.9m last quarter to \$15m, mostly in furnace systems for AXT's new manufacturing facility in the city of Dingxing, China (about 90 miles drive south of the existing Beijing plant). Together with finalizing the purchase of the facility, cash, cash equivalents & investments hence fell by \$9.2m from \$87.5m to \$78.3m.

For the seasonally weak fourth-quarter 2017, AXT expects revenue to drop to \$26–27m, due to InP falling back slightly, although germanium will remain strong (despite one customer taking a bit less material because of Christmas) and GaAs will be "surprisingly" strong. Operating expenses should remain at the current level (including about \$500,000 in one-time items related to personnel plus end-of-year employee bonuses — in Q1/2018, AXT expects OpEx to drop back to a more normalized and sustainable level of \$5.2–5.3m). Net income is expected to be \$0.07–0.09 per share.

Full-year 2017 revenue should therefore be about \$99m (up 22% on 2016), driving earnings per share up 47% on 2016.

"We're seeing customers more proactively planning for future demand and working with us to ensure that their need can be met," says Young. "For example, during

this quarter [Q3], we received our first multi-million dollar long-term order for indium phosphide substrates. While this order is not a guarantee of revenue, it does demonstrate that customers are viewing our product as a strategic part of their planning and an important part of their growth," he adds. AXT is currently increasing InP capacity at its Beijing facility.

The relocation of GaAs manufacturing to Dingxing is on schedule (after being accelerated to take advantage of the market opportunity in 3D sensing). The site has about 140,000ft<sup>2</sup> of existing manufacturing space and 50,000ft<sup>2</sup> designated for offices and dormitories, plus plenty of space for expansion to support the increasing demand for substrates.

"We are actively preparing the new facility for the requirements of GaAs manufacturing," says Young. "We are also in the process of installing and testing that new relocated equipment. In addition, we're working to complete our initial staffing and training requirement," he adds. "Within only six months of acquiring the facility, we already have our first single-crystal ingots grown. And extensive testing has been shown that they have a consistent quality level as those products produced at our Beijing facility. We continue to expect to have an initial qualification substrate late this quarter, and we're working with customers to set a qualification beginning in Q1."

"We are planning for a staged relocation of GaAs throughout 2018... we will produce substrates from both our current location at Beijing and the new Dingxing site for a period of time," Young says.

"We are not required to move InP and Ge substrate production lines at this time. Those substrates will continue to be manufactured in our Beijing facility for the foreseeable future," notes Young. "Over time, we will evaluate our plan for a possible relocation."

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## Veeco ships new-generation EPIK 868 MOCVD systems to China for high-volume LED production

### Four-chamber configuration and increased wafer carrier capacity yields 2.3x greater throughput than EPIK 700

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has shipped multiple TurboDisc EPIK 868 gallium nitride (GaN) metal-organic chemical vapor deposition (MOCVD) systems to several leading Chinese LED makers for the production of light emitting diodes for solid-state lighting applications.

Compared with previous generations, the EPIK 868 MOCVD system enables cost per wafer savings of more than 20%, with a combined advantage of best operating uptime, low maintenance costs and what is claimed to be best-in-class wafer uniformity, as well as a compact architecture with the best footprint efficiency for high-volume LED production.

"The introduction of the lower-cost and higher-productivity EPIK 868 to the China LED market clearly demonstrates Veeco's long term commit-

ment to this important region," says president William J. Miller Ph.D.

"With the EPIK 868, our Chinese customers can continue to take advantage of Veeco's leading edge technology development and world-class service offerings at a significantly lower cost of ownership," he adds.

Based on Veeco's proven TurboDisc technology, the new EPIK 868 MOCVD system offers a four-reactor platform for the highest productivity and a 35% footprint reduction compared with the competition, it is claimed. Furthermore, the wafer carrier capacity can be increased for greater throughput per batch.

"The EPIK 868 is built upon a production proven TurboDisc platform with over 1000 chambers installed worldwide, providing the highest operating stability and efficiency," says Peo Hansson Ph.D., senior VP & general manager MOCVD Operations.

"Not only will the new EPIK 868 system improve our customers' productivity and cost of ownership, but it will also provide a highly reliable, leading-edge production tool," he adds.

The EPIK 868 features proprietary IsoFlange and TruHeat technologies, which provide homogeneous laminar flow and uniform temperature profile across the entire wafer carrier. These innovations produce wavelength uniformity to drive higher yields in a tighter bin.

The EPIK 868 system offers a 2.3x throughput advantage over the existing EPIK 700 system due to its four-chamber configuration and the ability to increase wafer carrier capacity. Veeco says customers can easily transfer processes from existing TurboDisc systems to the new EPIK 868 MOCVD platform for quick-start production of high-quality LEDs.

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

## Veeco receives first order for new GENxcel MBE system

### China's Acken Optoelectronics to use next-generation system for optical communication devices

Veeco Instruments says that the first shipment of its new GENxcel molecular beam epitaxy (MBE) system will be received by China's Acken Optoelectronics Ltd.

The GENxcel expands on the design of GENxplor (the best-selling MBE system since its introduction in August 2013) by providing a lower-cost, fully integrated deposition system that creates high-quality epitaxial layers on substrates up to 4" in diameter compared to the 3" capabilities of the GENxplor. The GENxcel system features an easy-to-use manual transfer system, 12 source ports and modern electronics fully integrated into a single frame design for

maximum laboratory footprint efficiency.

Acken Optoelectronics is a start-up company specializing in the development of high-speed communication devices including optoelectronic communications, RF switching, and low-noise amplifiers for mobile applications. The research is being led by Dr Yiqiao Chen to capture the 5G mobile communication market. Chen utilized Veeco's technology at Columbia University, where he conducted R&D on a Veeco GENII MBE system.

"Veeco's high-quality and high-performance MBE systems, combined with their local support, are unparalleled in the Chinese

market," comments Chen. "We are confident Veeco's systems and source technology will best enable us to advance our compound semiconductor development."

"Many customers were asking Veeco for a modern, manual-transfer, 4"-wafer MBE system," says Gerry Blumenstock, VP & general manager, Veeco's MBE business unit. "The obvious choice was to leverage the market-validated design principles of the GENxplor into a larger system," he adds. "The GENxcel is the ideal system to fulfill this market need for both R&D and pilot production."

[www.veeco.com/technologies-and-products/mbe-systems](http://www.veeco.com/technologies-and-products/mbe-systems)

# Riber grows revenue 87% year-on-year for first nine months of 2017

## Order book up 154% year-on-year, affirming target for full-year revenue to almost double

For third-quarter 2017, Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has reported revenue of €2.8m, up 145% on €1.1m a year ago.

Revenue for the three quarters to end-September 2017 hence amounted to €15.2m, up 87% year-on-year from €8.1m. This strong growth reflects the high level of sales of evaporators (cells and sources) for the photovoltaic and screen industries, as well as the solid trends in sales of services and accessories.

Specifically, revenue from Cells & Sources rose from €1.1m to €9.1m

and revenue from Services & Accessories rose by 25% from €3.3m to €4.1m, more than offsetting a 46% drop in Systems revenue from €3.7m to €2m (comprising two research MBE machines billed, compared with two machines including one production unit for the same period in 2016).

Segmenting total revenue by geographic region, 50% came from Asia, 34% from Europe, and 16% from North America.

The order book at the end of September was €26.6m, up 154% on €10.5m a year previously. This includes six MBE systems (including four production machines) worth

€10.1m (up 59% on €6.4m a year previously), plus strong growth for evaporators (Cells & Sources) to €10.7m (up from just €1m), and for Services & Accessories to €5.8m (up 87% from €3.1m) following the concrete progress made on several major contracts in third-quarter 2017. Moreover, the order book does not include the two production system orders announced in October.

In view of this, Riber is confirming its targets for full-year 2017, with revenue close to €30m (almost doubling from 2016's €16.5m) and at least €3m in income from ordinary operations.

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## CFIUS approves sale of Aixtron's ALD/CVD memory product line to South Korea's Eugene Technology

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany says that the investigation by the Committee on Foreign Investment in the United States (CFIUS) of the sale of its atomic layer deposition (ALD) and chemical vapor deposition (CVD) memory product line — based at its US subsidiary Aixtron Inc in Sunnyvale, CA, USA — to Eugene Technology Inc (announced in late May)

has resulted in a determination that there are no unresolved US national security concerns from CFIUS' perspective. Eugene Technology Inc is a US subsidiary of South Korea-based Eugene Technology Co Ltd (which makes single-wafer ALD, CVD & plasma deposition and surface treatment systems).

CFIUS has hence approved the deal. Aixtron now expects the transaction to be closed in 2017.

In May, the firm said that Aixtron Inc would continue to provide sales and support for its continued businesses, and to pursue its thin-film encapsulation (TFE) activities. The agreed purchase price of \$45–55m (to be paid in cash) includes inventory and other pre-paid assets, the value of which (due to ongoing business) is to be determined at the time of closing.

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

## Elite Advanced Laser orders further Aixtron AIX G5+C MOCVD system to scale up GaN epi and device capacity for power electronics

Elite Advanced Laser Corporation (eLASER) of Chung Ho Dist, New Taipei City, Taiwan, which provides electronics manufacturing services (EMS) for optoelectronic and radio frequency (RF) components, has placed a repeat order for an Aixtron AIX G5+C MOCVD system to produce GaN epiwafers and devices for power electronics applications.

The production tool will be installed during second-half 2017, complementing existing capacity. It integrates Penta-Injector technology (for best material

uniformities across the entire wafer diameter) and is equipped with a cassette-to-cassette (C2C) wafer transfer module for full automation of GaN processes.

"We have been impressed by the speed at which eLASER has transferred their device manufacturing processes on our system technology. Therefore, we are convinced that the recent addition of our AIX G5+C platform — which has become the tool of record at leading GaN power electronics manufacturers — will support the

company's goal to gain further market share in the GaN power electronics ecosystem," comments Aixtron's president Dr Bernd Schulte. "While offering configurations of 8x150mm and 5x200mm, the tool meets the toughest requirements from the silicon industry in terms of uniformity and particles. Thereby, Aixtron's G5+C system technology is breaking down the barriers to bring GaN into silicon production lines."

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

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

## EPFL orders Aixtron system for 2D materials research

Switzerland's École Polytechnique Fédérale de Lausanne (EPFL) has purchased an Aixtron BM NOVO system. The versatile tool, which can produce virtually all variations of two-dimensional materials (2D) required for emerging optoelectronic applications, is dedicated to support EPFL's research projects coordinated by professors Andras Kis and Aleksandra Radenovic.

The BM NOVO uses a unique combination of plasma-enhanced chemical vapor deposition (PECVD) technology and metal-organic chemical vapor deposition (MOCVD) technology to enable the growth of high-quality 2D materials such as transition-metal dichalcogenides

(TMDCs), e.g. molybdenum disulfide (MoS<sub>2</sub>) or tungsten diselenide (WSe<sub>2</sub>).

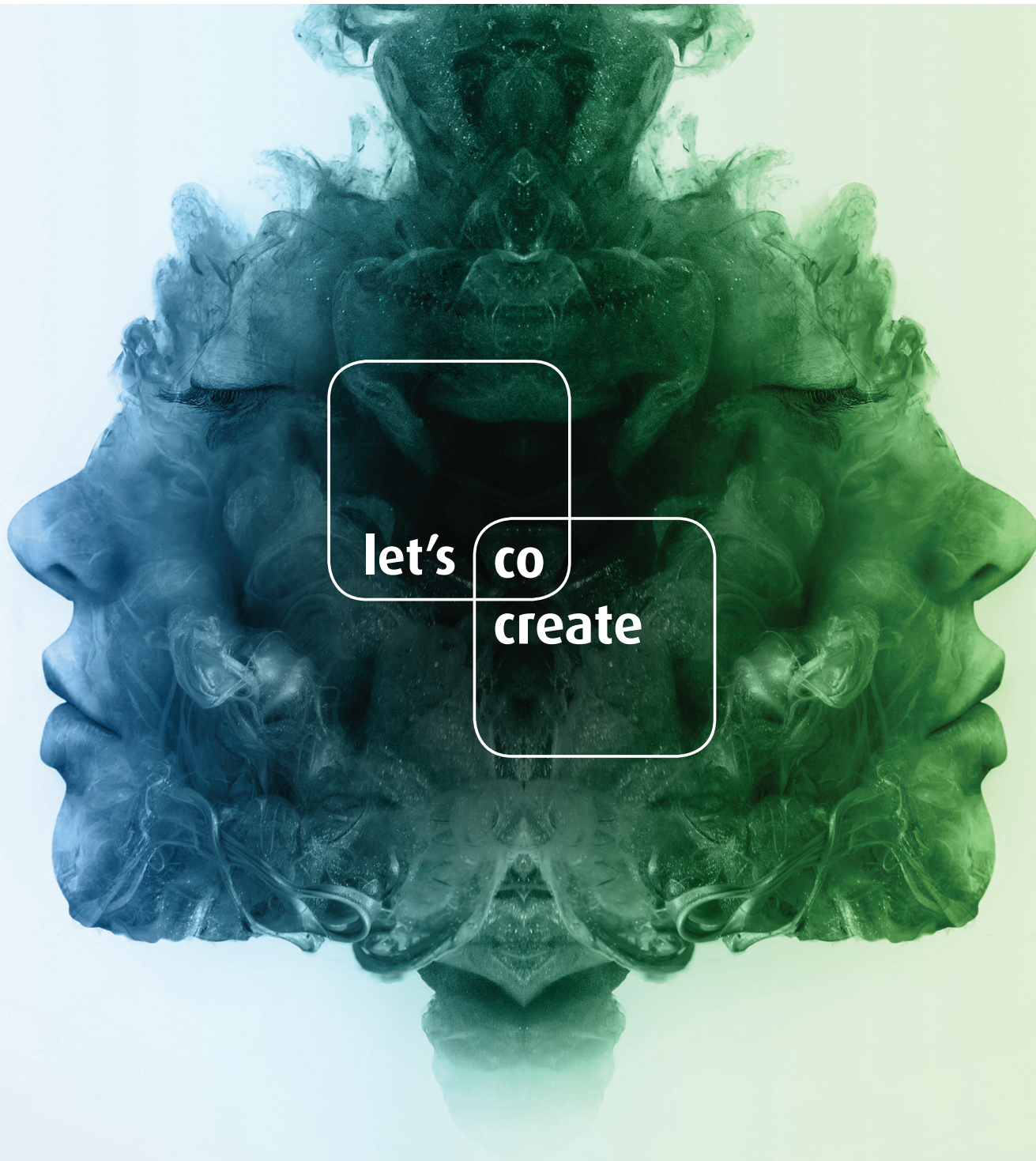
TMDCs combine atomic-scale thickness with unique electrical, optical and mechanical properties, making it a potential material of choice for use in optoelectronic, electronic, energy storage, spintronic, sensing and even in DNA sequencing applications. Considering this wide range of capabilities, the new BM NOVO was developed to solve critical TMDCs deposition challenges while providing the reliability required to develop cutting-edge applications.

"Aixtron's new BM NOVO system will provide the flexibility and reliability that are required to advance

our research, which focuses on the investigation of electrical properties, fundamental physics and practical applications of 2D materials such as TMDCs," comments Kis, a leading expert on 2D materials research.

"We are looking forward to the cooperation with Aixtron, as the company's innovative new platform will support our research in the field of single molecule biophysics, which includes the further development of techniques and methodologies based on optical imaging, biosensing and single molecule manipulation," says Radenovic, who leads EPFL's research on 2D materials for biophysics.

[www.epfl.ch](http://www.epfl.ch)



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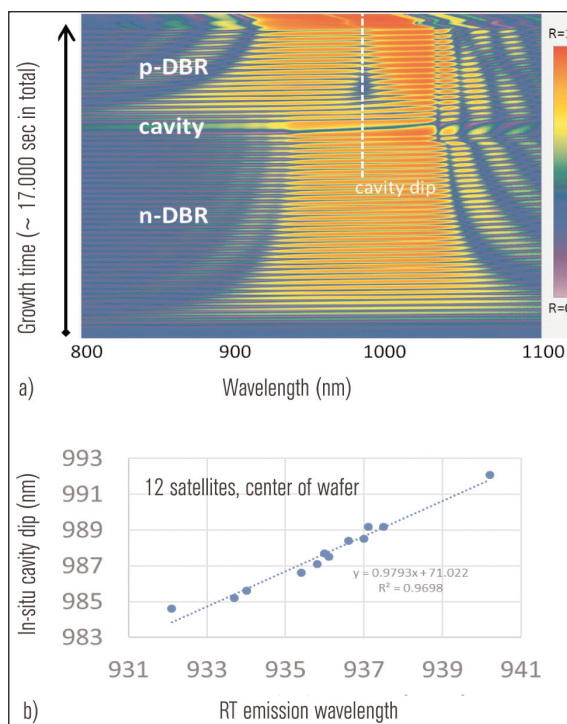
# LayTec ships further EpiTT VCSEL systems to leading VCSEL maker in USA

Last year in-situ metrology system maker LayTec AG of Berlin, Germany reported the first sale of its EpiTT VCSEL (vertical-cavity surface-emitting laser) for indium phosphide (InP)-based epitaxy to a leading European customer. In second-quarter 2017 LayTec completed development of the respective tool for gallium arsenide (GaAs)-based VCSEL growth. The next two systems have now been shipped (in September) to a leading VCSEL maker in the USA.

EpiTT VCSEL adds full spectral capabilities to the established performance of EpiTT (wafer temperature sensing at 950nm and growth rate measurement based on three-wavelength reflectance).

Two spectral ranges can be chosen: 630–1100nm for GaAs-based near-infrared (NIR) VCSEL epitaxy and 1000–1700nm for InP-based IR VCSEL processes.

Either system delivers direct access to cavity dip position and stop-band wavelength control already during MOCVD. The cavity dip position is extremely sensitive to the accurate thickness and composition of QWs (quantum wells)/ QBs (quantum barriers), oxidizing AIAs and other functional layers in



**940nm VCSEL grown in 12 x 4"-wafer Aixtron planetary G3 MOCVD reactor of a European industrial customer (full load qualification run). (a) color-coded spectral fingerprint of satellite #1 (center of wafer). 36 such in-situ signatures have been generated for center/half-radius/edge regions of all the 12 wafers. (b) Room-temperature ex-situ on-wafer emission in 12 wafer centers compared with the respective in-situ cavity dip wavelength position. The cavity dip measured in-situ is fitted automatically in real-time to the measured spectrum (after last AlGaAs layer of p-DBR was completed at growth temperature) by LayTec's EpiNet 2018 software. Good correlation between in-situ measurement and ex-situ data shows that EpiTT VCSEL gives a reliable forecast of device performance.**

the cavity. For optimum laser performance, this cavity dip position has to be in exact correlation to QW emission wavelength.

Here another strength of the EpiTT VCSEL comes into play: tight control of wafer temperature for highly precise QW composition. However, during cavity growth for some VCSEL designs, the standard wavelength of the pyrometer overlaps with the high-reflectivity band of the underlying n-doped distributed Bragg reflector (n-DBR), causing

high reflectance and hence low thermal emissivity of the wafer. LayTec therefore added the possibility to customize the pyrometer wavelength of the EpiTT VCSEL.

A second pyrometer module can be chosen between 810nm, 850nm, 980nm. This allows accurate wafer temperature measurement for a wide range of VCSEL MOCVD processes. The Figure gives an example for a VCSEL with a target emission wavelength of 940nm.

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

## LayTec ships in-situ metrology system to GaN-on-SiC customer

LayTec has shipped a comprehensive EpiCurve TT/Pyro 400 in-situ metrology hybrid system to an industrial customer in North America. The metrology station combines automated in-situ wafer bow and film thickness measurements with two pyrometry wavelengths: near-infrared (NIR) at 950nm and near-ultraviolet (near-UV).

In gallium nitride on silicon carbide (GaN-on-SiC) and gallium nitride on silicon (GaN-on-Si) metal-

organic chemical vapor deposition (MOCVD) technology, the growth of sophisticated nucleation and strain management layers is essential for material quality and final device performance, says LayTec.

At the same time, these layers are a challenge for highly accurate wafer temperature control: IR light from other hot parts of the reactor is scattered into the NIR pyrometer and causes Fabry-Perot artifacts, affecting its precision. However,

the GaN buffer specifically emits thermal radiation in the near UV and the temperature measured with Pyro 400 is not affected by the NIR thermal radiation scattered by the buried functional layers. Therefore the combination of NIR pyrometry with Pyro 400 allows precise control of the wafer temperature during the whole deposition process, says LayTec.

[www.laytec.de/epicurve](http://www.laytec.de/epicurve)  
[www.laytec.de/pyro400](http://www.laytec.de/pyro400)

## AES' SEMI-GAS Xturion Blixer enables on-site blending of forming gas mixtures

Applied Energy Systems (AES) of Malvern, PA, USA — which provides high- and ultra-high-purity gas delivery systems, services and solutions (including design, manufacturing, testing, installation, and field service) — is showcasing the capabilities of its SEMI-GAS Xturion Blixer to support various processes that require forming gas mixtures. The Blixer is said to provide a cost-effective alternative to purchasing expensive pre-mixed gas cylinders by enabling operators to blend their own mixtures on-site in their facility.

The ultra-high-purity gas mixing blender is used across a diverse range of industries to uniformly mix H<sub>2</sub> and N<sub>2</sub> concentrations in customizable ratios that meet distinct process requirements. Mixtures can be adjusted in real-time via the system's GigaGuard PLC controller, which features a 9" Siemens color touchscreen for intuitive operation, allowing the user to fine-tune formulations on demand.

This makes the system suitable for high-volume applications, eliminating the need to stock a variety of pre-mixed forming gas concentrations, decreasing the frequency of cylinder change-outs, reducing tool downtime, increasing productivity, and ultimately providing the end user with a significant cost savings, says the firm.

The Blixer system is designed to provide a continuous flow of precise gas blends and includes a static mixing tube and surge/mixing tank to address dynamic flow changes and effectively maintain mix tolerances. It is also equipped with a Thermal Conductivity Hydrogen Gas Analyzer, featuring auto-calibration capability and a low-flow alarm, to ensure ±1% blending accuracy. Its PLC controller includes Ethernet connectivity to allow seamless integration with a facility's monitoring system, and the system's hydrogen hazardous gas detector and automatic shutdown feature alert oper-

ators during undesirable system conditions.

"We have found the Blixer to be especially beneficial to customers using forming gas mixtures because it gives them flexibility to custom-blend H<sub>2</sub>/N<sub>2</sub> concentrations in the exact ratios they desire — instead of investing in expensive pre-mixed cylinders that still may not be precisely mixed to their unique process requirements," says technical inside sales engineer Greg Havrilla.

In addition to the Xturion Blixer, a complete turnkey blending solution is also available, which includes an Xturion Mechanical Back-Up Gas Supply, a Centurion Automatic Hydrogen Source System, a Decaturion Manual Nitrogen Wall Mount System, and Applied Services onsite installation support and operator training.

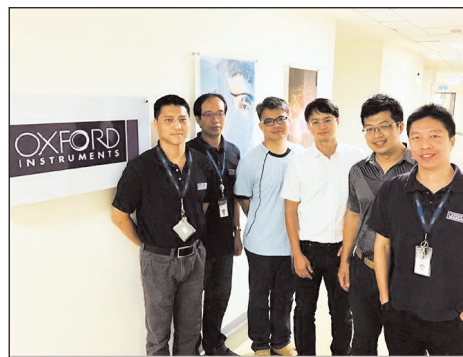
[www.appliedenergysystems.com/semi-gas/xturion-custom-gas-equipment](http://www.appliedenergysystems.com/semi-gas/xturion-custom-gas-equipment)

## Oxford Instruments installs new plasma etch equipment at its applications lab in Taiwan's ITRI

UK-based Oxford Instruments plc has boosted plasma process solutions for its customers in Asia by recently installing plasma etch equipment in their applications laboratory at Taiwan's Industrial Technology Research Institute (ITRI), further enhancing the existing etch and deposition capabilities already provided there by Oxford Instruments.

The new PlasmaPro 100 Cobra and PlasmaPro 100 Polaris ICP etch tools were installed earlier in October and are designed to serve the firm's Asian customers, with a focus on the optoelectronic, wide-bandgap discrete device and sensors markets.

The new tool installations "complement our existing plasma etch



**Staff at Oxford Instruments' applications laboratory at Taiwan's Industrial Technology Research Institute .**

and deposition systems already established in ITRI, enabling us to deliver efficient local service to our Asian markets," says Ian Wright, VP sales & service for Asia, Oxford

Instruments Plasma Technology (OIPT). "Our customers have the added benefit of full support from our dedicated applications team based in Taiwan, ensuring a fast response to customer enquiries."

Oxford Instruments says that these recent improvements to the ITRI laboratory continue the long-standing research-based collaboration agreement between the two companies, based on Oxford Instruments providing a research center staffed by its process engineers at ITRI to the benefit of the extensive Far East customer base.

Oxford Instruments adds that its process lab at ITRI is performing leading process research and is ready to receive samples from customers.

[www.oxford-instruments.com](http://www.oxford-instruments.com)

## EVG & SwissLitho co-developing nanoimprint lithography for single-nanometer-scale 3D optical structures

EV Group of St Florian, Austria — a supplier of wafer bonding and lithography equipment for semiconductor, micro-electro-mechanical systems (MEMS), compound semiconductor, power device and nanotechnology applications — and SwissLitho AG of Zurich, Switzerland (which makes maskless nanoimprint lithography tools) have announced a joint solution to enable the production of 3D structures down to the single-nanometer scale.

Initially demonstrated within the Single Nanometer Manufacturing for Beyond CMOS Devices (SNM) project funded by the European Union's Seventh Framework Program (EU FP7), the joint solution uses SwissLitho's novel NanoFrazor thermal scanning probe lithography system to produce master templates with 3D structures for nanoimprint lithography (NIL), and EVG's HERCULES NIL system with SmartNIL technology to replicate those structures at high throughput.

### Target applications

EVG and SwissLitho will initially target the development of diffractive optical elements and other related optical components that support photonics, data communications, augmented/virtual reality (AR/VR) and other applications, with the potential to expand into biotechnology, nanofluidics and other nanotechnology applications.

SwissLitho's NanoFrazor system will be used to create imprint masters. Compared with conventional

approaches, including electron beam (e-beam) and grayscale lithography, the novel technology has the unique ability to print 3D structures with what is claimed to be unsurpassed accuracy. EVG's HERCULES NIL system will then be used to create working templates for production use, cost-effectively and at high throughput, using the firm's proprietary large-area nanoimprint SmartNIL technology.

"SwissLitho's NanoFrazor solution is highly complementary to EVG's SmartNIL technology," comments EVG's corporate technology director Dr Thomas Glinsner. "Together, we can offer a complete NIL solution for photonics and other applications involving 3D structure patterning, providing significant opportunity for both companies to expand our customer base and market reach," he adds. "Our NILPhotonics Competence Center will be the first point of contact for customers interested in this joint solution, where we will be able to offer feasibility studies, demonstrations and pilot-line production."

Thermal scanning probe lithography (the technology behind the NanoFrazor) was invented at IBM Research in Zurich and acquired by SwissLitho. The maskless, direct-write lithography approach involves spin-coating a unique, thermally sensitive resist onto the sample surface before patterning. A heated ultra-sharp tip is then used to decompose and evaporate the

resist locally while simultaneously inspecting the written nanostructures. The resulting arbitrary resist pattern can then be transferred into almost any other material using lift-off, etching, plating, molding or other methodologies.

"We developed our NanoFrazor line to provide a high-performance, affordable alternative and extension to costly e-beam lithography systems," says SwissLitho's CEO Dr Felix Holzner. "The technology allows manufacturing of the master with many 'levels' in a single step. In particular, 3D structures with single-nanometer accuracy can be produced more easily and with greater fidelity compared to traditional e-beam or grayscale lithography methods."

The HERCULES NIL combines EVG's expertise in NIL, resist processing and high-volume manufacturing solutions into a single integrated system that offers throughput of up to 40wph (wafers per hour) for 200mm wafers. Its configurable, modular platform accommodates a variety of imprint materials and structure sizes, allowing greater flexibility in addressing manufacturing needs. In addition, its ability to fabricate multiple-use soft stamps helps to extend the lifetime of master imprint templates.

[www.swisslitho.com/nanofrazor-working-principle](http://www.swisslitho.com/nanofrazor-working-principle)  
[www.evgroup.com/en/products/lithography/nanoimprint\\_systems/uv\\_nil/hercules\\_nil](http://www.evgroup.com/en/products/lithography/nanoimprint_systems/uv_nil/hercules_nil)

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# Synopsys enhances photonic and optoelectronic modeling with release 2017.09 of RSoft

Synopsys Inc of Mountain View, CA, USA — which provides electronic design automation (EDA) software, semiconductor IP and services for chip and electronic system design — has released version 2017.09 of its Synopsys RSoft product portfolio of software tools for photonic component and optical communication system design, which includes new features to streamline and enhance photonic and optoelectronic modeling. The RSoft Photonic Component Design Suite is said to reduce development time with efficient analysis of silicon photonics components at the device, circuit and system levels. It also introduces an interface with Synopsys' HSPICE circuit simulation tool for cohesive, rigorous co-simulation of electronic components in photonic circuits.

New features of the RSoft Photonic Component Design Suite include:

- S-Matrix/PDK Generation Utility to automate the interface between RSoft component tools, the RSoft OptSim Circuit tool, and mask layout tools. The utility creates the S-Matrix of a photonic component using the RSoft FullWAVE, BeamPROP and ModePROP tools and exports it to OptSim Circuit to verify its performance in a photonic integrated circuit (PIC) or system. The final design can then be easily exported to mask layout tools to create an optical process design kit (PDK). The interface allows designers to efficiently create PICs from basic building elements and accurately test PIC performance prior to fabrication.
- Expanded effective index method (EIM) implementation in RSoft component tools. As a method for reducing 3D waveguide structures (such as silicon photonics components) into equivalent 2D structures for extremely fast and accurate performance simulations, EIM can increase simulation speeds by 100x or more.
- Improved RSoft FullWAVE pulsed and broadband simulation. This

feature allows engineers to accurately simulate the spectral response of photonic devices over a wide wavelength — or spectral — range with just a single simulation.

It is especially useful for analyzing resonant devices such as ring resonators.

- Expanded documentation and examples demonstrate how the RSoft tools' proprietary sub-cell meshing capabilities can significantly improve the accuracy and speed of photonic component simulations.

New features of the RSoft Photonic System Design Suite include:

- Interface between the RSoft OptSim and OptSim Circuit tools and Synopsys' HSPICE simulator for seamless optoelectronic analysis. With more than 25 years of successful design tapeouts, the HSPICE tool is said to be the industry's gold-standard electrical circuit simulator and offers foundry-certified electrical MOS device models. The RSoft-HSPICE interface supports precise co-simulation of electronic components in photonic circuits in both on-chip and off-chip optical configurations. RSoft OptSim and OptSim Circuit are claimed to be the only photonic simulation tools on the market that offer this capability.
- Updated PDKs, including the American Institute for Manufacturing Integrated Photonics (AIM Photonics) PDK version 1.5b and imec PDK version ISIPP50G, help to reduce PIC design costs and bring designers a step closer to fabrication through facilities supporting

**The RSoft Photonic Component Design Suite is said to reduce development time with efficient analysis of silicon photonics components at the device, circuit and system levels**

the AIM and imec processes.

- Support for Phoenix Software's OptoDesigner elastic connectors. Constraints from packaging and design rule checks can impose restrictive routing requirements on schematic-driven layouts. To overcome these constraints, OptSim Circuit supports OptoDesigner elastic connectors, where the shape and dimensions of the connectors are determined through tight integration with layout generation, and equivalent compact models for these connectors are created and simulated in OptSim Circuit.

- Addition of the Viterbi and Viterbi (V & V) Mth power Carrier Phase Estimation algorithm in the OptSim digital signal processing (DSP) library for MATLAB. Accurate estimation of the optical carrier in phase-modulated coherent fiber-optic transmission systems is a vital responsibility of DSP at the receiver. As the order of modulation increases, susceptibility to laser phase noise requires accurate methods for phase estimation. The V & V Mth power algorithm in the OptSim tool helps designers achieve accurate estimation of carrier phase for QPSK and PM-QPSK modulation formats.

"The latest release of the RSoft product family provides users with powerful, multi-level simulation solutions that address a range of photonic and optoelectronic design challenges," says George Bayz, VP & general manager of Synopsys' Optical Solutions Group. "The S-Matrix/PDK utility reduces the cost and complexity of building PIC elements, testing their performance and exporting mask layout files for processing. In addition, the unique RSoft-HSPICE interface enables designers to analyze and optimize optoelectronic circuit performance early in the design cycle," he adds.

[www.synopsys.com/optical-solutions/rssoft.html](http://www.synopsys.com/optical-solutions/rssoft.html)

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## Nitride files patent lawsuit in USA against Digi-Key

Nitride Semiconductor Co Ltd of Tokushima, Japan has filed a patent infringement lawsuit with the US District Court for the District of Minnesota against Digi-Key Corp, which sells UV-LED products on the Internet manufactured by Rayvio Corp of Hayward, CA, USA.

Nitride is seeking injunction, damages and accounting, asserting that

Digi-Key infringes its US patent 6,861,270 ('Method for Manufacturing Gallium Nitride Compound Semiconductor and Light Emitting Element') by selling UV-LED products made by Rayvio. The patented invention is said to contribute to improving the light-emitting efficacy of LEDs. On 23 May, Nitride sued Rayvio in the US District Court,

Northern District of California, alleging infringement of the same patent.

Nitride says that, with professor Shiro Sakai at Tokushima University, in 2000 it developed the first highly efficient UV-LED, and has since continued to make and sell UV-LED, involving huge investment in R&D.

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

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

## LG Innotek exhibits UV LEDs at LED Japan

At LED Japan 2017 in Chiba, Japan (4–6 October), Seoul-based LG Innotek (a subsidiary of South Korean electronics company LG Group) exhibited about 30 types of UV LED packages (optimized on the basis of UV wavelength and optical power) as well as modules for sterilization (developed with the firm's proprietary technologies) as it aims to make inroads into the Japan market.

In particular, the firm introduced Japan's first UV LED sterilizer for escalator handrails, emitting 275–278nm-wavelength light to

destroy germ DNA. The product can sterilize germs for the whole duration of escalator operation and is easy to install, says the firm. Since its launched in Korea and China last July, it has been installed in about 30 locations, including shopping malls, hospitals and airports.

LG Innotek also showcased UV-C LED modules for sterilization that can be installed in home appliances including water purifiers, air purifiers etc. The firm will also show a cork sterilization module, installed in LG Electronics' 'PuriCare Slim Updown'

direct water purifier. Unlike mercury UV lamps, the module does not generate harmful heavy metals and, due to its durability, it does not easily break.

LG Innotek also exhibited 365, 385, 395, 405 and 415nm-wavelength UV-A LEDs for curing equipment in manufacturing facilities. Curing hardens coating agents, adhesives etc or dries inks. The firm showed a 305nm UV-B LED, which is gaining attention for biotechnology and medical applications.

[www.lginnotek.co.kr](http://www.lginnotek.co.kr)

## ProPhotonix adds optical options to UV LED curing range

ProPhotonix Ltd of Salem, NH, USA, a designer and maker of LED illumination systems and laser diode modules for OEMs and medical equipment firms, has supplemented its range of COBRA Cure FX Series of UV LED curing systems with new optical options that provide higher intensity and dose, allowing end users to further optimize them to requirements of their specific application.

ProPhotonix has designed the COBRA Cure FX Series to optimize the advantages of UV LED technology while offering unique features. The configurable UV LED curing series offers end users the flexibility to optimize their chosen product for specific application requirements. For example, in some applications, generating the highest possible energy density (dose) is the clear priority, while in others, due to

space restrictions, the prevention of curing at the print head may take priority over energy density. With the new optical options, the same COBRA Cure FX can be configured differently to address both application scenarios.

The optical design of a UV LED curing system impacts performance. With more than a decade of experience in UV LED systems and an in-house optical engineering team, ProPhotonix can optimize solutions for specific application requirements. The COBRA Cure FX now has three optical options. Each is custom designed to maximize uniformity, ensuring an even cure. With the new options, depending on the optical configuration chosen, the energy density delivered can range from 5.1J/cm<sup>2</sup> to 7.8J/cm<sup>2</sup>. For the higher-power COBRA Cure FX3, the

energy density ranges from 43.4J/cm<sup>2</sup> to 55J/cm<sup>2</sup>, depending on the configuration selected.

"UV LED technology offers significant advantages over traditional technologies for a wide range of UV curing applications," says Ken Reynolds, business and technology manager. "We excel at adapting this technology for use in very specific and challenging applications... we are taking what is a certified, stable and reliable platform and progressively developing additional options, allowing users to optimize the COBRA Cure FX Series to address their specific application challenges to configure their UV LED curing system."

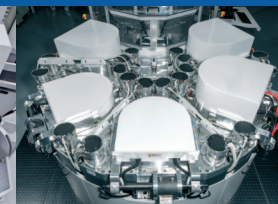
The new optical options were displayed at Labelexpo Europe 2017 in Brussels, Belgium in September.

[www.prophotonix.com/led-and-laser-products/UV-Solutions](http://www.prophotonix.com/led-and-laser-products/UV-Solutions)

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# Seoul Semiconductor's Horticultural Series LEDs deliver entire spectrum from UV-C to far-red

South Korean LED maker Seoul Semiconductor Co Ltd says that its new Horticultural Series LEDs – available in chip-on-board (COB), mid-power, and high-power packages – makes it the only LED maker to provide lighting designers with the complete spectrum of light used for growing plants, from ultra-violet (UV-C) to far-red. The new product family also includes Seoul's SunLike Series natural spectrum LEDs, which produce light that closely matches the spectrum of natural sunlight.

The firm introduced the new Horticultural Series LEDs at the 2017 Horticultural Lighting Conference USA in Denver, CO on 17 October. One of the invited speakers was Dr Peter Barber, product marketing manager for Seoul VioSys, on 'The Myriad Ways That UV LEDs Will Impact Society Through Horticultural Lighting'.

## Full spectrum for horticultural applications

While many conventional LED makers have developed horticultural-optimized LEDs in the visible light spectrum from violet (~390nm) to red (~700nm) wavelengths, the new Horticultural Series LEDs extends this spectrum to include multiple ultraviolet bands (UV-A, UV-B, UV-C), as well as into far-red bands (~700–800nm). The extension of this new LED product series beyond the ends of the visible spectrum provides horticultural lighting designers with the capability to develop the widest range of light sources beneficial for growing and propagating different types of vegetables and plants in indoor settings, says Seoul Semiconductor.

Also playing a critical role in the new family is Seoul Semiconductor's recently introduced SunLike LED technology, which is claimed to be the first LED to closely match the spectrum of natural sunlight. This provides a light source more like natural light than conventional



'white light' LEDs, giving lighting designers a wider range of options as they develop horticultural-specific lighting systems.

"By extending the spectrum of LEDs to include both ultraviolet and far-red light sources, Seoul Semiconductor provides horticultural lighting designers an entirely new spectrum of possibilities in developing lighting systems for specific plant growth and propagation," says Mark McClear, VP, Americas.

"Our Horticultural Series LEDs include high-power, mid-power and COB devices, enabling the design of a wide range of lighting fixtures – from high-bay and directional lights to rack-mounted fixtures for vertical farming systems – all from a single LED manufacturer."

## SunLike Series COB LEDs

For lighting fixtures designed to produce light that closely matches the spectrum of natural sunlight, Seoul offers a range of standard COB LED modules ranging from 6W to 25W.

## High-power Horticultural Series LEDs, including UV, white and color devices

For high-bay and other lighting fixtures, Seoul's Horticultural Series LEDs include the following options:

- UV-C — producing a dominant wavelength of 275nm, these unlensed UV LEDs can be used for sterilization;
- UV-B — producing a dominant wavelength between 280nm and 310nm, these unlensed UV LEDs are rated at 10mW with a photo-synthetic photon flux (PPF) value of 0.25µmols/s;

- UV-A — producing a dominant wavelength between 360nm and 400nm, these lensed UV LEDs are rated at 636mW with a PPF value of 2.2µmols/s.

- Deep Blue — featuring a dominant wavelength between 449nm and 461nm, these deep-blue dome-lensed LEDs are rated at 650mW with a PPF of 2.6µmols/s;

- Deep Red — with a dominant wavelength of between 646nm and 665nm, these visible red LEDs are rated at 345mW with a PPF of 2.32µmols/s;

- Far-Red — producing a dominant wavelength of ~730nm (peak), these near-infrared LEDs are rated at 260mW with a PPF of 1.64µmols/s; and

- White — these high-power white LEDs feature a light output of 168lm with a PPF of 2.4µmols/s.

## Mid-power Horticultural Series LEDs, including SunLike natural spectrum LEDs & color devices

For vertical rack systems and other close-up lighting fixtures, Seoul's Horticultural Series LEDs include the following mid-power options in standard 3030 packages:

- SunLike 5000K — with a color temperature range of 2700–5000K, these LEDs produce light that closely matches the spectrum of natural sunlight, and feature a light output of 22.3lm with a PPF of 0.38µmols/s;

- Deep Blue — featuring a dominant wavelength of between 449nm and 461nm, these blue mid-power LEDs are rated at 155mW with a PPF of 0.62µmols/s;

- Deep-Red — with a dominant wavelength of between 646nm and 665nm, these visible red LEDs have a PPF of 0.43µmols/s, and a light output of 77lm/mW; and

- Far-Red — producing a dominant wavelength of ~730nm (peak), these near-infrared mid-power LEDs are rated at 50mW with a PPF of 0.38µmols/s.

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

## Lumileds adds deep red, far red and CoB purple LEDs to LUXEON SunPlus range for horticulture lighting

LED maker Lumileds of San Jose, CA, USA has launched three new products in its LUXEON SunPlus Series of LEDs for horticulture lighting.

The LUXEON SunPlus Series is claimed to be the only line of LEDs on the market to be tested and binned by photosynthetic photon flux (PPF). The portfolio of colors enables wavelength tuning for maximum crop yield in both greenhouse and vertical farming applications. The addition to the LUXEON SunPlus 35 Line of Far Red and Deep Red will enable designers of vertical farm and interweaving fixtures to tune the spectrum specifically for the crop being grown. The new LUXEON SunPlus CoB Line, available in Purple, is designed for greenhouse applications where attaining high PPF and fast time to market are top priorities.

The LUXEON SunPlus 35 Line is optimized for vertical farming in shallow tiers, so uniformity is

optimized at very short distances. The Deep Red (650-670nm) and Far Red (720-740nm) wavelengths join the existing Royal Blue (445-455nm), Lime (broad spectrum) and three shades of Purple with varying contributions of blue (2.5%, 12.5% and 25%) in a 3.5mm x 3.5mm format. "These essential red wavelengths are combined with blue to give the exact spectra needed for each crop," says Jennifer Holland product line director of the LUXEON SunPlus Series. "Our Horticulture Lighting Calculator is especially helpful in this context because lighting manufacturers can experiment with LED ratios and spectral power distributions before building the fixtures," she adds.

Customer success and market adoption of the LUXEON SunPlus 35 Purple and the need for even greater PPF in a single device led to the development of the LUXEON

SunPlus CoB Purple (12.5% blue) product. In contrast to vertical farming, where lighting is positioned a short distance from plants, greenhouse lighting requires deep penetration into the plant canopy, which is achieved with a directional CoB. The CoB portfolio complements the LUXEON SunPlus 20 and 35 Lines, which offer a variety of colors to optimize the spectrum for greenhouse applications. The CoB form factor also means that standard optics, holders and drivers are available to help manufacturers accelerate time to market of their fixtures. "The chip on board approach allows us to maximize PPF to as high as 350µmol/s from a single source," says Holland. The LUXEON SunPlus CoB Purple is available with 15mm, 19mm and 32mm light-emitting surfaces.

[www.lumileds.com/horticulture/products](http://www.lumileds.com/horticulture/products)

## Seoul Semiconductor quarterly revenue rises by 14%

For third-quarter 2017, South Korean LED maker Seoul Semiconductor Co Ltd has reported revenue of KrW305bn, up 14% on KRW267bn last quarter due to strong sales of its Acrich MJT, Wicop, UCD and filament LED products.

Within the lighting division, more than one-third of customers have already shifted to adopt Acrich MJT (multi-junction technology), which is expected to account for over 50% of sales in general lighting next year. Filament LEDs are rapidly becoming popular in the decorative lighting market, where they are replacing conventional LEDs, says the firm.

In the Display segment, sales grew due to strong adoption of Acrich (which enables optimal local dimming in premium UHD TV ultra-high-definition televisions) and UCD (which brings exceptional

color rendering to displays, it is claimed).

The package-free LED Wicop (which features greatly enhanced brightness and enables slim displays, says the firm) already accounts for double-digit overall sales. The application of Wicop has now extended beyond automotive daytime running lights (DRLs) to automotive headlamps. Year-on-year automotive lighting sales growth of more than 30% in Q3/2017 proved highly profitable, notes the company.

Despite a continued decline in average selling price (ASP), operating profit has risen 27% quarter-over-quarter and 54% year-on-year to KrW30.6bn, boosted greatly by sales of high-end products (due to their differentiated technologies) as well as continued cost and process innovations.

The firm expects its new factory in Vietnam and the implementation of smart factory systems to further strengthen cost innovations in the future.

For fourth-quarter 2017, Seoul Semiconductor expects revenue of KrW270-290bn — relatively high considering the exceptional Q3 results and the fact that Q4 is typically off-season for LED makers.

Chief financial officer Sangbum Kim says that SunLike (a new LED technology launched in June which produces light that closely matches the spectrum of natural sunlight) has been very well received, with great interest from customers worldwide. Also, the previously launched LED drivers (which integrate invertors into chips) will continue to grow sales and profit in future, he adds.

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

# Cree quarterly revenue rises despite Lighting Product sales falling and Wolfspeed capacity constraints

## Accelerating Wolfspeed capacity investment to double power device capacity by end 2018

For fiscal first-quarter 2018 (ended 24 September 2017), Cree Inc of Durham, NC, USA has reported revenue of \$360.4m, down 3% on \$371.2m a year ago but up slightly on \$358.9m last quarter.

Revenue for Lighting Products (mainly LED lighting systems and lamps) was \$149.7m (42% of revenue), down 3% on \$154.7m (43% of revenue) last quarter and 19% on \$183.8m (50% of revenue) a year ago. Commercial lighting revenue fell slightly from last quarter, primarily due to continued weakness in the North America market, the lingering near-term effect of the quality hold that occurred during fiscal 2017, and project delays due to the hurricanes in Florida, Texas and Puerto Rico. Consumer lighting sales were seasonally lower, as expected.

Revenue for LED Products (chips and components) was \$144.5m (40% of revenue), up slightly on \$143.4m (40% of revenue) last quarter and up 5% on \$137.5m (37% of revenue) a year ago.

Revenue for the Wolfspeed business (Power & RF devices and silicon carbide materials) was \$66.2m (18% of revenue), up 9% (more than the expected 4%) on \$60.8m (17% of revenue) last quarter and up 33% on \$49.9m (13% of revenue) a year ago.

"While our current Wolfspeed capacity continues to be constrained, we continue to have success in achieving additional throughput due to productivity improvements that enable us to ship higher revenue," says chief financial officer Mike McDevitt.

Wolfspeed gross margin was 49%, rebounding from 45.5% last quarter (and above the 47% a year ago), due to a more favorable product mix, higher factory utilization, and improved production.

LED Product gross margin was 26.9%, up from 25.9% last quarter (due mainly to a more favorable product mix) but down from 30.4% a year ago.

Lighting Product gross margin has fallen further, from 26.8% a year ago and 23.8% last quarter to 21.3%, due to lower commercial sales, lower factory utilization, and higher warranty costs.

Overall company gross margin was 28.3%, up from 28% last quarter but down from 30.4% a year ago (and below the expected 29%).

Operating expenses (OpEx) have risen further, from \$80m a year ago and \$97m last quarter to \$99m. However, this is lower than the expected \$101m, due primarily to lower variable performance-based compensation.

On a non-GAAP basis, net income was \$4.1m (\$0.04 per diluted share), down from \$15.1m (\$0.15 per diluted share) a year ago but up slightly from \$3.8m last quarter.

Cash flow from operations has risen further, from \$18.1m a year ago and \$52.7m last quarter to \$54.1m. Although patent spending has been cut from \$3.5m last quarter to \$2.5m, spending on property, plant & equipment (PP&E) has grown further, from \$19.3m a year ago and \$30m last quarter to \$36.5m. So, total capital expenditure (CapEx) has correspondingly risen, from \$21.6m a year ago and \$33.5m last quarter to \$39m. Free cash flow was hence \$15.2m, falling back from \$19.2m last quarter but a contrast to -£3.5m a year ago.

During the quarter, cash and investments (net of line-of-credit borrowings) rose by \$18m, from \$466m to \$484m. At the end of the quarter, Cree had \$141m outstanding on its line of credit.

For fiscal second-quarter 2018 (ending 24 December 2017), Cree

targets revenue of \$340–360m, with Wolfspeed growing incrementally (as additional productivity gains provide some upside to near-term capacity constraints); LED Product revenue level sequentially; and Lighting Product revenue falling by 8% (due to the current North American market softness and possible short-term impacts from the recent hurricanes).

Gross margin should be about 28.5%. Wolfspeed and LED Product margins are expected to be slightly lower sequentially due to forecasted customer and product mix, while Lighting Product margin is targeted to rise slightly due to cost-improvement initiatives.

Operating expenses are expected to rise by just \$1m to \$100m (similar to fiscal Q1). There will be only a nominal impact from the new joint venture Cree Venture LED Company Ltd with San'an Optoelectronics Company of Xiamen, China (formed to produce mid-power lighting-class LEDs), in which Cree has a 51% stake and acts as exclusive sales agent for North America, South America, Europe and Japan. However, the JV is targeted to have a larger impact beginning in fiscal Q3 (when its contribution to overall revenue will start to become significant, as more products are introduced and qualified by customers, says McDevitt).

Net income is targeted to range between a loss of \$1m (\$0.01 per diluted share) and a profit of \$4m (\$0.04 per diluted share).

For full-year fiscal 2018, Cree continues to target CapEx of \$220m, driven primarily by expanding Wolfspeed's production capacity to alleviate existing supply constraints.

Due to accelerating the Wolfspeed capacity investments to support the growth opportunity forecasted over the next several years, Cree contin-



ues to expect overall fiscal 2018 free cash outflow of -\$20m.

Cree continues to target bringing additional materials capacity on line as it exits fiscal Q2, doubling SiC wafer capacity for external materials customers by the end of calendar 2018. The firm is also on target for additional Power & RF device capacity to start coming on line in fiscal Q4 (to double Power device capacity by the end of calendar

2018, compared with the end of fiscal 2017). "We are internally qualifying going to the larger wafer size on 150mm and then have to qualify that with customers," says McDevitt.

"We're going to work on three things in the near-term, first evaluating and focusing the strategy and the direction of the company; second, improving execution in our existing business; and third, engaging the workforce and getting

everyone pulling in the same direction," states new CEO Gregg Lowe. "We will evaluate all the areas where we're investing resources and ask four key questions. one, what is our unique differentiation; two, which customers care about this differentiation; three, what are the dynamics of the market for these customers; and four, can we be a top player," he adds.

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

## Cree names Gregg Lowe as chief executive officer

Cree has appointed Gregg Lowe as president & CEO and a member of the board of directors. He succeeds Chuck Swoboda, as per the transition plan announced in May.

Robert Ingram, current board member and lead independent director, assumes the position of chairman. Swoboda remained on the board until the annual meeting of shareholders on 24 October.

From 2012 through 2015, Lowe was president & CEO of Freescale Semiconductor, a \$5bn firm with 17,000 staff and products serving automotive, industrial, consumer and communications markets. Prior to that, he had a career



spanning 28 years at Texas Instruments, most recently as senior VP & leader of the analog business.

"I want to thank Chuck Swoboda for guiding this company for the past 16 years," says Lowe. "His leadership helped solidify Cree as an industry leader in multiple businesses," he adds.

In addition to his experience with semiconductor companies, Lowe holds numerous board positions including Silicon Labs in Austin, Texas; Baylor Healthcare System

in Dallas, Texas; and The Rock and Roll Hall of Fame in Cleveland, Ohio, where he co-chairs the education committee for the board.

Lowe holds a Bachelor of Science degree in electrical engineering from the Rose-Hulman Institute of Technology and has completed the executive program at Stanford University. He is the recipient of the Rose-Hulman Institute of Technology Career Achievement Award, honoring both his accomplishments in the semiconductor industry as well as his community service. Additionally, he was awarded an Honorary Doctorate of Engineering from the Institute in 2014.

## Cree expands chip-on-board LED portfolio with high-current XLamp LED arrays

Cree has launched a family of XLamp CMA high-current LED arrays that provide what is claimed to be the best lumen density and efficacy for metal-based chip-on-board (COB) LEDs. Optimized for operation at high drive currents, the CMA LEDs deliver up to 2.5 times the lumen density of Cree's standard-density CXA2 LEDs. The new CMA LEDs are compatible with the existing ecosystem of holders and optics for the CXA2 LED family, enabling lighting manufacturers to boost the lumen output of their products with minimal redesign.

"Since the new high-current CMA LED arrays are compatible with the standard-density CXA2 LED family,

we can easily deliver more visual impact while maintaining the same optics options and color quality choices that our customers are looking for," comments Andrea Gallucci, head of optics & electronics at Italian lighting firm Artemide S.p.A. "These new CMA LEDs will speed up the pace of performance enhancements within both our iconic and innovative luminaire designs."

The CMA LED arrays feature a new metal COB technology that delivers what is claimed to be higher reliability than competing metal COBs. In addition, the CMA LEDs can be mounted directly to the heat sink, which eliminates the need for holders, simplifies the luminaire

manufacturing process, and reduces system cost.

The CMA family includes five LEDs with light-emitting surface (LES) sizes ranging from 9mm to 23mm to address a wide variety of applications. Featuring Cree's EasyWhite bins, the XLamp CMA LED arrays are available in correlated color temperatures (CCTs) of 2700-6500K with standard color options of 70, 80 and 90 CRI (color rendering index) and premium color options that include high-fidelity (98 CRI) and specialty color points. Product samples are available now, and production quantities are available with standard lead times.

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

# Osram unveils Eviyos LED prototype for smart headlights; market launch planned for 2020

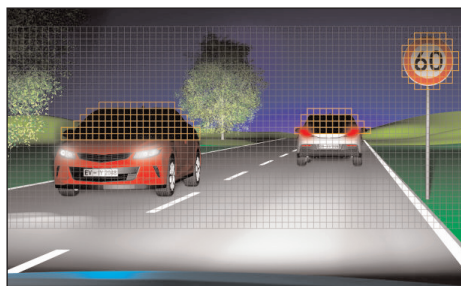
## Adaptive front-lighting system research project completed last October

Osram Opto Semiconductors GmbH of Regensburg, Germany claims that its newly developed Eviyos prototype is the first hybrid LED, representing progress towards the first market-ready smart-controllable high-resolution LED. As soon as oncoming traffic is detected the appropriate pixels are automatically switched off so drivers of oncoming vehicles are not dazzled.

Integrated in a demonstrator from Osram Specialty Lighting, the prototype is on show for the first time at the International Symposium on Automotive Lighting (ISAL 2017) in Darmstadt, Germany (25–27 September).

Eviyos has its basis in the  $\mu$ AFS (adaptive front-lighting system) research project that was completed in October 2016. Coordinated by Osram Opto, the project involved industrial partners Daimler AG, Fraunhofer Gesellschaft, Hella and Infineon Technologies.

The prototype combines two technologies in one component: a light-



**As oncoming traffic is detected the appropriate pixels are automatically switched off so drivers of oncoming vehicles are not dazzled.**

emitting chip and individual pixel control electronics. This combination means that the 1024 pixels of Eviyos plus the driver are all accommodated in a footprint of about 4mm x 4mm. The light source has minimum luminous flux per pixel of 3lm at a drive current of 11mA. Initial prototypes have already exhibited more than 4.6lm per pixel. Customers can vary the number of hybrid LEDs in their applications and supplement them with conventional LEDs, depending on the particular

requirements that need to be met.

"With Eviyos we are helping to make the roads safer and improve comfort and convenience for drivers," says marketing manager Thomas Christl. "We are proud that we can present the first prototype so soon after completing the research project," he adds. "We are now another stage further toward series production."

Osram Opto says that, as well as being compact and powerful, Eviyos is also energy-efficient due to the precise control and dimmability of the individual pixels. The only pixels that are ever on are the ones that are actually needed at the time.

At its planned launch at the start of 2020 Eviyos will form a separate product family offering a wide range of possible applications. Smart headlights are just one of the potential areas in which intelligent selective pixel control can be applied, the firm concludes.

[www.isal-symposium.de](http://www.isal-symposium.de)  
[www.osram.com](http://www.osram.com)

## Samsung partners with TÜV SÜD on collaborative testing program for automotive LED components

Samsung Electronics Co Ltd of Seoul, South Korea and TÜV SÜD AG of Munich, Germany, a global technical services provider of quality, safety and sustainability solutions, have developed a new testing program for Samsung's automotive LED components. A ceremony has been held at the headquarters of TÜV SÜD Korea Ltd in Seoul to unveil the new testing program.

The agreement is said to mark the first time in the industry that an automotive LED component maker has partnered with a global testing and certification company to test the quality, performance and reliability

of automotive LED components. Automotive LED component makers are generally required to submit in-house testing results to supply their products to OEMs. With TÜV SÜD's verification processes, Samsung says that it will be able to offer a high degree of validation and technical assurance for its automotive LED customers.

Through the program, Samsung's automotive LED components will be tested with TÜV SÜD based on AEC-Q102, the international standard for automotive components, as well as additional relevant safety tests adopted by Samsung and TÜV SÜD. When a component passes a

jointly administered test, the final report will include a certificate with TÜV SÜD's double octagon mark.

"TÜV SÜD's validation of the quality, safety and reliability of our automotive LEDs will provide another very important barometer," says Sung-Kwan Lim, VP of the LED Quality Team at Samsung Electronics.

In July, Samsung Electronics' LED testing laboratory was awarded an Acceptance of Client's Testing certificate by TÜV SÜD in recognition of the quality and reliability of Samsung's automotive LED component testing processes.

[www.samsung.com](http://www.samsung.com)  
[www.tuv-sud.com](http://www.tuv-sud.com)



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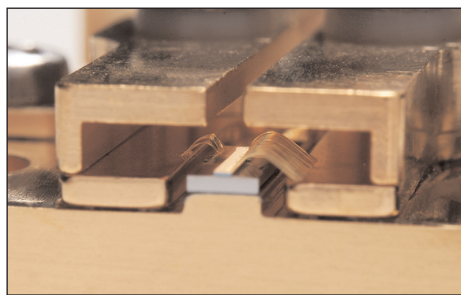
# FBH develops 1178nm InGaAs QW DBR laser diode yielding frequency-doubled yellow 589nm laser module

## Stress tests indicate stable operation at 2–2.5W for over 5000hr

Laser diodes emitting in the yellow spectral range are key components for applications such as laser cooling of sodium atoms and time-resolved fluorescence spectroscopy, notes Berlin-based Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH), which researches compound semiconductor-based electronic and optical components, modules and systems. However, this yellow spectral region is currently not accessible directly with laser diodes. One solution for realizing such sources is based on high-brilliance laser diodes with a highly strained indium gallium arsenide (InGaAs) quantum well (QW) emitting at 1178nm and subsequent non-linear frequency conversion (R.Bege et al, 'Watt-level second-harmonic generation at 589nm with a PPMgO:LN ridge waveguide crystal pumped by a DBR tapered diode laser', Opt. Lett., vol.41, no.7, p1530 (2016)).

In 2015, FBH developed watt-level distributed Bregg reflector (DBR)-tapered laser diodes (Figure 1) with a highly strained quantum well emitting at 1178nm. Based on these, reliability and optical output power could be further improved by optimizing the laser structure. The new laser diodes show an optical output power of about 3.5W, a nearly diffraction-limited beam with an  $M^2_{1/e^2}$  value smaller than 1.5, and a narrow-band single-mode emission, which is indispensable for efficient frequency doubling in a nonlinear crystal.

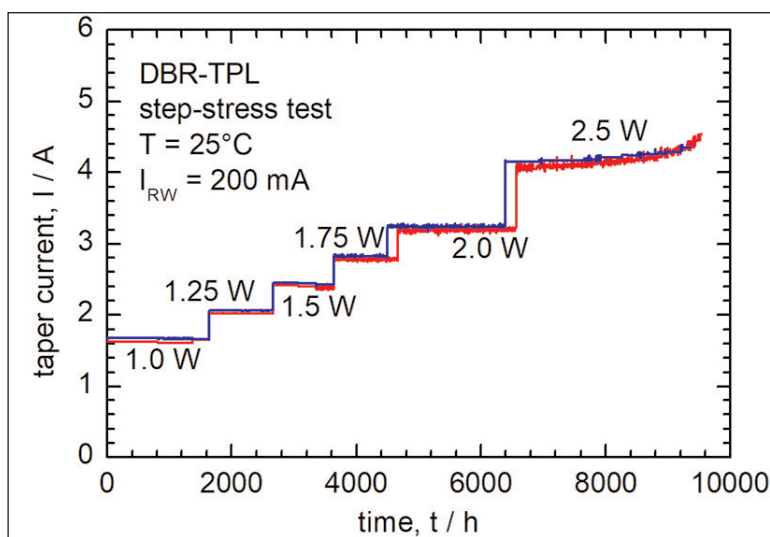
The power current characteristics up to a taper current of 7A are shown in Figure 2. Threshold current was less than 150mA and the slope efficiency was about 0.7W/A. The low series resistance of less than 100m $\Omega$  resulted in a record conversion efficiency of more than 45% at 2.5W output power. The spectrum at 2.5W shows a single peak at 1178.0nm with side-mode



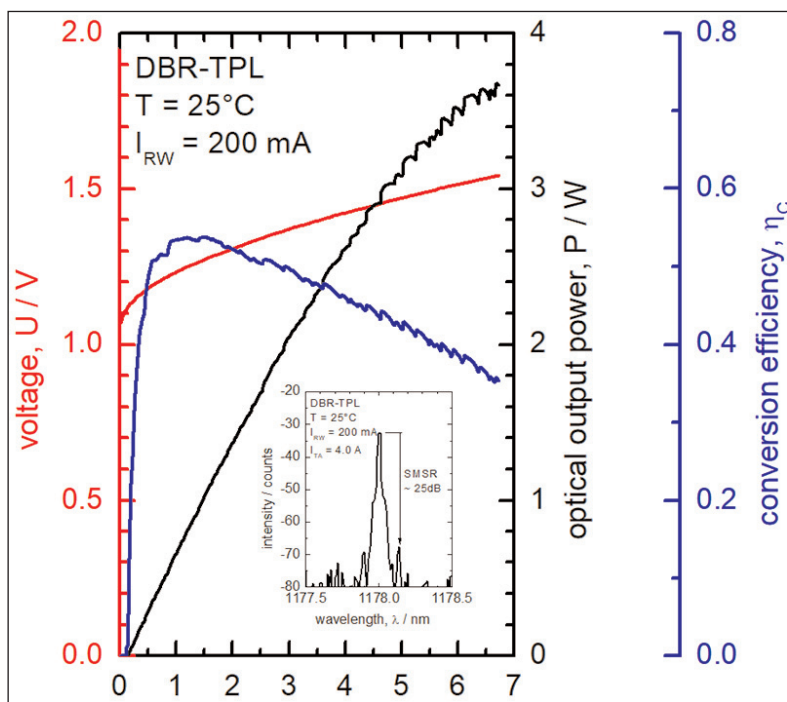
**Figure 1:** Tapered DBR laser diode mounted on CS heat sink.

suppression of more than 30dB.

At the previously demonstrated power level of 1W the improved lasers show no degradation. A constant power step-stress test was hence performed to estimate the



**Figure 2:** Characteristics of DBR tapered laser at 25°C up to a taper current of 7A. Inset: emission spectrum at 4A (about 2.5W output power).



**Figure 3:** Constant power step-stress lifetime transients of two DBR tapered lasers up to a power level of 2.5W.

reliability of the new design. The optical output was then successively increased to 2.5W, before degradation behavior became visible (see Figure 3), demonstrating that stable

operation at 2–2.5W can be maintained for more than 5000hr.

FBH says the lasers should allow construction of rugged, miniaturized yellow-emitting laser modules with an output of several hundred milliwatts, suitable for biomedical applications and fundamental research.

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

# FBH demos III-V electronics capability at Productronica, including InP and silicon heterointegration

Berlin-based Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) — which researches compound semiconductor-based electronic and optical components, modules and systems — is presenting a selection of current developments and advances of its power amplifiers, circuits and heterointegrated chips in hall B2, booth 317 at Productronica 2017 in Munich (14–17 November). FBH is exhibiting jointly with partners from the Fraunhofer Group for Microelectronics and fellow Leibniz institute IHP-Innovations for High Performance Microelectronics of Frankfurt (Oder), Germany.

FBH's heterointegrated chips for terahertz applications, for example, combine the advantages of two technologies at the chip level: the high output power of indium phosphide (InP) with the complexity of silicon technology.

Further exhibits target digitalization and the future mobile communications standard 5G, including digital power amplifiers that offer efficient performance management and the highest flexibility simultaneously in addition to broadband operation.

## Pushing frequency boundaries and combining advantages with heterointegrated chips

Regarding high-performance communications, frequencies in the subterahertz range are gaining increasing attention. To overcome the exponentially growing volume of short-range data traffic, wireless transmission routes are needed in the 100–500GHz band. Other applications in this band include materials testing, security technology for passenger and baggage screening, and high-resolution radar technology for intricate robotics applications.

All these system applications require electronic circuits that can deliver high output power in the sub-terahertz range, and they cannot be built using conventional semiconductor technology. Instead,

FBH uses the InP for its integrated circuits. InP heterojunction bipolar transistors (InP-HBTs) can currently achieve cut-off frequencies of more than 500GHz ( $f_{max}$ ) at a collector current of 20mA. The breakdown voltage lies above 4V, enabling high output power.

An industry-compatible process line for InP circuit wafers is being built at FBH in the scope of the German government Federal Ministry of Education and Research (BMBF) initiative Research Fab Microelectronics Germany (FMD), launched in April. This process line also allows FBH — together with IHP — to integrate InP circuits onto silicon-germanium (SiGe) BiCMOS technology. The high output power of InP can hence be combined with the complexity of silicon technology. Millimeter-wave and sub-terahertz modules can therefore be created on a single chip, which is paramount for portable and cost-effective system applications. This process is also offered to external customers as a foundry service.

## Components for 5G

In preparing the technical infrastructure for 5G, hardware components must be made more efficient and more flexible, says FBH. This can be aided by increasing the degree of digitalization. Currently, the focus is on power amplifiers because they dominate the efficiency, and thus the operating costs, of the entire system.

Up to now, multiple separate modules

have always been required to accommodate different communication standards and frequencies. FBH has therefore been working for several years on developing new digital amplifier architectures offering efficient power management, maximum flexibility, and broadband operation. The long-term goal is a fully digital transmitter in which one chip serves all frequency bands.

Complementary to this, FBH is researching powerful modulation and encoding methods, which largely determine the properties of digital amplifiers. It has already developed a novel modulator that can be built using conventional digital components. It also allows signals to be generated by all kinds of modulation methods.

FBH's digital power amplifiers have already achieved competitive overall efficiency and linearity compared with established analog amplifier concepts such as Doherty. One recent power amplifier offers overall efficiency of more than 40% at 10dB PAPR (peak-to-average power ratio) in the range of around 1GHz.

Another method for digitalizing power amplifiers is discrete envelope tracking (ET). Modulating the supply voltage of the amplifier output stage ensures high power efficiency despite the strongly fluctuating instantaneous power of modern broadband modulation methods. Modulation is performed by switching the voltage back and forth only between a number of specific (discrete) constant voltages. This digitalized version of ET yields highly efficient broadband solutions. New records were recently achieved at FBH, namely a modulation bandwidth of 120MHz in a 75W amplifier at 1.8GHz. This ET concept can also be converted relatively easily for millimeter-wavelength amplifiers, as is crucial for 5G base stations.

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

**An industry-compatible process line for InP circuit wafers is being built at FBH in the scope of the BMBF initiative FMD. This process line also allows FBH — together with IHP — to integrate InP circuits onto SiGe BiCMOS**

# Northumbria University partnering in EU's VisIoN project on visible light communications

## Four-year project to explore LiFi communication for electronic devices in smart homes, cars, factories and businesses

Northumbria University in Newcastle, UK is the only UK institution chosen to take part in the European Commission (EC)-funded €3.75m (£3.44m) Visible light communications (VLC)-based Interoperability and Networking (VisIoN) research project, which will explore how light could be used to allow electronic devices to communicate in the smart homes, cars, factories and businesses of the future. The project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 764461.

VisIoN is being coordinated by Dr Mohammad-Ali Khalighi of the Ecole Centrale Marseille, Fresnel Institute, in France, and is supported by six academic and five industry partners from seven European countries including Spain, France, Germany and Czech Republic. The project began at the start of October and will run for four years. Northumbria has been awarded over £440,000 for its part in the project.

Over the last 12 years, Northumbria has developed expertise in visible light communications through its Optical Communications Research Group, led by professor Zabih (Fary) Ghassemlooy. As a key project partner, Northumbria will help to train a new generation

of early-stage researchers in visible light communications, as well as contributing to better scientific understanding and technical knowledge in the field. This will include exploring how the technology can be used in smart transportation, and medical and manufacturing environments, with Northumbria academics supporting PhD students, running tutorials and workshops, and writing academic papers.

"Visible light communication (also known as LiFi) is completely transforming the concept of telecommunication," says Ghassemlooy. "Modern LED lights are extremely energy efficient and long lasting and it is predicted that in the near future LEDs will be the main source of light worldwide. LEDs can also be used for indoor GPS and sensing, thus opening up new frontiers in research in this emerging green technology," he adds.

"The benefit of LEDs is that they are semiconductor devices... we can switch these bulbs on and off at very high speeds, thus allowing data to be sent from LED lights to devices such as computers, smart phones, traffic signs and a wide variety of other receivers," Ghassemlooy continues. "This communication takes place faster than the human eye can process, so we would simply see a constant flow of light, providing us with illumination

while also transporting data quickly, safely and securely."

Northumbria's Optical Communications Research Group focuses on theoretical investigation, simulation and practical implementation of devices, and systems for optical wireless communications, visible light communications, free space optical communications, radio over fibre, and high-speed optical switching and routing.

The group is carrying out pioneering work on visible light communications and organic visible light communications (the first in the world, it is claimed) in collaboration with Siemens (Germany), University College London and others. Northumbria's Agilent-sponsored Photonic Research Laboratory is the first of its kind in the north of England, with unique test and measurement facilities.

The research group was established by Ghassemlooy, who has published about 700 papers including three books on Optical Wireless Communications. He is also the founder and chairman of the Institute of Electrical and Electronics Engineers (IEEE)- and the Institution of Engineering and Technology (IET)-sponsored International Symposium on Communication Systems, Network and Digital Signal Processing (CSNDSP).

<http://soe.northumbria.ac.uk/ocr>

## Future Electronics to distribute Lumentum's optical transceiver products in Americas

Future Electronics of Montreal, QC, Canada has signed a distribution agreement authorizing it to market and sell the optical transceiver products of Lumentum Holdings Inc of Milpitas, CA, USA in the Americas.

"Lumentum is a leader in the

optical transceiver market and their products complement our networking solutions offering," comments Philippe Vauclair, director of marketing at Future Electronics.

"Future is one of the leading distributors of top-tier optical tech-

nology solutions and we have been impressed by their field organization and commitment to customer service," comments Chris Pfistner, VP, product line management, Datacom, at Lumentum.

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

# Philips Photonics-led European consortium completes VIDaP VCSEL project

Philips Photonics of Ulm, Germany — which provides vertical-cavity surface-emitting laser (VCSEL) technology for datacom, consumer and industrial applications — on 26 September officially completed 'VIDaP' (VCSEL Pilot Line for Illumination, Datacom and Power Applications), after leading the four-year €23m project jointly sponsored by the German Federal Ministry of Education and Research (BMBF) and the European Union, and executed under the umbrella of the European program ECSEL (Electronic Components and Systems for European Leadership).

Since its inception in 2014, the project has focused on making significant advances in highly automated manufacturing, bringing VCSEL production to the same level of maturity as the LED industry. Other partners were IQE Ltd, STMicroelectronics, industrial production equipment firm Sidel, imaging firm SICK AG, datacom

firm Mellanox Technologies Ltd, and the Technical University of Eindhoven.

Global revenues for the VCSEL market are currently several hundred million dollars, and are expected to swell to over \$1bn in 2022.

Prior to the project, VCSELs were only manufactured in small quantities, with largely unautomated processes. Philips and its consortium partners have now demonstrated the capability to manufacture VCSELs to the same standards as other high-volume semiconductor components. The capability is expected to help unlock the potential of new solutions such as high-speed data transmission, 3D recognition, optical sensors such as Lidar and digital industrial thermal processes, whilst significantly reducing the size of sensors and energy consumption in data centers and thermal industrial processes.

Following the announcement last November that Philips was expanding and doubling the capacity of its

laser diode facility (on track for completion by the end of 2017), Philips has produced a cumulative 700 million VCSELs. This rapid growth in demand has triggered follow-up investments that will lead to another doubling of capacity by early 2018, says the firm.

"With the digital revolution firmly underway, the market need for VCSELs is rapidly accelerating," says Philips Photonics' general manager Joseph Pankert. "Anticipating this demand, over the past few years we have invested consistently in research, product development and efficient manufacturing processes," he adds. "Today, our products are widely used in data centers, smartphones and a number of industrial applications, with the advancements brought about by the project helping to secure Philips a leading European position in this growing segment of optoelectronics."

[www.ecsel-ju.eu](http://www.ecsel-ju.eu)

[www.photonics.philips.com](http://www.photonics.philips.com)

# KDPOF shipping samples of first automotive-grade Gigabit Ethernet POF transceiver to car makers & suppliers

Fabless semiconductor supplier KDPOF of Tres Cantos, Madrid, Spain — a supplier for automotive gigabit connectivity over POF (plastic optical fiber) — is shipping samples of its KD1053 automotive-grade Gigabit Ethernet POF (GEPOF) transceivers to car makers and their tier-1 suppliers. The first public demonstration was at the VDI Congress ELIV (ELECTRONICS In Vehicles) 2017 on 18–19 October at the World Conference Center in Bonn, Germany.

"The production start of our automotive POF transceiver marks a significant milestone on our path to make automotive gigabit Ethernet a reality," says CEO & co-founder Carlos Pardo. "It is the first fully integrated automotive transceiver

to implement the physical layer of Gigabit Ethernet over POF," he claims.

KDPOF provides comprehensive support equipment such as application notes, reference design, evaluation boards and kits to enable users a fast and easy design start. Automotive applications of the KD1053 include 100Mbps and 1Gbps Ethernet links such as battery management systems (BMS), inter-domain communications backbones, antenna hubs, autonomous driving, and ADAS (advanced driver assistance systems) with surround view.

KDPOF says that the KD1053 fully meets the requirements of car makers by providing high connectivity with a flexible digital host

interface, low latency, low jitter and low linking time. It also complies with the new standard amendment IEEE Std 802.3bv for gigabit Ethernet over POF, defining physical layer specifications and management parameters for automotive, industrial and home networking applications utilizing POF. The standard amendment responded to the demand for high-speed Ethernet solutions. KDPOF says that plastic optical fiber provides unique capabilities for applications where long link lengths are not required, not only outperforming copper solutions in electromagnetic compatibility and immunity but also providing galvanic isolation, lower weight and low cost.

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

# Lithuania's Brolis establishes R&D division for silicon photonics in Belgium

**Brolis' GaSb long-wave IR lasers to be combined with UGent–imec's CMOS-compatible silicon-on-insulator photonic integrated circuits**

Brolis Semiconductors of Vilnius, Lithuania has established a new R&D division Brolis Semiconductors BVBA in Ghent, Belgium focused on the design and development of novel integrated photonic systems, combining its proprietary III-V long-wave infrared light source technology with CMOS-compatible photonic integrated circuit (PIC) technology. Special emphasis is directed towards the development of new OEM gallium antimonide (GaSb)/silicon-on-insulator (SOI) system-on-a-chip laser technology for sensing applications in the 1.5–3.5 $\mu\text{m}$  spectral range and beyond for healthcare and industrial markets.

"Brolis is delighted to add photonic integrated circuit technology to the existing technology portfolio — we believe it provides a new dimension to our existing III-V semiconductor technology," says Augustinas Vizbaras, co-founder & head of chip technology. "The addition of silicon technology to GaSb is expected to pave the way to an integrated hybrid chip technology with completely new functionality — such as OEM remote laser sensors for industrial and healthcare applications with a footprint of a few  $\text{mm}^2$ , which could enter any handheld, wearable device platform offering features not available today," he adds. "We are particularly happy to land in Ghent — a world famous location for silicon photonics technology research. Successful cooperation with the Photonics Research Group [of



Ghent University (UGent)] provided a decisive push towards making directional efforts in commercialization of GaSb/SOI technology," Vizbaras reckons.

"Over the years Brolis has managed to bring GaSb-based laser diode technology to an industrial level with beyond state-of-the-art device performance and scale," comments Dr Andreas De Groote, who is to lead the design effort for the photonic integrated circuit technology at the new location. "The next big step is to merge these GaSb chips as key components with photonic integrated circuit technology based on CMOS-compatible silicon-on-insulator technology. Moreover, we should bring it to an industrial level, suitable for consumer market applications," he adds.

"While silicon photonics has predominantly been studied for optical

transceivers, there are fantastic opportunities in the field of sensing as well," says professor Gunther Roelkens of the Photonics Research Group at UGent–imec. "The combination of GaSb III-V optoelectronics and silicon photonics can enable many applications in this domain," he adds.

"This investment testifies to the strong reputation of Flanders in photonics R&D," reckons Thomas Castrel, economic counsellor at the Vilnius office of Flanders Investment & Trade, the export and investment promoting agency of the Flemish government (Belgium). "Companies are choosing the Flemish region for R&D activities because of the presence of world-class universities and research institutes combined with a friendly fiscal environment for research driven businesses."

[www.brolis-semicon.com](http://www.brolis-semicon.com)

## Brolis completes buy-out of shares from VC fund LitCapital

Brolis Semiconductors has completed the buy-out of shares from VC fund LitCapital. The share buy-back process was initiated by

the founders in 2015 by attracting long-term investors lead by Lithuanian high-tech laser companies Light Conversion, Eksma and

ARP Invest. Brolis is currently controlled by Vizbaras family, Light Conversion, Eksma and ARP Invest. [www.litcapital.lt](http://www.litcapital.lt)



## CST Global receives £318,039 as part of SUPER8 project to develop 200Gbps, 8-channel CWDM transceivers

III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK (a subsidiary of Sweden's Siverts IMA Holdings AB) says that it is receiving £318,039 as a consortium member of the £1.1m Innovate UK government-funded SUPER8 research project, which aims to develop a scalable 200Gbps super-thermal, 8-channel CWDM (coarse wavelength division multiplexing) architecture. This will be applied to an ultra-high-speed, industry-standard transceiver platform for use in the optical data communications of hyper-scale cloud data centers.

The SUPER8 project consortium partners include CST Global, the Compound Semiconductor Centre (CSC) — a joint venture between Cardiff University and epiwafer foundry & substrate maker IQE plc of Cardiff, Wales, UK — and PIC (photonic integrated circuit)-based transceiver maker Kaiam of Newark, CA, USA (whose main manufacturing is plant in Livingston, Scotland, UK).

"Cloud services, video-on-demand and the Internet of Things are increasing data bandwidth demand in global communications networks," says CST Global's technical director Andrew McKee. "This is driving the need for higher-capacity networks with greater transmission rates and a lower cost base," he adds.

"CWDM architecture is the solution. It allows the bandwidths of existing optical networks to be increased by improving optical filtering to increase the quantity of wavelengths transmitted in a single fiber," McKee continues. Low-cost, uncooled ridge-waveguide DFB lasers are used for the optical transmission, which the consortium of CST Global, CSC and Kaiam will model, build, test and optimize. Lasers are supplied as known-good-die-on-tape to Kaiam for packaging, characterization and qualification.

"Lasers in the CWDM architecture offer reduced power consumption and increased reliability over existing DWDM architecture solutions," McKee concludes.

[www.CSTGlobal.uk](http://www.CSTGlobal.uk)

## Glasgow's professor John Marsh speaks at PIC 2017

At the Photonic Integration Conference 2017 in Eindhoven, The Netherlands (26 September), professor John Marsh of Scotland's University of Glasgow (whose research has focused on semiconductor lasers, integrated optics, and their commercialization) gave a presentation emphasizing how the moment for photonic integration in the access market has finally arrived. "It is no longer a question of if photonic integration is going to come to the access market, but more a question of when," says Marsh.

"The research has been going on since the 1980s but has to wait a long time because, so far, discrete components have been able to do the job. China, Japan and Korea were the first countries to implement passive optical networks (PONs) in the access network on a large scale. Now their networks are migrating from 2.5Gb/s to 10Gb/s, and soon PONs will use multiple wavelength channels at 25Gb/s," he adds.

"Photonic integration will be needed to do this, but integration needs large volumes to lower the

cost and the major companies are in fact a barrier here, as they have not defined a long enough roadmap for the required standards," Marsh notes. "These standards are needed so the investment can be made in the integration technology."

The advantages for photonic networks users are huge, Marsh says. Typical PONs are able to deliver 2.5Gb/s, and this will improve to no less than 25Gb/s. Although this data rate is shared by many users, both commercial enterprises and the public will enjoy a 10-fold speed improvement.

But standardization is also needed to make the required equipment for the public market cheap enough, says Marsh. This also depends on what platforms are chosen, and there is broadly a choice of three: indium phosphide (InP), silicon photonics, and a hybrid form. InP is used in the long-haul network, with Infinera Corp of Sunnyvale, CA, USA being the market leader in photonic integrated circuits. In the short-haul data market, Intel is backing silicon photonics.

These each have their technological advantages, and logically one might expect one of these platforms to be adopted for the access market. However, Marsh thinks there is a good chance that a hybrid-system might prevail. "This can make use of a rather simple and an unexpected technology, the hard-disk drive. In around 18 months, the next generation of hard-disk drives will bring photonic integration technology to the market for a very low cost — you have to implement the photonics technology for one or two dollars in each disk drive," he adds. "This is the type of major breakthrough that will allow you to make a very complex 100Gb/s transceiver for the access market for \$25."

The optical transceiver market is predicted to grow rapidly, from \$7bn in 2018 to \$10bn by 2021, with all growth attributed to high-speed transceivers using photonic integration. Costs must be reduced, however, and the barriers faced by photonics can be compared with historical progress in electronics.

[www.gla.ac.uk/schools/engineering](http://www.gla.ac.uk/schools/engineering)

# Fabless silicon photonics firm Skorprios acquires manufacturer Novati

## Fab enhances Skorprios' heterogeneous integration process and manufacturing capability, enabling rapid productization

Fabless silicon photonics system-on-chip (SoC) company Skorprios Technologies Inc of Albuquerque, NM, USA has acquired Novati Technologies LLC, a semiconductor integration company with a fabrication plant in Austin, TX.

Skorprios delivers highly integrated products based on its proprietary wafer-scale heterogeneous integration process (which monolithically integrates silicon with III-V gain materials used as the active medium). This hence leverages the existing silicon manufacturing ecosystem to enable high-bandwidth interconnectivity at what are said to be mature CMOS manufacturing costs. The platform can be used to address a wide range of applications, including high-speed video, data and voice communications for networking, cloud computing, consumer, and medical.

Novati's fab is said to be known for its innovative work in 2.5D/3D

integration, photonics, MEMS sensors, and micro fluidics for medical applications. Prior to the acquisition, Skorprios had developed its heterogeneous integration process in collaboration with Novati, and was fabricating its ICs in Novati's foundry.

Skorprios says that the acquisition gives it the ability to better meet growing demand via:

- vertical integration of its heterogeneous integration process (increasing volume throughput and allowing control of its critical supply chain);
- decreased fab cycle times (by providing access to focused production lines in the foundry); and
- faster time to market (expediting the development of new products, resulting in faster time to market and revenue realization).

"The ability to develop and commercialize products based on our proprietary heterogeneous

integration process in our own foundry is the next logical step in the evolution of our company," says Skorprios' chairman, founder & CEO Stephen Krasulick. "Skorprios will be well positioned to deliver highly differentiated products with shorter development cycles... There are tremendous synergies between Skorprios' heterogeneous integration platform and the technologies currently being developed and offered at Novati," he adds.

"Novati's highly customized fab solutions are uniquely positioned to support the revolutionary Skorprios products," says John Hamma, senior VP, Services business unit of Skorprios.

Skorprios says that, after the acquisition, it will immediately ramp up production, starting with its 100Gb QSFP CWDM4 optical transceiver.

[www.skorpriosinc.com](http://www.skorpriosinc.com)  
[www.novati-tech.com](http://www.novati-tech.com)

## MACOM opens Optoelectronics Innovation Lab in China

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has opened its Optoelectronics Customer Innovation Lab, with multiple top-tier optical networking customers in attendance (including Huawei, APAT, Mentech, Xgiga, Ruigu, Moduletek, Hi-Optel, CIG, and Lumentum) representing the metro/long-haul, cloud data-center, wireless backhaul and passive optical network (PON) access markets.

As a hub of 100G, 400G and beyond optical and photonic development, the new lab is located in KeXing Science Park, Shenzhen, China, and focuses on supporting

customers using MACOM's optoelectronic and photonic components to enable cloud data centers, client access and metro/long-haul applications.

At the opening MACOM displayed live demonstrations covering its silicon photonics CWDM4 L-PIC transmitter (combined with a 100G ROSA optical transmission link for 100G, 400G and beyond), a 200G PAM-4 optical interconnect link (based on MACOM's analog chipsets for cloud data centers) and 10G-PON total solutions to the region's top customers, enabling their 100G, 400G-and-beyond optical applications.

"The opening of MACOM's Optoelectronics Innovation Lab allowed us to showcase the

progress we have made leveraging our preeminent product and technology portfolio across CWDM4, PAM-4 and 10G PON Solutions," says Vivek Rajgharia, senior VP & general manager, Lightwave business unit, at MACOM. "This is another step in our efforts to drive optical design innovation and collaboration with our customers, servicing global demand," he adds. "Our customers today are looking to MACOM to not only deliver industry-leading components but also accelerate their time to market, working closely with them on technical and design support to enable their deployments," concludes Rajgharia.

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

## PHIX Photonics Assembly raises first round of investment Funding to accelerate scaling up assembly & packaging of PICs

After in April initiating an assembly & packaging production line for high-volume fabrication of photonic integrated circuit (PIC) modules at the University of Twente's High Tech Factory, PHIX Photonics Assembly of Enschede, The Netherlands has raised a first round of investment, led by Oost NL (East Netherlands Development Agency, which focuses on the provinces of Gelderland and Overijssel) through funds available via Innovatiefonds Twente.

"We have strong support from the province of Overijssel, Innovatiefonds Twente, Saxion Hogeschool, the University of Twente, and the world-class photonics companies such as LioniX International, which established a unique position and reputation in a suite of application markets for photonic integrated circuits," says Albert Hasper, director of PHIX B.V.

"With the creation of PHIX Photonic Assembly in April 2017, we secured access to test, assembly and packaging modules for large volumes," he adds. "With this first round of investment, led by Oost NL, we can accelerate the scaling up of our assembly and packaging processes for photonic integrated circuits."

PHIX will work in close cooperation with the Fraunhofer Project Center on packaging standards for high-volume manufacturing of integrated photonics modules and with Phoenix Software on developing the appropriate photonic design kits, dedicated for assembly and packaging, to secure volume scalability and fast time-to-market of novel sensors in datacom, telecom and medical applications.

Hans van den Vlekkert, CEO of LioniX International (initiator and orchestrator of the establishment of PHIX B.V.) emphasizes the need for the presence of a strong, regional eco-system, where education, design, manufacturing and volume production are at hand.

"We have seen accelerated growth

of the integrated photonics market over the past year, especially for the demand of devices that are based on our low-loss TriPleX platform," says Vlekkert. "We have delivered many prototypes to international customers and anticipate that volume demand for the PIC

modules is starting, which requires an efficient organization, such as PHIX B.V., where the infrastructure and production flow are tailored to achieve cost-effective assembly and packaging of PIC modules," he concludes.

[www.phix-photonics-assembly.com](http://www.phix-photonics-assembly.com)



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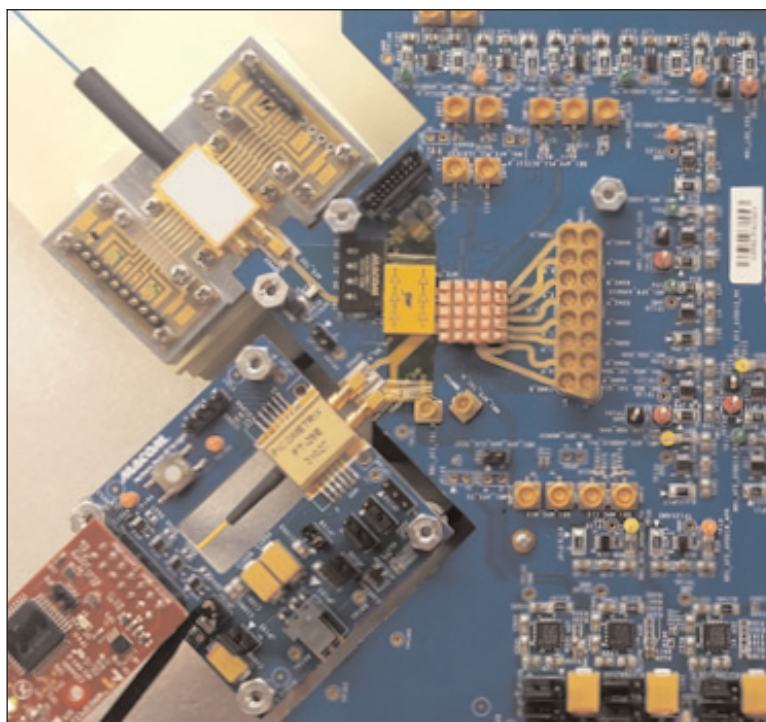
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# MACOM launches first end-to-end 100G single-lambda solution scalable to 400G for cloud datacenters

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched what it claims is the first complete 100G single-lambda solution that enables the cost structure with the supply-chain flexibility for main-stream cloud datacenter deployment. Designed to help accelerate the deployment of 100G optical interconnects at cloud-scale cost structures, MACOM says that its 100G Single Lambda Solution enables customers to quickly and easily integrate high-performance MACOM components and get to market faster with the next generation of 100G optical modules.

The 100G Single Lambda Solution leverages the firm's 53 Gbaud PAM-4 technology to deliver 100G throughput over a single wavelength. 100G single lambda is an approach that has been endorsed by the IEEE that can dramatically reduce the number and cost of optical components typically housed in an optical transceiver module. It is implemented in QSFP optical modules enabling plug & play compatibility with existing systems, accelerating customers' field deployment of the technology, and bypassing the need for switches and routers to be developed before they can deploy their end solutions in volume.

"The breadth of MACOM's analog, optical and photonic technology portfolio, combined with our deep domain expertise and cloud-scale manufacturing capability, position us as the clear industry leader in 100G-enabling components on the pathway to 200G, 400G and 800G connectivity," reckons Preet Virk, senior VP & general manager, Networks, at MACOM. "By aligning our cloud datacenter strategy with the requirements of our end customers, we're enabling the highest-



**MACOM's 100G single-lambda solution.**

performance, most cost-effective module solutions for next-generation cloud datacenter infrastructure."

Leveraging a 16nm FinFET process node, MACOM's PRISM mixed-signal PHY that underpins the 100G Single Lambda Solution is reckoned to be a generation ahead of competing PHYs developed at larger, planar geometries. Designed for 53Gbaud PAM4 operation with an integrated linear laser driver, forward error correction (FEC) and a flexible digital signal processor (DSP)-based equalizer, PRISM is said to enable ease of integration, delivering cloud-scale economics and cost structures.

PRISM is complemented by MACOM's silicon photonics based optics consisting of a laser integrated with a photonic integrated circuit (PIC) chip that leverages the firm's patented etched facet technology (EFT).

MACOM's 100G Single Lambda Solution hence includes the following products:

- PRISM mixed-signal PHY (MATP-10025);

- 53GB PAM-4 single-lambda 100GL-PIC (MAOP-L561PP);
- 1x53GB PAM-4 TIA (MATA-005817);
- 4x53GB PAM-4 TIA (MATA-03819 and MATA-03919);
- 1x53GB PAM-4 PIN photodiode BSP56A/QA; and
- PAM-4 TOSA/ROSA for 53GB applications.

MACOM says that this highly integrated photonic solution drives additional cost optimization, enabling cloud-scale manufacturing capabilities for customers.

"Cloud datacenters have moved quickly to deploy first-generation 100G modules, but insatiable data demands, unrelenting cost pressures and compressing upgrade cycles require a new generation of modules that enable datacenters to eliminate capacity, throughput and cost constraints," comments Kevin LeFebvre, principal analyst at market research firm Ovum. "MACOM's Single Lambda 100G Solution embodies the technology innovation and 100G-to-400G roadmap acceleration needed to keep pace with unabated cloud datacenter growth."

MACOM showcased its 100G Single Lambda Solution through video demonstration at the 43rd European Conference on Optical Communication (ECOC 2017) in Gothenburg, Sweden in September.

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

[www.macom.com/applications/optical-networking/data-center](http://www.macom.com/applications/optical-networking/data-center)

# MACOM launches first complete portfolio for 10G PON OLT & ONU infrastructure

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched what it claims is the first complete portfolio for 10G passive optical network (PON) applications, enabling optical line terminal (OLT) and optical network unit (ONU) infrastructure.

Building on the firm's industrial-scale manufacturing capabilities, the new 10G PON portfolio enables seamless component integration and cost efficiencies to help accelerate 10G PON infrastructure build-outs.

"The shift to 10G GPON is underway with initial deployments in all major regions worldwide," notes Julie Kunstler, principal analyst at market research firm Ovum. "The current 2.5G GPON infrastructure cannot meet continuing bandwidth growth from both residential and non-residential subscribers and applications," she adds. "In the ultra-cost sensitive, highly competitive fiber access market, MACOM's technology and product developments to minimize both integration complexities and costs while reduc-

ing deployment times will be well received."

MACOM's solution portfolio combines the inherent performance and supply scalability advantages of electro-optic modulated lasers (EOMs), complemented by a range of pre-qualified, interoperable avalanche photodiodes (APDs), transimpedance amplifiers (TIAs), laser drivers, and CDR (clock & data recovery) chips. Leveraging MACOM's L-PIC technology platform and patented etched facet technology (EFT) for high-volume, low-cost laser manufacturing, MACOM reckons that its 10G PON portfolio is poised to replicate the breakthrough cost-structure reductions that it previously achieved in 2.5G PON.

MACOM claims to be the only supplier to provide the entire range of 10G PON components, while delivering EOML technology that overcomes the performance, yield and cost limitations of electro-absorptive modulated lasers (EMLs). The firm says that its application expertise and end-to-end chip-set enables customers to go to market with tightly integrated 10G PON systems at aggressive timescales, significantly shortening the design and

development cycles required to independently validate component interoperability. MACOM claims that it is the only firm that can provide the cost structure, capacity and supply chain flexibility for high-volume, client-side applications.

"MACOM's leading market share in the PON domain — where we've shipped over 135 million lasers to date— is a testament to customers' trust in our proven technology platforms and volume-scale manufacturing efficiency," says Vivek Rajgarhia, senior VP & general manager, Lightwave, at MACOM. "With the introduction of our 10G PON solution portfolio, we've again affirmed our commitment to helping customers overcome the challenges of deploying advanced optical technologies at massive scale and lowered cost structures."

Components are sampling to customers now, with full production planned for first-half 2018. MACOM showcased its 10G PON solution portfolio at September's European Conference on Optical Communications (ECOC 2017) in Gothenburg, Sweden.

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

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

## MACOM exhibits portfolio enabling optical network connectivity at 100G, 400G and beyond at ECOC 2017

MACOM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) showcased its portfolio of optoelectronics and photonic solutions at the 43rd European Conference on Optical Communication (ECOC 2017) in Gothenburg, Sweden in late September.

With its portfolio of electronic components, lasers and photodiodes expanding to address designs in wireless, enterprise and

storage networks applications, MACOM says that its experience in optical networking is enabling smart solutions from cloud data-center networks to long-haul core networks to FTTH access networks. To better enable customers as the demand for data grows, the firm continues to provide next-generation solutions to meet requirements of size, power and signal integrity of high-speed networks.

MACOM's portfolio includes L-PIC transmitters, R-PIC receivers, patented self-aligning EFT (etched facet technology) lasers,

transimpedance amplifiers (TIAs), clock/data recovery (CDR) circuits — including its recent Lightwave Innovation Award winning MATA-37644 and MALD-37645 chipset — cross-points, silicon photonics, 53GB PAM-4 PHYs, 10G PON portfolio and ROSAs and TOSAs for data centers, enterprise and telecom optical systems operating up to 100G, 400G and beyond.

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

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# Infinera claims industry-first milestones

## Multi-channel InP-based PICs enable 100GBaud transmission rate and 1024QAM modulation scheme

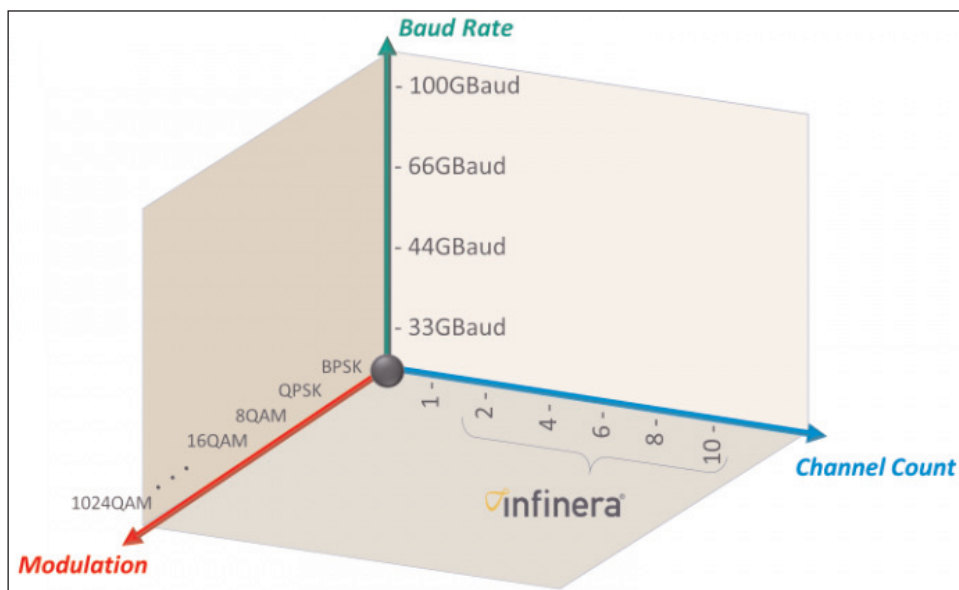
Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical transport networking systems incorporating its own indium phosphide-based photonic integrated circuits (PICs), says that it has achieved two industry-first milestones for coherent technologies that increase the capacity and reach of optical transport networks to the next level.

The first drives optical transmission technologies to 100 gigabaud (GBaud), and the second enhances modulation technology to 1024QAM (quadrature amplitude modulation). These new technologies are designed to deliver the highest possible capacity on a single wavelength for varied distances, helping operators to extract the best performance from their optical transport networks.

"Infinera uniquely uses vertical optical integration to extract maximum performance from the optical transport network," comments Andrew Schmitt, lead analyst at Signal AI. "The new levels of performance in baud rate and modulation schemes for terabit wavelengths exhibited at ECOC are a good example of how this approach can eventually result in production solutions with greater capacity and reach."

Optical transport networks enable cloud-based services to reach users around the world, and rely on three axes for increasing transmission performance:

- **Baud rate** (at which modulation symbols are sent): The typical deployed baud rate is 32GBaud with the quadrature phase-shift keying modulation carrying 4 bits per baud, resulting in 100 gigabits per second of transmission. While industry optoelectronics are moving to 66GBaud development demonstrations, Infinera claims to be first to showcase 100GBaud using 32QAM to achieve a single-wavelength 1 terabit per second (Tb/s)



data rate using multi-channel indium phosphide (InP)-based photonic integrated circuits (PICs) integrated with electronic driver and amplifier application-specific integrated circuits. This result was presented at the European Conference on Optical Communications (ECOC 2017) in Gothenburg, Sweden (18–20 September).

- **Modulation scheme** (converting bits to symbols): At ECOC, Infinera showcased the higher-order modulation scheme of 1024QAM using advanced constellation shaping algorithms and Nyquist subcarriers, allowing wavelengths to be spaced close to each other to maximize the data rate for a certain reach. The Infinera test bed used 66GBaud at 1024QAM to

**Infinera claims to be first to showcase 100GBaud using 32QAM to achieve a single-wavelength 1Tb/s data rate using multi-channel InP-based PICs integrated with electronic driver and amplifier application-specific integrated circuits**

reach 1.32Tb/s, yielding spectral efficiency of 9.35 bits per second per hertz over 400km (an industry first).

- **Channel count** (implementing multiple parallel wavelengths on a single module to create a coherent super-channel): As baud rates increase, placing optical components closer together on an integrated chip reduces component size and power while increasing reliability.

Baud rate and modulation scheme have been addressed by the industry for some time, with Infinera now setting new milestones for each. The firm says that its PIC technology uniquely enables high-channel-count coherent super-channels. These technologies indicate the next level of capacity and reach achievable in the years to come, it adds.

"Infinera is delivering optical engines at a faster cadence to help operators achieve exceptional capacity and reach performance on their transport network infrastructures," says co-founder & president Dr Dave Welch. "As 5G wireless and cable video services take off, Infinera offers significant value to transport network operators by designing industry-first solutions," he adds.

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

## Unclear China demand drives NeoPhotonics cuts Workforce reduction, real-estate consolidation, and write-downs of inventory and idle assets to lower breakeven revenue level

As part of its continuing actions to improve profitability and cash flow, NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated optoelectronic modules and sub-systems for high-speed communications networks in telecom and data-center applications) has implemented restructuring actions including a workforce reduction, real-estate consolidation, a write-down of inventory for certain programs and assets, and a write-down of idle assets.

These actions are intended to accelerate the return to profitability by lowering the breakeven revenue levels for profitability and free cash flow, while maintaining the focus on core capabilities, including coherent components and solutions for data-center interconnect and telecom systems. The actions are expected to reduce quarterly operating expenses with immediate impact and achieve a reduction of about \$2m when fully realized in first-quarter 2018.

The costs to implement these actions are expected to be \$4.8m (\$4.2m in asset-write off costs plus \$0.6m in severance costs), with \$4.6m incurred in third-quarter 2017 and the rest in fourth-quarter 2017.

"Lacking a clear indication of increased demand in China in the third quarter, we initiated several operational changes with the goal of expediting our return to profitability, including implementing certain restructuring initiatives designed to align our business with the current demand environment and lowering manufacturing output to manage inventory levels," says chairman & CEO Tim Jenks. "We have maintained our research and development focus on products for next generation coherent systems, operating at 400Gb/s to beyond 1Tb/s, wherein our advanced hybrid photonic integration provides the highest value," he notes.

In addition, for third-quarter 2017 NeoPhotonics has reported preliminary estimated revenue of \$69–71m (down from \$73.2m in Q2), with gross margin of 14–17% (down

from 23.9%) and loss per share of \$0.35–0.27 (worsening from \$0.15) on a non-GAAP basis (excluding restructuring charges and end-of-life inventory write-downs of \$4.6m, acquisition-related costs of \$0.2m, amortization of intangibles of \$0.3m, and the impact of stock-based compensation of \$1.9m, of which \$0.3m is estimated for cost of goods sold). This compares with the previous forecast of \$70–76m for revenue, 24–27% for gross margin and \$0.17–0.07 for loss per share.

In addition to restructuring charges, gross margin and net loss were negatively impacted by the decision to reduce production levels during Q3 resulting from a lack of visibility into future demand levels in China. While this reduction impacted overall capacity utilization and gross margin respectively in Q3, NeoPhotonics expects that these actions will help to reduce inventory levels in Q4.

Cash, cash equivalents and restricted cash totaled about \$74m at the end of Q3, down further from \$79m at the end of Q2.

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

## Source Photonics to double InP laser production capacity with new fab in China, driven by 100G and 400G markets

Source Photonics Inc of West Hills, CA, USA (which provides broadband access optical components and modules) and the Jintan Economic Development Zone have announced the establishment of a new optical laser production plant in Jintan, China.

Increasing demand for more bandwidth in cloud data centers, optical networks, wireless communications systems and fiber-to-the-home (FTTH) is creating the need for more efficient and higher-throughput optical lasers and related transceivers, says Source Photonics. With the need to

evolve from single-channel to multi-channel optical connectivity products to overcome physical barriers, indium phosphide (InP) laser volumes are expected to grow rapidly over the next several years. In support of these growing requirements, Source Photonics is investing in a new fabrication plant.

Accommodating wafer metal-organic chemical vapor deposition (MOCVD), chip processing, and related component production, the new fab will more than double the firm's existing output of InP lasers and related components. It will augment its existing fab in Hsinchu,

Taiwan, which has more than doubled its output over the past three years and introduced more advanced devices required for the current 100G and emerging 400G markets. Initial production in the new facility will begin in second-quarter 2018.

"The new facility in Jintan will allow us to improve our service levels to our customers and bring productive and leading-edge technology to market," says CEO Doug Wright. "It will be a world-class facility, the first of its kind in China," he claims.

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

## Source Photonics adds 100G QSFP28 transceivers for OTU4 data-rate & extended-temperature operation

With the migration from 10G and 40G to 100G data rates accelerating considerably until 2020 (with over 15 million 100G ports expected to be deployed), Source Photonics Inc of West Hills, CA, USA (which provides broadband access optical components and modules) says that it has anticipated the rapid expansion in deployment of 100G modules seen during 2017 by positioning itself through early R&D and investments in operational infrastructure in 100G small-form-factor long-reach single-mode devices.

After sampling the first generation of 100GBASE-LR4 in QSFP28 form factor in 2014, Source Photonics went into full-scale production in

2015. The firm says that continuous investment in its indium phosphide (InP) fab as well as in transceiver production infrastructure has allowed it to react to the increasing volume needs as well as to the cost requirements of customers. Capacity expansion will support the production of more than half a million modules annually by early 2018.

Building on the technical 100G LR4 platform as well as production operations for complex small-form-factor modules, Source Photonics is expanding its product portfolio to address market needs for the 100G QSFP28 form factor by adding support for modules with OTU4 data-rate and extended-temperature

operation up to 85°C for 100GBASE-LR4 and 100G CWDM4 (2km) and 4WDM-10 (10km) modules. In addition, longer-reach 100G applications of up to 40km are supported by a 100G 4WDM-40 MSA-compliant module. These complementary transceivers will be available for sampling in fourth-quarter 2017 and will move to full production in first-quarter 2018.

Further R&D investments are funding multiple projects for 28Gbaud and 53Gbaud PAM4-based next-generation technology for 100G and 400G products to be released to production in 2018.

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

## Source Photonics and Credo demo single-lambda 100G connectivity over 20km of fiber with compact TOSA and ROSA assemblies

At the European Conference on Optical Communications (ECOC) in Gothenburg, Sweden (18–20 September), Source Photonics demonstrated single-lambda 100Gb/s connectivity over 20km of fiber using a compact TOSA (transmitter optical sub-assembly) and ROSA (receiver optical sub-assembly) capable of 53Gbaud PAM4 operation.

The increasing demand for more bandwidth in Cloud data centers is creating the need for more efficient and higher-throughput optical transceivers beyond the currently deployed 100G 4x25G wavelength division multiplexing (WDM) technology, states Source Photonics. The next-generation transceivers will need to support higher-order modulation techniques such as PAM4 (4-level pulse amplitude modulation) and higher-data-rate operation at 53Gbaud. The implementations that can be supported with this technology include 400G-DR4/FR4 in addition to 100G-DR/FR/LR, notes the firm.

The demonstration consists of Source Photonics internally packaged TOSA and ROSA sub-assemblies in an optical loopback configuration through 20km of single-mode fiber (SMF) using a single 100G channel of Credo's low-power PAM4 IC technology. The bit-error-rate (BER) after 20km of fiber remained better than the KP4 FEC (forward error correction) requirement and was around  $5 \times 10^{-5}$ . The TOSA is based on Source Photonics' externally modulated laser (EML) technology, which provides the necessary bandwidth to achieve a TDECQ (transmitter dispersion eye closure quaternary) value below 2.5dB. The room-temperature link budget of 10dB provides considerable margin for the most significant link specifications under development in the industry, allowing production margin for performance variations. The results show that the building blocks necessary to realize 53Gbaud single-lambda operation are available and ready to serve the needs of next-generation data-

center deployments.

The demonstration achieves with one laser and one receiver what currently requires four lasers and four receivers — facilitating not only lower-cost future 100G but also accelerating the development of 400G products, it is reckoned.

"We are continuing to invest in next-generation technology, such as single-lambda 100G, as part of our commitment to providing leading-edge solutions for data centers," says Manish Mehta, Source Photonics' executive VP, product line management.

"The hyper-scale Cloud providers have spoken and 100G per lambda solutions are a key connectivity priority," says Rajan Pai, Credo's VP of system applications. "Our unique SerDes architecture allows us to deliver single-lane 100G performance at the lowest power, which will enable the volume deployments of 100G and 400G optical modules."

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## Credo demos single-lane 100G PAM-4 for hyper-scale data-center connectivity in 100G, 200G & 400G networks

In Keysight's booth at the European Conference on Optical Communications (ECOC 2017) in Gothenburg, Sweden (18–20 September), Credo Semiconductor of Milpitas, CA, USA, which provides mixed-signal semiconductor technology for data-center, enterprise networking and high-performance computing appli-

cations, demonstrated single-lane 100G PAM-4 (4-level pulse amplitude modulation) serializer-deserializer (SerDes) performance.

Hyper-scale data-center providers view 100G-per-lambda optical connectivity as a strategic priority, says Credo. The demonstration hosted in the Keysight booth showed the

complete transmit path from two 50G PAM-4 host-side interface lanes to a single-lane 100G PAM-4 optical Tx. Implementations that can be supported with this technology include 400G-DR4/FR4 in addition to 100G-DR/FR/LR.

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

## Credo demos single-lane 50G NRZ in support of 400G CWDM8 MSA to enable deployment of 400G 2km & 10km links in data centers

At ECOC, Credo Semiconductor also demonstrated single-lane 50G NRZ (non-return-to-zero) transmission.

A device supporting CDR (clock & data recovery) functionality for 50G PAM4 host-side electrical facing interfaces to 50G NRZ optical

line-side facing interfaces is a key enabling building block for optical modules conforming to the CWDM8 MSA (8-wavelength coarse wavelength division multiplexing multi-source agreement), says Credo.

Working with Keysight, Credo showed a live demo of its low-power 50G PAM4 to 50G NRZ technology in support of the CWDM8 MSA's effort to accelerate 400G optical module deployments.

<https://cwdm8-msa.org>

## NeoPhotonics showcases 64Gbaud coherent product suite

At the European Conference on Optical Communications (ECOC) in Gothenburg, Sweden, NeoPhotonics Corp of San Jose, CA, USA showcased its suite of 64Gbaud optical components for coherent systems operating at 600G and above.

Headlining the suite is the 64Gbaud micro-modulator (Micro-MOD) with integrated drivers, which has now begun sampling. NeoPhotonics has also begun shipping its 64Gbaud micro-intradynic coherent receiver (Micro-ICR) and its low-profile ultra-narrow-linewidth tunable laser for 400G and 600G applications.

The highest data rates depend on NeoPhotonics 64Gbaud coherent product suite. 64Gbaud components double the symbol rate over standard 100G (32Gbaud) coherent systems. Higher symbol rates increase bandwidth while maintaining superior optical signal-to-noise ratio (OSNR), spectral density and reach performance. For this reason, system designers choose to move to higher baud rates before higher-order modulation when they need to increase the capacity per wavelength.

**64Gbaud Micro-MOD (CDM):** NeoPhotonics' 64Gbaud, polarization-multiplexed, quadrature micro-modulator is currently being sampled to major customers and features a co-packaged indium phosphide (InP) modulator with linear, high-bandwidth, differential drivers in a compact package to operate in 400G-and-beyond pluggable modules that demand reduced size and power consumption.

**64Gbaud Micro-ICR:** NeoPhotonics' Class 40 high-bandwidth micro-intradynic coherent receiver is in volume production and is designed for 64Gbaud symbol rates, doubling the RF bandwidth of standard 100G ICRs. The 64Gbaud Micro-ICR supports higher-order modulation such as 64 QAM (quadrature amplitude modulation).

**Low profile Micro-TL:** NeoPhotonics' ultra-narrow-linewidth external cavity tunable laser has been proven in volume production and is now configured in a smaller, lower-profile package, designed to meet the stringent requirements for packaging density in pluggable

modules (including at 400G and 600G data rates). The external cavity laser has a significantly narrower linewidth, which is advantageous for higher-order modulation formats.

"Our 64Gbaud symbol rate optical components for coherent transport provide system designers with the optical tools that match increases in DSP [digital signal processing] capability to enable higher spectral densities and longer reaches," says chairman & CEO Tim Jenks. "Each of these products is based on our hybrid photonic integration technology and leverages our existing proven design platforms, which allows us to ramp production rapidly to match customer demands while maintaining high quality and reliability," he adds.

In addition, as part of the ECOC Market Focus Program, Dr Winston Way, NeoPhotonics' chief technology officer, Systems, presented a paper 'Applications of 64 Gbaud Optical Components and Modules'.

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# Finisar demonstrates first 100G QSFP28 eSWDM extended reach and 10G tunable BiDi transceivers, as well as 100G QSFP28 ER4f transceiver

At the European Conference on Optical Communications (ECOC 2017) in Gothenburg, Sweden (18–20 September), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA demonstrated several products, including what it claims is the first 100G QSFP28 eSWDM4 transceiver offering the longest reach in the industry for multimode fiber (MMF), a 10G tunable BiDi transceiver for wireless, CATV and enterprise networks, a 100G QSFP28 ER4f transceiver supporting 40km 4WDM applications, and two new members of its optical instrumentation family.

## 100G QSFP28 eSWDM4

### extended-reach transceiver demo

As a new member of its suite of extended-reach QSFP28 form-factor modules, the 100G QSFP28 eSWDM4 transceiver leverages Finisar's SWDM4 technology and enables 200, 300 and 400m links at 100G data rates over OM3, OM4 and OM5 duplex multi-mode fiber (MMF), respectively. The module provides what is claimed to be the longest fiber reach among duplex MMF solutions in the industry for 100G QSFP28 Ethernet applications. Duplex MMF allows data-center operators to upgrade from 10G to 100G without installing extra fiber.

At ECOC, Finisar demonstrated a QSFP28 eSWDM4 module transmitting live data over 300m of OM4 MMF connected to a receiving QSFP28 eSWDM4 module. A network tester will display an error-free link using forward error correction (FEC). The new transceiver offers what is claimed to be the industry's most cost-effective 100G solution for 300m links. It interoperates with standard-reach 100G QSFP28 SWDM4 modules and can be used with existing duplex fiber infrastructure deployed for legacy applications, such as 10G.

## 10G tunable BiDi SFP+ transceiver demonstration

At ECOC, Finisar introduced what is claimed to be the industry's first tunable BiDi SFP+ transceiver for wireless and metro-access networks. The dual-band bidirectional DWDM architecture fits one pair of channels into a 100GHz band. It supports full C-band tunability with 40 bidirectional point-to-point links on a single fiber, increasing fiber capacity by a factor of 80 compared with 'grey-optics' traditionally used to serve these network applications. It can also be used within existing 100GHz DWDM fiber plants.

The dual-band bidirectional DWDM architecture uses standard C-band optics and 100GHz multiplexers and de-multiplexers without requiring cyclic AWG (arrayed waveguide grating) or L-band tunable lasers needed for conventional bidirectional DWDM solutions.

In addition, it halves the number of patch cables, simplifying field installation costs with fewer connectors. The proposed tunable BiDi SFP+ transceiver is reckoned to be the most fiber efficient and lowest-cost 10G DWDM solution on the market for end-customers.

**The 100G QSFP28 eSWDM4 transceiver leverages Finisar's SWDM4 technology and enables 200, 300 and 400m links at 100G data rates over OM3, OM4 and OM5 duplex MMF, respectively. The module provides what is claimed to be the longest fiber reach among duplex MMF solutions in the industry for 100G QSFP28 Ethernet applications**

The live demo included multiple tunable BiDi SFP+ modules supporting 40 bidirectional point-to-point links on a single fiber. A self-wavelength tuning feature using Finisar's transceiver-to-transceiver digital optical communication (T2DOC) channel technology is also being demonstrated.

## 100G QSFP28 ER4f transceiver demonstration

As the newest member of Finisar's suite of extended-reach 100G QSFP28 modules, the ER4f transceiver module enables 40km links at 100G data rates over duplex single-mode fiber (SMF) with FEC on the host, or 30km links with duplex SMF without FEC. With what is claimed to be industry-leading power consumption of less than 4W, the QSFP28 ER4f transceiver supports both Ethernet and OTU networking applications and complies with the 4WDM MSA (multi-source agreement).

The demo showcases the QSFP28 ER4f module transmitting live traffic to a receiving QSFP28 ER4f module over 40km duplex SMF. A bit error rate (BER) tester will display an error-free link post FEC. **Optical instrumentation portfolio** Finisar also demonstrated new members of the WaveShaper and WaveAnalyzer optical instrumentation portfolio. The WaveAnalyzer 100S Compact Optical Spectrum Analyzer demonstrates high-speed measurements of optical transmission signals with great resolution, including OSNR measurement and WDM analysis. The WaveShaper A-Series demonstrates arbitrary filtering of optical signals in various port configurations including 1x1, 1x19, and 10x10, each with individual amplitude and phase shapes across the wavelength range. Both products are available now.

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

## Finisar Flextone for wavelength-tunable transceiver

Finisar Corp of Sunnyvale, CA, USA has introduced Flextone, a new hardware-configurable feature that simplifies deployment of dense wavelength division multiplexing (DWDM) wavelength-tunable optical transceivers in remote PHY access networks constructed by multiple system operators (MSOs).

The industry-first Flextone feature allows up to 96 wavelength-tunable optical transceivers in a remote PHY network to self-configure their wavelengths to operate over the DWDM infrastructure without input from the host equipment nor intervention from technicians. Technicians simply insert the universal transceivers into any host port in the head-end equipment and remote PHY nodes, and connect them to any of the optical multiplexer ports with fiber optic patch cables. Firmware contained in the transceivers determines the appropriate wavelengths to link the head-end equipment to each remote PHY node.

"Wavelength-tunable optical transceivers with the Flextone enhancement significantly reduce operational expenditure for MSOs when deploying remote PHY networks," says director of product management Shawn M. Esser. "Cable operators only need to stock one universal wavelength-tunable transceiver compared to stocking many different fixed-wavelength modules. Flextone capability reduces configuration time of the transceivers for a link from hours to minutes. In addition, it simplifies installations because technicians do not have to trace fibers from the optical multiplexer to the remote PHY nodes, which could be a distance of 2km or longer."

Finisar's 10Gb/s wavelength-tunable duplex and dual-band bidirectional (BiDi) transceivers will offer the Flextone feature. The latter was introduced in September as the industry's first tunable dual-band BiDi SFP+ transceiver which fits a pair of wavelengths into each port

of standard 100GHz DWDM multiplexers and de-multiplexers. This allows 80 wavelengths to be deployed over existing 40-wavelength DWDM networks, increasing the data capacity from 200Gb/s to 400Gb/s in each direction over a single fiber without replacing the entire infrastructure. Because it only has one optical connection for the pair of wavelengths, the BiDi transceiver also halves the number of fiber optic patch cables, simplifying installation and saving space.

Finisar displayed Flextone at the Society of Cable Television's (SCTE) 2017 Cable-Tec Expo in Denver (18-20 October). The firm also displayed UltraSpan optical amplifiers which extend reaches of remote PHY access networks to 80km and longer, and coherent optical transceivers for business services that can deliver up to 200Gb/s on a single optical wavelength to enterprises.

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## Inphi launches COLORZ-Lite shorter-reach 20km 100G DWDM QSFP28 modules for campus and data-center interconnects

Inphi Corp of Santa Clara, CA, USA (a provider of high-speed mixed-signal ICs for communications, computing and data-center markets) has expanded its COLORZ portfolio with COLORZ-Lite: 100G DWDM in QSFP28 form factor for campus and data-center interconnects (DCI).

Launched at the Optical Fiber Communications (OFC 2016) trade show, COLORZ is claimed to be the first silicon photonics 100G PAM4 (4-level pulse amplitude modulation) platform solution for 80km DWDM DCI. The addition of COLORZ-Lite now offers campus and data centers a cost-optimized solution for shorter distances up to 20km. Inphi collaborated with optoelectronic component maker II-VI Inc of Saxonburg, PA, USA to demonstrate COLORZ-Lite and II-VI's Optical Line Subsystem, showcased a 20km campus DWDM link in its booth at the European Conference on Optical Communications (ECOC 2017) in Gothenburg, Sweden (18–20 September).

Cloud traffic continues to drive data-center growth, and machine-to-machine communication is increasing aggregate traffic at an even faster pace. Applications such as network virtualization are also

driving the need for low-latency requirements and pushing the need for data to be stored closer to end users. With the need to support these growing bandwidth requirements, and to reduce the bottlenecks caused by fiber exhaust, the industry requires a low-cost and high-bandwidth inter-operable solution between network elements, says Inphi. Designed for campus and data-center networks ranging up to 20km, COLORZ-Lite DWDM in QSFP28 form factor is a cost-optimized alternative solution to grey optics such as LR4, eLR4 and ER4 that is said to alleviate the fiber shortage bottlenecks and enables enterprise and cloud operators to scale their network.

"The ability to provide high-bandwidth DWDM connectivity across data centers in a campus environment enables cloud operators to rapidly scale their capacity," comments Timothy Doiron, principal analyst, Intelligent Networking practice, at ACG Research. "In a recent study, we concluded that COLORZ-Lite lowered the total cost of ownership by up to 68% in a distributed campus versus grey optics when considering the cost of leased fiber."

Leveraging its PAM digital signal processing (DSP) technology, linear drivers and transimpedance amplifiers (TIAs), Inphi has introduced a new set of 100G-capable optics optimized for the QSFP28 hot-pluggable form factor. COLORZ-Lite hot-swappable devices plug into any QSFP28 100G Ethernet port of any standard switch or router. COLORZ-Lite can support up to 40 DWDM channels on a single fiber, giving network operators a 40x increase in fiber utilization or spectral efficiency (4Tb/s versus 100Gb/s in a single fiber pair).

"COLORZ-Lite brings flexibility and ease of service delivery to cloud network operators constrained by fiber exhaust or that require extended link reaches up to 20km," says Loi Nguyen, Inphi's founder & senior VP, Optical Interconnect. "COLORZ-Lite 100G QSFP28 pluggable modules, combined with II-VI's cost-optimized optical line subsystem, enables cloud operators to scale their networks, reduce costs and increase their ease of deployment."

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## II-VI Inc announces Optical Line Subsystem platform for data-center interconnects

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has launched its Optical Line Subsystem platform for data-center interconnects (DCI), which is optimized for direct-detect DWDM transceivers, including the new COLORZ-Lite 100G PAM4 (4-level pulse amplitude modulation) based on the COLORZ silicon photonics platform from Inphi Corp of Santa Clara, CA, USA (a provider of high-speed mixed-signal ICs for communications, computing and data-center markets).

Cloud service providers require increasingly scalable, cost-effective and power-efficient solutions to meet the rapidly growing demand for DCI. II-VI's Optical Line Subsystem multiplexes, amplifies and demultiplexes multiple wavelengths of COLORZ-Lite data streams to achieve a combined transmission rate of up to 4Tb/s over a 20km reach in a compact one-rack-unit (1RU) form factor. II-VI says that this capability offers cloud service

providers and enterprise customers a cost-optimized direct-detect DWDM solution for these distances.

"The COLORZ-Lite direct-detect DWDM technology enables cloud service providers to alleviate fiber exhaust resulting from the high usage of 100G grey optics," says Dr Loi Nguyen, founder, senior VP, Optical Interconnect, at Inphi. "The key to achieving this is the II-VI Optical Line Subsystem technology, which enables the transport of direct-detect data streams at significantly lower cost points than any other competing solution," he comments.

"We have been working closely with Inphi to design from the ground up a disaggregated Optical Line Subsystem that delivers disruptive performance at a low cost," says Dr Sanjai Parthasarathi, VP, product marketing & strategy, of II-VI's Optical Communications Group. "We are uniquely positioned to deliver this high-value solution due to our vertically integrated

technology and market leadership in optical amplification, wavelength multiplexing and demultiplexing, tunable dispersion compensation, optical channel monitoring and fiber integrity monitoring," he reckons.

At the European Conference on Optical Communications (ECOC 2017) in Gothenburg, Sweden (18-20 September), II-VI's Optical Line Subsystem and Inphi's COLORZ-Lite 100G PAM4 platforms were jointly demonstrated in Inphi's booth.

In II-VI's booth it showcased new products driven by advances in its materials and technology platforms. The product showcase included subsystems solutions, highly compact optical amplifier solutions tailored to enable high-bit-rate DWDM transceivers, embedded monitoring solutions for transport networks, as well as key devices and sub-assemblies for data-center transceivers.

[www.ii-vi-photonics.com](http://www.ii-vi-photonics.com)  
[www.inphi.com](http://www.inphi.com)

## II-VI Inc presents at ECOC Market Focus on emerging highly compact amplification for coherent transmission

Dr Sanjai Parthasarathi — VP of product marketing & strategy, Optical Communications Group, at Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA — spoke in the Market Focus event (on 20 September) at the European Conference on Optical Communications (ECOC 2017) in Gothenburg, Sweden, reviewing emerging highly compact amplification solutions for coherent transmission.

High-bit-rate coherent transmission is one of the fastest-growing segments of the optical networking market, driven especially by pluggable coherent transceivers for metro and data-center interconnects. Increasingly complex

transmission formats and silicon technologies require compact, low-noise amplification to overcome modulation losses. The talk assesses emerging compact amplification solutions, focusing on enabling components such as pump lasers, hybrids, tunable filters and their integration.

At the ECOC exhibition (18-20 September), II-VI showcased the most recent additions to its portfolio of solutions for optical networks. These include:

- the small-form-factor dual interleaver platform for high-bit-rate transmission and emerging applications in optical access networks;
- the Flexible Structure Optical Module (FlexSOM) erbium-doped fiber amplifier (EDFA) platform,

designed to enable ultra-compact amplification in next-generation 100, 200 and 400G coherent transceivers; and

- the Optical Line Subsystem platform for data-center interconnects (DCI), which is optimized for direct-detect DWDM transceivers, including the new COLORZ-Lite 100G PAM4 platform from Inphi Corp of Santa Clara, CA, USA (a provider of high-speed mixed-signal ICs for communications, computing and data-center markets).

At ECOC, II-VI's Optical Line Subsystem and Inphi's COLORZ-Lite 100G PAM4 platforms were jointly demonstrated in Inphi's booth.

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# Oclaro unveils integrated coherent receiver and transmitter for 400G & 600G networks up to 64Gbaud

At the European Conference on Optical Communications (ECOC 2017) in Gothenburg, Sweden (18–20 September), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) launched photonic integrated coherent transmitters (ICTs) and intradyne coherent receiver (ICRs) for 400G and 600G applications. The components can be configured for multiple data rates, enabling users to cover a wide range of network applications from data-center interconnects (DCIs) to ultra-long-haul transmission.

“With our ICR and ICT product offerings, customers will be able to design high-performance coherent systems that are both flexible in the bandwidth offered per port and cost competitive by maximizing the data that can be carried on a single wavelength,” says Beck Mason, president of Oclaro’s Integrated Photonics business unit. “These new components leverage Oclaro’s proven expertise in photonic integration and indium phosphide technology.”

The 64Gbaud ICT combines an ultra-narrow-linewidth laser with a high-bandwidth dual QPSK Mach-Zehnder modulator to support flexible baud rates up to

64Gbaud and 64-QAM modulation. This enables transmission from 100G to 600G. Built-in semiconductor optical amplifiers (SOAs), a tunable filter and a variable optical attenuator (VOA) eliminate the need for external optical components and simplify assembly while enabling operation in colorless networks. The ICT provides a local oscillator (LO) feed with +12dBm output power for optimal receiver performance.

The 64Gbaud ICR is a fully integrated coherent receiver that supports flexible data rates from 100G to 600G. It can operate at rates up to 64Gbaud with modulation schemes such as 64-QAM. The 64Gbaud ICR has an integrated monitor photodiode (MPD) and VOA to support single-

**With our ICR and ICT product offerings, customers will be able to design high-performance coherent systems that are both flexible in the bandwidth offered per port and cost competitive by maximizing the data that can be carried on a single wavelength**

channel and multi-channel applications in colorless networks. It is compliant with the form factor specified in OIF Implementation Agreement OIF-DPC-MRX-01.0.

The 64Gbaud ICR almost doubles the bandwidth without changes in responsivity relative to 32Gbaud parts. This enables the 64Gbaud ICT-ICR pair to meet link budgets in existing networks while more than doubling the capacity. The compact form factors and integrated functionality (with no external optical components needed) of the 64Gbaud ICT and ICR pair make them suitable for the stringent size requirements on next-generation 1.2Tb SLEDs.

Oclaro expects to sample its 64Gbaud ICR and ICT products in fourth-quarter 2017.

In addition, Oclaro’s 43Gbaud ICT and ICR have been deployed in high volume for applications up to 250G/wavelength worldwide. These components are now available for use in compact form factors such as CFP-DCO and CFP2-ACO. The highly integrated 43Gbaud ICR/ICT offers what is claimed to be industry-leading performance with no need for external optical components such as erbium-doped fiber amplifiers (EDFA), VOAs or splitters.

## Oclaro showcases portfolio of 25G, 100G, 200G and 400G components, line-side modules and transceivers

At ECOC, Oclaro launched a line-up of 100G and 400G components and modules featuring the latest innovations in indium phosphide (InP) technology and photonic integration, providing increased bandwidth, smaller form factors and lower power dissipation.

“These products are key to delivering the speed, power consumption and faceplate density needed to meet the world’s explosive bandwidth demands,”

says chief commercial officer Adam Carter.

Among Oclaro’s full portfolio of components and modules for 25G, 100G & 400G, products on display at ECOC included the following:

- a 5x7-inch 400G single-wavelength coherent transponder featuring Ciena’s Waveserver 4Ai digital signal processor (DSP) chip;
- an intradyne coherent receiver (ICR) and integrated coherent transmitter (ICT) operating at

64Gbaud;

- an expanded portfolio of single-mode CFP2 transceivers supporting multiple link distances and bandwidths for the metro, long-haul, and data-center interconnect markets; and
- a full suite of QSFP28 single-mode transceivers, including ones that support the new 4WDM MSA Group’s 10, 20 and 40km specifications.

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

## Emcore begins customer sampling of OBI-mitigated RFoG optical networking unit transceiver

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 — is sampling its new radio-frequency-over-glass (RFoG) optical networking unit (ONU) transceiver with key customers for qualification.

Announced at the ANGACOM 2017 Exhibition & Congress for Broadband, Cable and Satellite in Cologne, Germany at the end of May, the new RFoG ONU transceiver is an optical beat interference (OBI)-mitigated design utilizing the firm's linear externally modulated laser (L-EML). The unit was showcased, along with Emcore's complete line of CATV network solutions, at the SCTE's 2017 Cable-Tec Expo in Denver, CO (18–20 October).

RFoG technology enables cable multiple service operators (MSOs) to offer a fiber-to-the-premise (FTTP)-type architecture without changes to standard equipment in the head-end or central office. As subscriber density increases however, OBI signal degradation can present challenges to overall system performance. Emcore says that its RFoG ONU transceiver overcomes those obstacles by eliminating the

effects of OBI through proprietary upstream laser wavelength management, significantly improving RFoG network performance in high-density customer environments.

The RFoG ONU transceiver is compliant with the SCTE (Society of Cable Telecommunications Engineers) RF-over-glass specification. It is designed to support standard CATV downstream and upstream transmission bands for voice, video and data signals in single-family and multiple-dwelling unit applications. Downstream it receives a 1550nm forward-path optical signal carrying an RF cable television spectrum up to 1.2GHz, making it compatible with the cable industry's DOCSIS 3.1 standard. For return path, it supports digital upstream transmission operating at 1610nm that supports a 5–85MHz spectrum.

"Key customers are excited to sample the unit for qualification within their systems," says VP of marketing Gyo Shinozaki. "The combination of OBI mitigation and an economically compelling solution make this an attractive option for RFoG."

At the Cable-Tec Expo, Emcore also showcased its latest DOCSIS 3.1, 1550nm CATV transmitters utilizing the L-EML technology with a rack-

mount system display featuring the Medallion 8100 1550nm CATV transmitter, Medallion 7000 series CATV fiber amplifier and 2100 optical A/B switch. In addition, the firm is displaying its new, compact 1.2GHz, 1550nm L-EML-based mini-transmitter card subassembly designed for a range of CATV applications. Emcore will also feature its latest high-density laser package technology with the forthcoming XMD, which incorporates the firm's proven 1550nm QAM laser technology into an ultra-compact form-factor that is about a third the size of Emcore's classic 14-pin butterfly laser module.

"Adoption of our L-EML technology continues at a rapidly expanding rate and our new 'mini-Tx' subassembly provides all the core elements required for designers to quickly integrate the L-EML device technology into a variety of CATV transmitter platforms," says senior product line director Grant Olecko. "Everyday the true benefits of linear fiber optics to the node in HFC [hybrid fiber coaxial] networks becomes more apparent compared to baseband digital links being evangelized by some in the industry," he adds.

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

## Oclaro enters high-volume production of single-carrier 400G/lambda lithium niobate modulator

Oclaro Inc of San Jose, CA, USA (which makes components, modules and subsystems for optical communications) has announced volume production of its lithium niobate (LiNbO<sub>3</sub>) polarization-multiplexed quad Mach-Zehnder (PM-QMZ) modulators, which enable data rates up to 400G on a single wavelength, allowing users to quickly and cost effectively transition to faster network architectures for growing bandwidth demands.

"Oclaro has a proven history in delivering high-speed, high-volume lithium niobate external modulators that customers need to deploy high-bandwidth coherent networks up to 400G," says Beck Mason, president of Oclaro's Integrated Photonics business.

The single-carrier PM-QMZ LiNbO<sub>3</sub> external modulator is a high electro-optic bandwidth PM-QMZ device that integrates into a hermetic package an input beam splitter, four parallel

Mach-Zehnder modulators configured for I-Q modulation, a polarization combiner, and monitor photodiodes for power and bias control. Key features of the modulator include: a 3dB electro-optic bandwidth exceeding 30GHz; an extinction ratio above 25dB (to enable complex modulation formats); insertion loss below 12dB for high efficiency; and support for L-band operation (similar to all other Oclaro LiNbO<sub>3</sub> modulators).

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

# Fraunhofer ISE lays cornerstone for Center for High-Efficiency Solar Cells

Construction of new €32.6m lab building to be completed by end 2019

Fraunhofer Institute for Solar Energy Systems ISE in Freiburg, Germany has laid the cornerstone of its new Center for High-Efficiency Solar Cells, which is financed by a total of €32.6m from the federal government and the state government of Baden-Württemberg. Construction is scheduled to be completed by the end of 2019.

Over the past 15 years, the photovoltaics market has grown by more than 30% per year, with the costs of PV modules declining by more than 80% over the same period. Yet the potential for photovoltaics is far from exhausted, says Fraunhofer ISE. Research and industry are working hard to further improve efficiency and reduce the costs of solar cells while also addressing aspects of sustainable production.

Fraunhofer ISE recently set several records for solar cell efficiencies: 22.3% for multicrystalline silicon solar cells; 25.8% for a monocrystalline cell based on TOP-Con technology, and (exceeding the limits of silicon as a material) 31.3% efficiency for a tandem solar cell comprising a III-V multi-junction solar cell on a silicon cell. With its III-V multi-junction concentrator solar cell, the institute also achieved the overall record for photovoltaic efficiency at 46.1%.

## Adjusting infrastructure to meet challenges

Building on this foundation, the new Center for High-Efficiency Solar Cells will replace the outdated cleanroom for solar cell development with infrastructure equipped for the next generation of solar cells. "In designing the new cleanroom facilities, we were able to adjust the infrastructure to meet the latest technological challenges," says director Dr Andreas Bett. "We are grateful to the Federal Ministry of Education and Research (BMBF)



Image of the Center for High-Efficiency Solar Cells on the Fraunhofer Institute for Solar Energy Systems ISE campus on Berliner Allee.



Cornerstone laid for the Center for High-Efficiency Solar Cells at Fraunhofer ISE. From left to right: Georg Brechensbauer of Brechensbauer Weinhart + Partner Architects, professor Alfred Gossner, Executive Board Fraunhofer-Gesellschaft, MinDirig Günther Leßnerkraus, Ministry for Economic Affairs, Labor and Housing, Baden-Württemberg, professor Margit Zacharias, VP for Innovation and Technology Transfer, University of Freiburg, professor Stefan Glunz, Head of Division, Photovoltaics, Fraunhofer ISE, professor Hans-Martin Henning, Director Fraunhofer ISE, Dr Andreas Bett, director Fraunhofer ISE.

and the Federal State of Baden-Württemberg for financing the new laboratory building," he adds.

"When it comes to the cost-effective realization of the energy transition, our energy system analyses make clear that photovoltaics and

wind energy will be the pillars of our future energy supply," says professor Hans-Martin Henning, the other director under Fraunhofer ISE's new joint leadership system.

Fraunhofer ISE is making a "major contribution to the affordability and success of the energy transition," comments Baden-Württemberg's Minister of Economic

Affairs, Labor and Housing Dr Nicole Hoffmeister-Kraut. "The new Center for High-Efficiency Solar Cells is an important element in maintaining this position."

[www.ise.fraunhofer.de/en/press-media/press-](http://www.ise.fraunhofer.de/en/press-media/press-)



# Solar-Tectic granted US patent for low-cost, high-efficiency III-V thin-film tandem solar cell on glass substrate

Solar-Tectic LLC of Briarcliff Manor, NY, USA says that the US Patent and Trademark Office has granted it US patent 15/205,316 'Method of Growing III-V Semiconductor Films for Tandem Solar Cells' for high-efficiency and cost-effective solar cells made on glass or flexible plastic substrates for various industrial applications, such as rooftops to help charge battery-powered electric automobiles (EVs). The technology also promises to be useful in manufacturing LEDs. The inventor is CEO Ashok Chaudhari.

The patent (the first ever for a thin III-V layer on crystalline silicon thin-film) covers group III-V compounds such as gallium arsenide (GaAs) and indium gallium phosphide (InGaP) for the top layer, as well as all inorganic materials, including (silicon, germanium etc) for the bottom layer. In the patented technology, ultra-thin films of III-V materials and silicon (or germanium) replace expensive, thicker wafers, lowering costs dramatically.

III-V tandem (or multi-junction) cells fabricated on wafers such as silicon are being developed with high efficiencies of about ~30%. The highest dual-junction cell efficiency (32.8%) came from a tan-

dem cell that stacked a layer of GaAs atop crystalline silicon. Manufacturing costs are expensive, especially if a germanium wafer is used as the bottom material in the two-layer tandem structure. To compete with low-cost silicon wafer technology (which comprises 90% of the global solar panel market), efficiencies must not only be as high as silicon wafers or greater (lab records of 21.7% and 26.7% for poly- and monocrystalline silicon-based cells, respectively) but manufacturing costs must also be lower.

Solar-Tectic says that this is achievable in the patented technology, which uses common industrial manufacturing processes and at low temperature. There is no wafer involved, which saves material and energy. Instead, a thin film allows precise control of growth parameters. A glass substrate instead of a wafer also allows for a bifacial cell design for increased efficiency.

A cost-effective ~30%-efficient III-V tandem solar cell in today's market could dramatically reduce the balance of system (BoS) costs and reduce the need for fossil-fuel-generated electricity, says the firm. Silicon wafer technology based on

polycrystalline or monocrystalline silicon could become obsolete, it adds.

Importantly, the entire patented process for the III-V tandem cell can be environmentally friendly, since non-toxic metals can be used to deposit the crystalline thin-film materials for both the bottom layer in the tandem configuration as well as in the top III-V layer, notes Solar-Tectic.

The firm adds that the technology also has great promise for LED manufacturing using, for example, gallium nitride.

Solar-Tectic has launched a Tandem Series of solar cell technologies, which includes a variety of different proven semiconductor photovoltaic materials for the top layer on silicon and/or germanium bottom layers. Recently, patents were also granted for a tin perovskite and germanium perovskite thin-film tandem solar cell.

The US International Trade Commission (ITC) ruling on 22 September means that it is likely that tariffs will be imposed on crystalline silicon wafers sold in the USA. However, these tariffs will not apply to thin-film solar cell technology such as Solar-Tectic's, the firm notes.

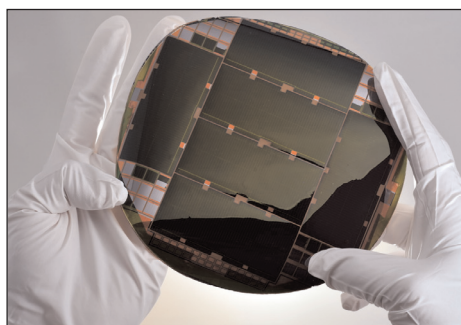
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# MicroLink signs exclusive license agreement to manufacture NREL IMM solar cell technology

MicroLink Devices of Niles, IL, USA has entered into an exclusive license agreement to commercialize the patented inverted metamorphic multi-junction (IMM) solar cell technology of the US Department of Energy's (DOE) National Renewable Energy Laboratory (NREL). The IMM solar cell architecture enables the manufacture of solar cells with very high efficiency as well as light weight (ideal for powering satellites and solar aircraft).

As the most efficient solar cells, multi-junction solar cells based on germanium substrates have historically been used exclusively in very high-performance satellite applications. The IMM design is an innovative approach to further improve efficiency by integrating an optimum combination of three or more compound semiconductor materials. IMM multi-junction solar cells are manufactured by depositing thin layers of semiconductor on a substrate such as gallium arsenide (GaAs). A metamorphic buffer layer enables the growth of junction materials with optimum bandgaps for energy conversion, such as indium gallium arsenide (InGaAs), that are not lattice-matched to the GaAs substrate. MicroLink has



**A 6-inch MicroLink high-efficiency, lightweight and flexible ELO IMM solar cell wafer.**

demonstrated an efficiency of 32.3% under 1-sun AM0 using an IMM design.

IMM solar cells are synergistic with MicroLink's proprietary epitaxial lift-off (ELO) technology, which has been under development for the past ten years. Using the ELO process, MicroLink can peel off thin layers of active solar cell material that were deposited on the GaAs substrate. Removing the substrate enables the fabrication of solar cells with exceptional light weight and specific powers greater than 3000W/kg. The substrate can also be used multiple times to lower manufacturing costs. The development of MicroLink's ELO technology was sponsored by numerous US

agencies including NASA, DARPA, the Air Force Research Laboratory, the Office of Naval Research, NAVAIR, Army Research Office, Army REF, CERDEC, and the DOE.

"We have been working for more than a decade on the scale-up and manufacturing of this design, which enables us to provide very compelling solar solutions for powering high-altitude long-endurance (HALE) aircraft and space satellites," says MicroLink's president & CEO Dr Noren Pan.

MicroLink has previously announced a production contract to provide ELO multi-junction solar sheets to Airbus Defence and Space for use on the Zephyr's HALE platform. The Zephyr is a new class of unmanned air vehicle (UAV) that operates as a high-altitude pseudo-satellite (HAPS), enabling affordable, persistent, local satellite-like services. The aircraft runs exclusively on solar power, and the Zephyr aircraft is at the forefront of the HAPS arena, holding world records with regards to absolute endurance (more than 14 days) and altitude (over 70,000 feet).

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

[www.defence.airbus.com/portfolio/uav/zephyr](http://www.defence.airbus.com/portfolio/uav/zephyr)

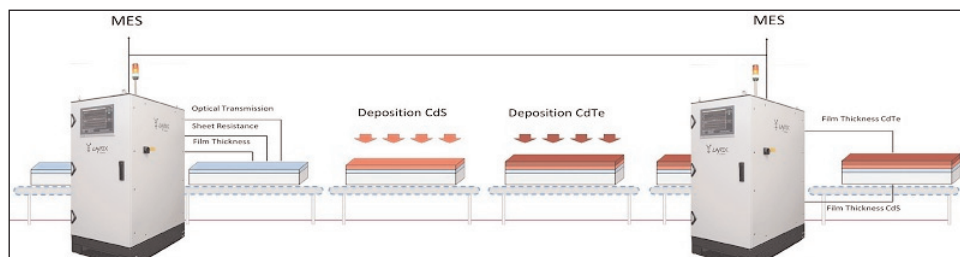
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# LayTec ships ILMetro in-line metrology station to China's CTIEC for CdTe-based thin-film PV

In-situ metrology system maker LayTec AG of Berlin, Germany has shipped two ILMetro in-line metrology stations to its customer CTIEC — part of China National Building Materials Group Corp (CNBM) — which has established a cadmium telluride (CdTe) thin-film photovoltaic (PV) production line in Chengdu based on technology developed by its German subsidiary CTIEC/CTF Solar.

The two 24/7 ILMetro inline metrology stations are fully integrated into the fab's manufacturing line and MES manufacturing execution system (see Figure).

ILMetro station #1 ensures 100% quality control of the incoming transparent conductive oxide (TCO)-coated solar glass substrates. It hosts a Suragus EddyCus in-line sheet-resistant unit and a LayTec Flames spectroscopic multi-head reflectance and transmittance system. Combining Eddy-current and spectral-optical methods provides full and automated statistical process control (SPC) of all key performance parameters of the TCO glass. The measured SPC data of station



Two ILMetro stations fully integrated into CTIEC's CdTe PV manufacturing line.

#1 are forwarded both to the fab's MES system and to station #2.

ILMetro station #2 combines a LayTec Flames system (a multi-head optical metrology system for monitoring multi-layer thin-film structures in large area processes) with a LayTec SolR metrology system (an in-line, contactless, fast-probing white-light reflectance measurement system, capable of measuring the properties and thickness of all layers throughout thin-film solar cell manufacturing processes, including TCO and absorber and buffer layers). Multiple optical heads detect infrared (IR) and visible-near-infrared (vis-NIR) spectral reflectance from the front side and from the back side of the CdTe thin-film PV modules.

The resulting thickness uniformity of the CdTe absorber layers and of the very thin cadmium sulphide (CdS) buffer layers again are permanently reported with high accuracy to the fab's MES system.

LayTec says that the ILMetro in-line metrology stations meet the IP54 and CE standards and are equipped with the necessary multiple interfaces for communication with the conveyor systems, third-party visual inspection systems as well as the fab's MES and local-area network (LAN) automation system. Remote service and software maintenance is provided through a firewalled LAN.

[www.ctf-solar.de](http://www.ctf-solar.de)

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

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

## BASF and SoloPower launch CIGS PV-based multi-layered roofing system combining power generation, waterproofing and water harvesting

Chemical firm BASF and SoloPower Systems of Portland, OR, USA, which designs, manufactures and deploys copper indium gallium diselenide (CIGS) flexible thin-film solar technology, have launched a seamless and multi-layered roofing system that combines energy efficiency, power generation, waterproofing and water harvesting.

Including roof panels, waterproofing membrane and solar panels, the system can be up to 60% lighter than conventional roofs due to the lightweight construction

materials throughout its design.

"The ability of this roof to combine, in a single product, best-in-class thermal insulation, water harvesting and solar power generation puts it ahead of the pack in generating both environmental benefits and rapid payback for customers," claimed SoloPower's chairman Neil Auerbach at the launch event.

"Incorporating existing technology from Germany and the United States, we have customized the system to enable optimum usage for climatic zones in South Africa,"

says Angus Peruzzo, managing director of BASF Construction Chemicals South Africa. Using composite structural insulated panels provides a cost-effective way to comply with the national energy-efficiency regulations South African National Standards (SANS) 10400XA. "Our collaboration with SoloPower and the launch of this multi-layered system will enable energy and other resources to be harnessed more efficiently for the long-term," Peruzzo adds.

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

# Deep-ultraviolet gallium nitride quantum dots in aluminium nitride

Internal quantum efficiency reaches 40% with 219nm-wavelength emission — 2x highest reported for aluminium gallium nitride alloy quantum wells.

Cornell University and University of Notre Dame in the USA have achieved 40% internal quantum efficiency (IQE) for 219nm-wavelength deep-ultraviolet (UV) emissions from gallium nitride/aluminium nitride (GaN/AlN) heterostructures, according to temperature-dependent photoluminescence studies [S. M. Islam et al, Appl. Phys. Lett., vol111, p091104, 2017]. The researchers say that the 40% IQE is more than two times the highest reported value for AlGaIn QW-based heterostructures at comparable short deep-UV wavelengths.

The researchers hope that their work will lead to rugged, portable, high-efficiency semiconductor light

sources for deep-UV applications such as water/air purification, bio-photonic diagnostics, sterilization, food preservation, security and environment monitoring, and industrial curing.

Alloys of GaN and AlN cover the spectral range 365–205nm with energy bandgaps that support photon emissions between 3.4eV (GaN) and 6.02eV (AlN). The Cornell/Notre Dame team used GaN quantum dots (QDs) separated by AlN barriers to increase photon energies and shorten wavelength.

The molecular beam epitaxy (MBE) was carried out on 1 $\mu$ m AlN on sapphire templates (Figure 1). The templates were prepared in the MBE chamber by

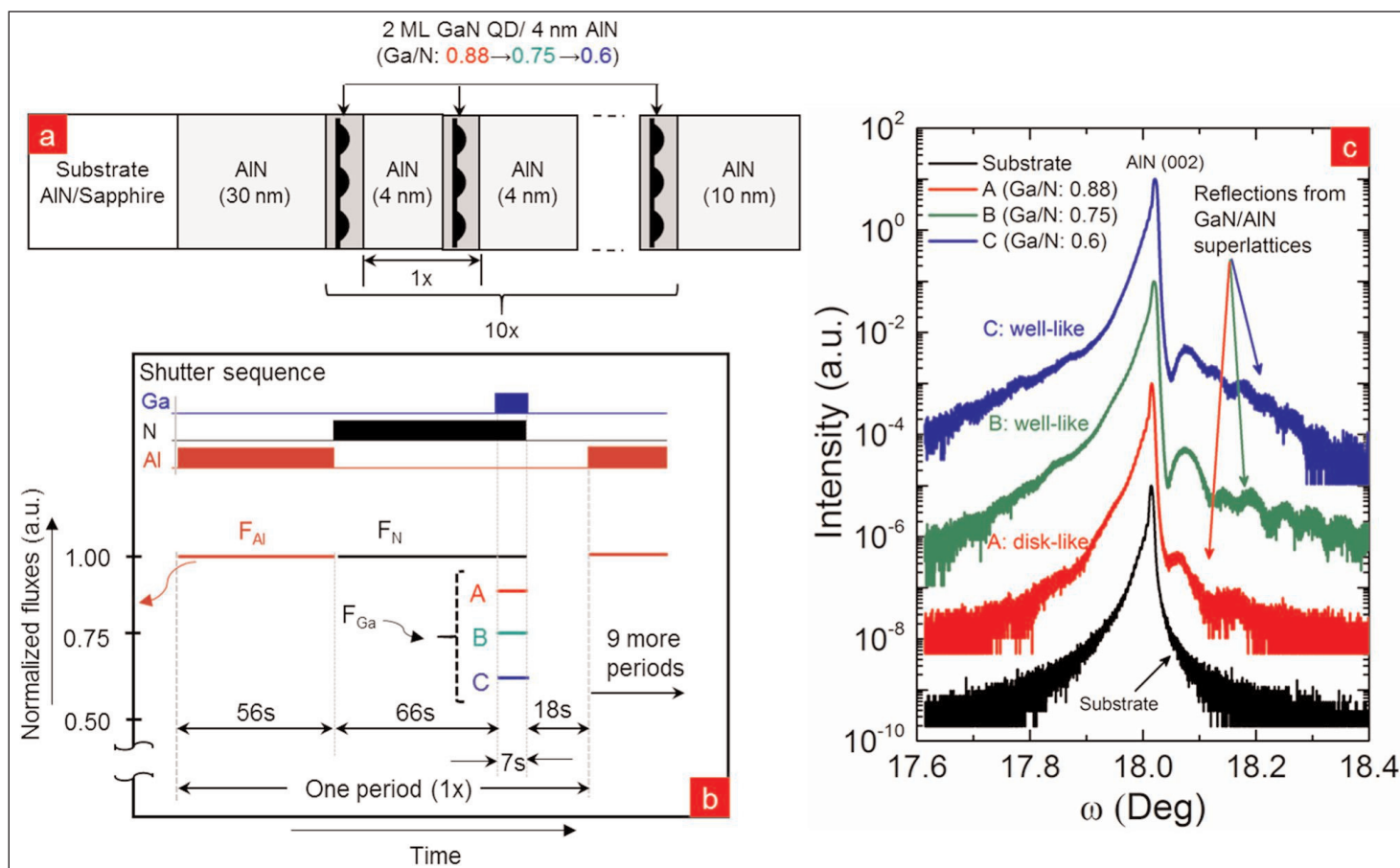
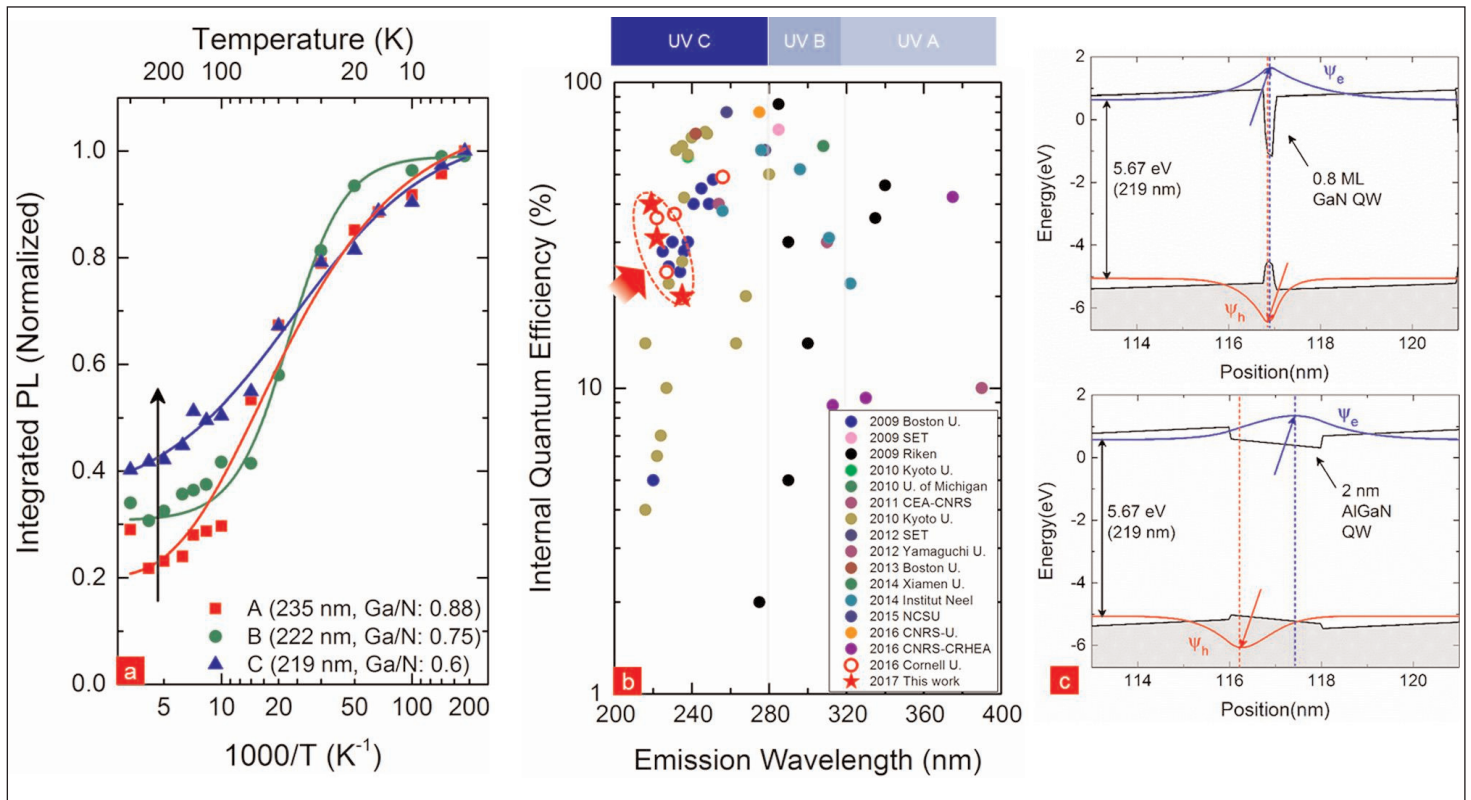


Figure 1. (a) Schematic of structure with 10 periods of ultra-thin GaN QDs in AlN barriers, (b) MBE growth diagram showing shutter sequence and relative III-V fluxes for 1 period of growth, and (c) high-resolution X-ray diffraction (HR-XRD)  $\omega$ - $2\theta$  scans showing signature of QD formation for sample A.



**Figure 2. (a) Estimation of IQE from temperature-dependent integrated PL spectra (solid lines are shown as guide), (b) comparison of measured IQE with AlGaIn based QWs, and (c) enhancement of IQE using GaN QWs due to reduced QCSE.**

7 hours outgassing at 200°C, and 2 hours at 450°C. The QDs were formed by depositing two monolayers of GaN separated by 4nm AlN barriers at 730°C. The barriers were grown using migration-enhanced epitaxy. Ten layers of QDs were grown on 30nm AlN buffer.

Stranski–Krastanov layer-plus-island growth was ensured by creating nitrogen-rich conditions through opening the Ga and N shutter simultaneously for 7 seconds. Dots were formed by interrupting the growth for 18 seconds after the GaN layer deposition, allowing the layer to decompose into islands.

The emission wavelength was dependent on the Ga/N ratio during MBE. X-ray analysis suggested sharp heterointerfaces between GaN and AlN material, with no intermixing to form AlGaIn alloy.

At 5K temperature, the photoluminescence (PL) from the samples showed peaks at 234nm (A), 222nm (B), and 219nm (C) wavelengths. These short wavelengths constitute the highest reported photon energy emissions from GaN to date, 5.67eV for 219nm wavelength, according to the researchers. Raising the temperature to room conditions (300K) red-shifted the peaks by about 4nm.

**The reduction of the GaN QW/QD thickness enhances the overlap integral, reversing the trend of decreasing IQE at shorter wavelengths. The emission matrix element is converted to surface emission**

Comparison with theoretical simulations suggested effective GaN thicknesses at 1.4 monolayer (A), 1ML (B) and 0.8ML (C). In line with these estimates, the PL intensity was lower for the shorter-wavelength and smaller GaN volumes of sample C. The simulations also suggested the confined structure was robust against the quantum-confined Stark effect (QCSE). In other words, the electric fields arising from spontaneous and strain-dependent charge polarization effects did not significantly reduce the overlap of the electron and hole wavefunctions. Large overlap is required for effective photon emission.

The simulations also resulted in estimates for linewidth broadening of 6nm (A), 30nm (B), and 36nm (C), which compared with actual measurements of 9nm (A), 20nm (B), and 19nm (C).

The IQE was estimated from the ratio of the 300K/5K PL, giving 20% for sample A and 40.2% for sample C (Figure 2). The researchers attribute the high IQE to the reduction of QCSEs. In contrast to AlGaIn quantum well PL, the IQE trend increases for shorter wavelengths. The researchers add: "This is achieved because the reduction of the GaN QW/QD thickness enhances the overlap integral, reversing the trend of decreasing IQE at shorter wavelengths. Furthermore, the emission matrix element is converted to surface emission, which is highly desirable for light extraction." ■

<http://dx.doi.org/10.1063/1.5000844>

Author: Mike Cooke

# LED lighting module market growing at 22.6% CAGR from \$4bn in 2016 to \$13.8bn in 2022, driven by mid-power modules

**Module makers are seeking higher-margin new applications as general lighting penetration leads to intense price pressure and competition, says Yole.**

**T**he LED lighting module market (including flexible LED strips) reached nearly \$4bn in 2016 and is rising at a compound annual growth rate (CAGR) of 22.6% during 2017–2022 to \$13.8bn, boosted by the emergence of innovative functions and the introduction of new segments including the automotive, smart lighting and horticultural markets, according to Yole Développement's new report 'LED Lighting Module Technology Industry & Market'.

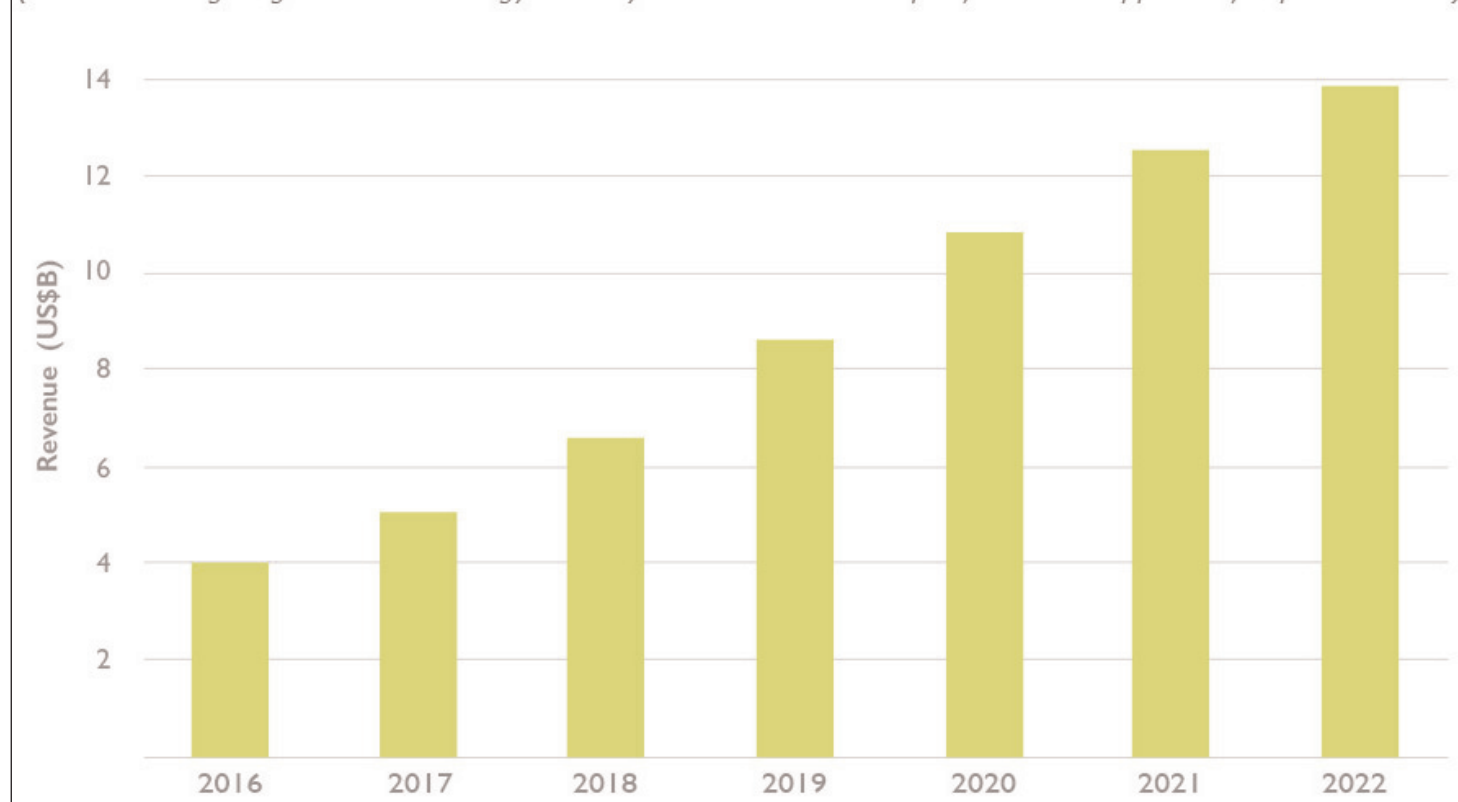
"LED technology is increasingly penetrating general lighting applications, thanks to how easily integrators can use it," says Pierrick Boulay, technology & market analyst, Solid-State Lighting.

General lighting is not a 'blue ocean market' any more, due to strong price pressure and intense competition between LED players. LED module makers are therefore seeking growth engines, following the example provided by the packaged LED industry a few years ago.

LED companies are hence diversifying their activities and seeking market opportunities. These emerging market segments (including horticultural lighting, automotive lighting and smart lighting) are going beyond visible light into the infrared (IR) or ultraviolet (UV) parts of the spectrum. All of these applications are attractive since they yield much higher profit margins compared with general lighting applications.

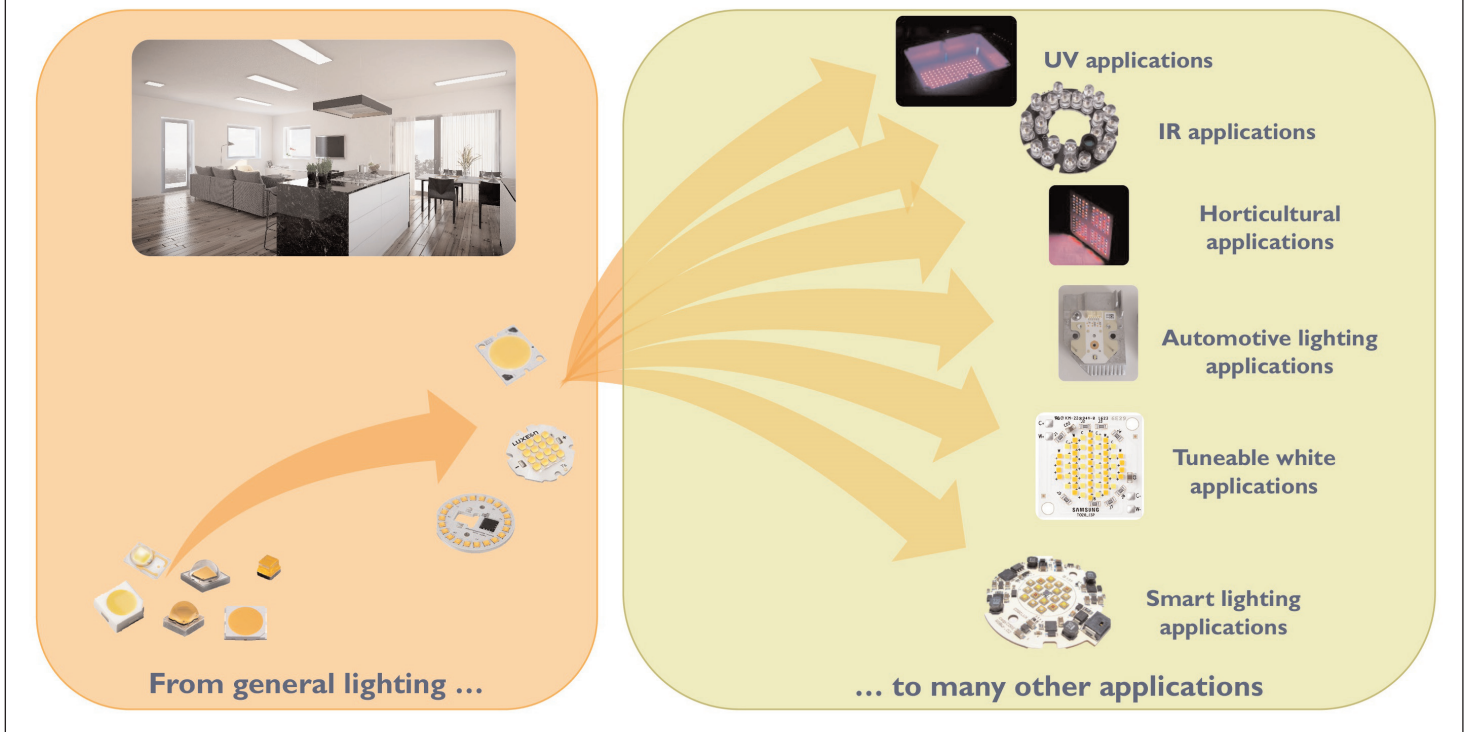
## LED lighting module market revenue forecast

(Source: LED Lighting Module Technology Industry and Market Trends report, Yole Développement, September 2017)



## From general lighting to many other applications

(Source: LED Lighting Module Technology Industry and Market Trends 2017 report, Yole Développement, September 2017)



The modules used in these applications require a high level of expertise, strong industrial knowledge, and technical skills, says Yole. So, LED module makers targeting these new applications are betting that integrators will not have the competences needed. In addition, high market demand will help them to move higher up the value chain.

"A good example is Everlight," says Boulay. "Initially positioned as a light source supplier, it then started developing COB [chip-on-board] technology. It is now seeking to enter the automotive lighting business, positioning itself as an advanced module supplier."

In parallel, beyond visible light, UV and IR LED modules are increasingly being used, pushed by rapidly growing applications like UV curing and IR surveillance cameras. Large numbers of LEDs are used in each module, and thermal management is crucial for performance, especially for UV applications.

Driven by mid-power modules, this industry will treble in

**Beyond visible light, UV and IR LED modules are increasingly being used, pushed by rapidly growing applications like UV curing and IR surveillance cameras. Large numbers of LEDs are used in each module, and thermal management is crucial for performance, especially for UV applications**

value in the next five years, it is forecast. Mid-power LEDs can therefore be used in almost all applications. In 2016, mid-power LED modules drove the market, providing 60% of revenue. In contrast, high-power LEDs are used only in applications requiring high luminous flux in a small module. As a result, the number of applications using high-power LED modules is limited and represents only 7% of revenues.

COB LED modules provide a compromise on size, light-emitting surface (LES) area, luminous flux and power consumption. They are therefore suitable for many applications, and lead the overall LED module market in volumes shipped. However, as these modules are relatively easy to manufacture in few steps, the associated average selling price (ASP) is low. Consequently, COB LED modules represent only 20% of market revenue.

In addition, flexible LED strips can be used directly as LED lighting systems, mostly in indirect lighting applications. Such modules can be easily implemented for residential and commercial lighting. Recent developments, like using LED chips instead of packaged LEDs on a flexible substrate, allow much higher efficiency, opening doors to new applications such as linear lighting, says Yole.

Yole participated in the LED Professional Symposium (LpS 2017) in Bregenz, Germany, at which Solid-State Lighting business unit manager Pars Mukish gave a presentation on '2017 LED Industry Update: Highlights and Future trends'. ■

[www.yole.fr/LED\\_Modules\\_MarketTrends.aspx](http://www.yole.fr/LED_Modules_MarketTrends.aspx)

# Automotive lighting market growing at 5.7% CAGR from \$27.7bn in 2017 to \$35.9bn in 2022

**Faster-than-expected growth being driven by widespread LED adoption, says Yole Développement.**

The automotive lighting market is rising at a compound annual growth rate (CAGR) of 5.7%, from \$25.7bn in 2016 to nearly \$27.7bn in 2017 and \$35.9bn in 2022, estimates market research firm Yole Développement in its report 'Automotive Lighting: Technology, Industry and Market Trends 2017'.

Growth is driven by natural LED cost erosion, increasing the LED penetration rate. Standardization of LED modules and their optimization are key factors behind the decreasing costs. This has resulted in more vehicles equipped with LED technology, says the report.

The automotive lighting market is facing unexpectedly fast growth combined with a technology revolution that will reshape the industry, says Yole. Since the first

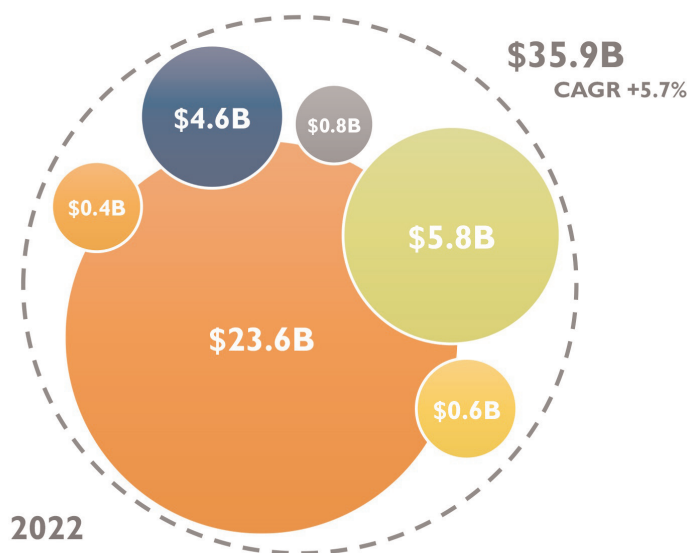
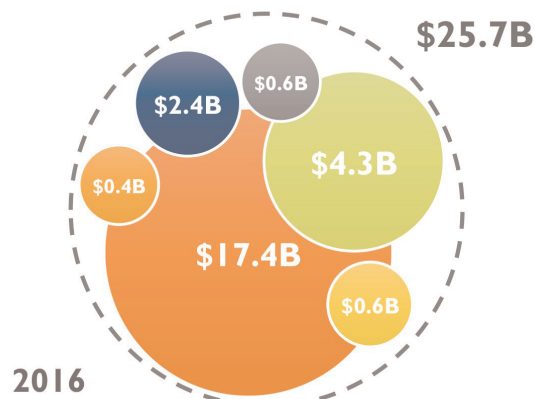
full LED headlamp was introduced in 2007, LED technology has gradually penetrated headlamp design. LED technology has allowed lighting to become a distinctive feature and enabled innovative functions such as glare-free adaptive high beam, introduced in 2013. The use of LED technology had been limited to high-end vehicles and has had to compete with traditional light sources, namely halogen and high-intensity discharge (HID/Xenon). Improved LED performance, lower power consumption and flexible design were the first enablers. Then, cost reductions helped LED technology to spread to all vehicle categories.

Automotive lighting is driven by exterior lighting and especially headlamps, generating more than two-thirds

## Automotive lighting market size 2016-2022

(Source: Automotive Lighting: Technology, Industry and Market Trends 2017 report, Yole Développement, October 2017)

- Headlamp
- Rear lighting
- Interior lighting
- Small lamps
- CHMSL\*
- Fog lamps

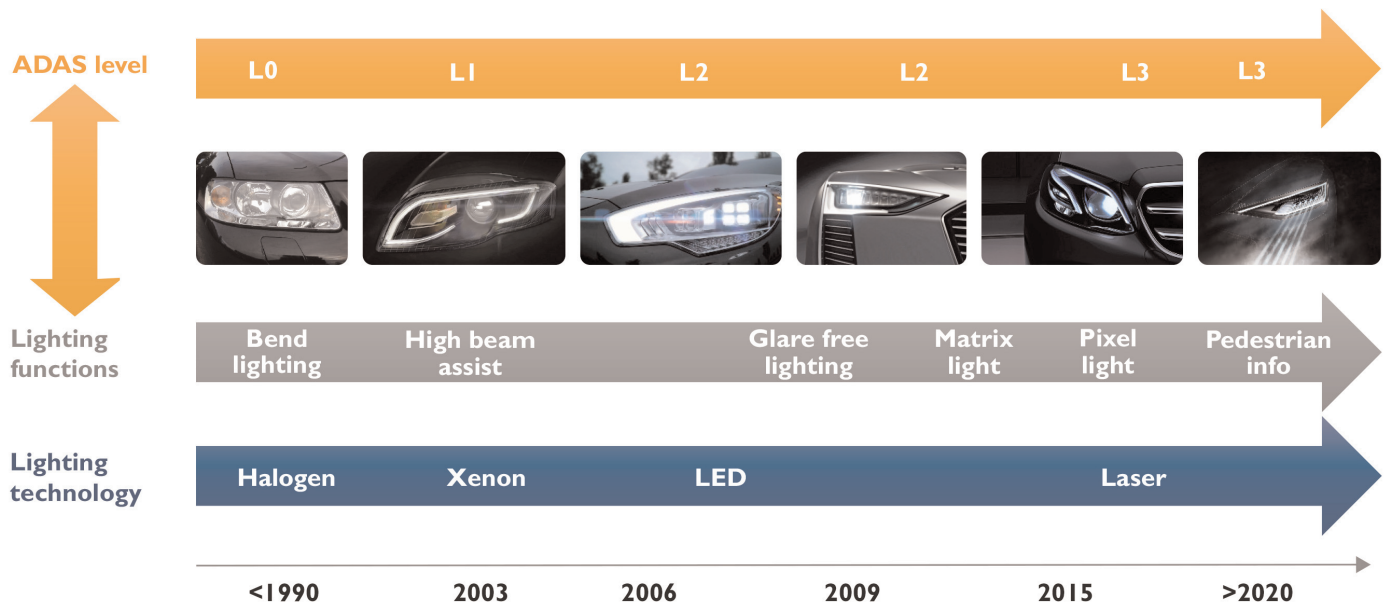


\*Center High Mounted Signal Light



## Synergies between ADAS and lighting technologies since the 90s

(Source: Automotive Lighting: Technology, Industry and Market Trends 2017 report, Yole Développement, October 2017)



ADAS levels: L0: Driver only - L1: Driver assistance - L2: Partial automation - L3: Conditional automation - L4: High automation - L5: Full automation

of total market revenue. Rear lighting is the second largest area, at 17%. Interior lighting represents almost 10% of revenue, but growth is expected to be linked to the development of autonomous vehicles and the creation of vehicles as 'living homes'. Other types of lighting, such as fog lamps, center high-mounted signal light (CHMSL) or small lamps, comprised the remaining 7% of revenue in 2016.

"More than 100 million vehicles will be sold in 2022, but this has only a limited impact on the lighting market," comments technology & market analyst Pierrick

Boulay. "The main reason for lighting growth is that the penetration of LED technology is spreading from high-end cars to mid-range and low-end cars," he adds. "LED technology propagation and more generally SSL [solid-state lighting] technologies will enable the development of new functionalities."

Yole will attend ForumLED 2017 in Lyon, France (13-14 December), where business unit manager Pars Mukish is chairing a session 'The market for LED lighting: State of the art & market trends' on 13 December (11am). [www.yole.fr/AutomotiveLighting\\_MarketTrends.aspx](http://www.yole.fr/AutomotiveLighting_MarketTrends.aspx)

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# Thinning p-type III-nitride layers to enhance effects of surface plasmons

**Researchers claim record-high modulation bandwidth in c-plane light-emitting diodes.**

National Taiwan University has used a magnesium pre-flow during epitaxy to enhance hole concentrations in aluminium gallium nitride (AlGaN) electron-blocking layers in indium gallium nitride (InGaN) light-emitting diodes (LEDs) [Chia-Ying Su et al, Optics Express, vol25, p21526. 2017]. This enabled thinner p-type GaN layers and thus boosted the effect of surface plasmon (SP) structures on LED performance. In particular, a record-high modulation bandwidth of 625.6MHz for c-plane InGaN LEDs is claimed. High modulation bandwidth is desired for visible-light communication application.

Surface plasmons are delocalized electron density oscillations. SP coupling to InGaN quantum wells (QWs) can enhance internal quantum efficiency, while reducing droop effects and increasing bandwidth. Coupling is naturally enhanced as the SPs and QW come into closer proximity. This is achieved by reducing the thickness of the intervening p-type layers from the typical 150nm to the range 38–78nm. Usually the p-GaN layer has to have a certain thickness to ensure adequate current spreading. Thinner p-GaN layers tend to increase turn-on voltage and differential resistance.

The Mg pre-flow also reduces the barrier to injection into the QW active region. The researchers comment: "In this situation, although a decrease of the p-GaN layer may still have the effects of increasing turn-on voltage and differential resistance, the significant enhancement of hole injection efficiency can compensate the performance degradation due to the decrease of p-GaN thickness."

Epitaxial material for the LEDs came from metal-organic chemical vapor deposition (MOCVD) on c-plane sapphire (Figure 1). The growth of the 18nm p-AlGaN EBL was preceded by a bis(cyclopentadienyl)magnesium (Cp2Mg) pre-flow step at 220 standard cubic centimeters a minute (sccm).

|                   |                     |               |
|-------------------|---------------------|---------------|
| Cap               | p <sup>+</sup> -GaN | 10nm          |
| Contact           | p-GaN               | 10nm-50nm     |
| Electron blocking | p-AlGaN             | 18nm          |
| Barrier           | GaN                 | 25nm-5nm=20nm |
| Quantum well      | InGaN               | 3nm           |
| Barrier           | GaN                 | 15nm          |
| Contact           | n-GaN               | 2μm           |
| Buffer            | Thin undoped GaN    |               |
| Substrate         | c-plane sapphire    |               |

**Figure 1. Epitaxial structures of LED.**

The pre-flow was carried out with the Ga and Al precursors off, but with the ammonia (NH<sub>3</sub>) nitrogen precursor on. During pre-flow the NH<sub>3</sub> decomposed, creating hydrogen that etched back the top GaN barrier by about 5nm, reducing the final thickness to 20nm.

For the p-GaN growth the flow of Cp2MG was increased to 280sccm. The 10nm p<sup>+</sup>-GaN cap used a 800sccm Cp2Mg flow. The substrate temperature during the pre-flow and p-type layers was 970°C.

Reference (R) LEDs were fabricated with 10μm-radius circular mesas. The p-contact pad was not put on the small mesa, but rather supported on a silicon dioxide layer with minimized parasitic capacitance. The p-contact — 20nm/100nm nickel/gold — covered about 80% of the mesa, with the remaining 20% covered with 5nm/5nm nickel/gold for current spreading.

LEDs with surface plasmon structures used 250°C molecular beam epitaxy (MBE) to deposit 10nm gallium-doped zinc oxide (GZO) as a current-spreading layer. The SP structure consisted of silver (Ag) nanoparticles (NPs) and a further current-spreading

layer of 5nm/5nm titanium/gold. The p-contact consisted of 20nm/100nm nickel/gold.

The GZO blue-shifts the silver nanoparticle SP resonance wavelength towards that of the blue emissions of the LEDs at ~465nm (Figure 2). The silver nanoparticles were formed by depositing a 2nm silver layer and then annealing at 250°C for 30 minutes in nitrogen atmosphere.

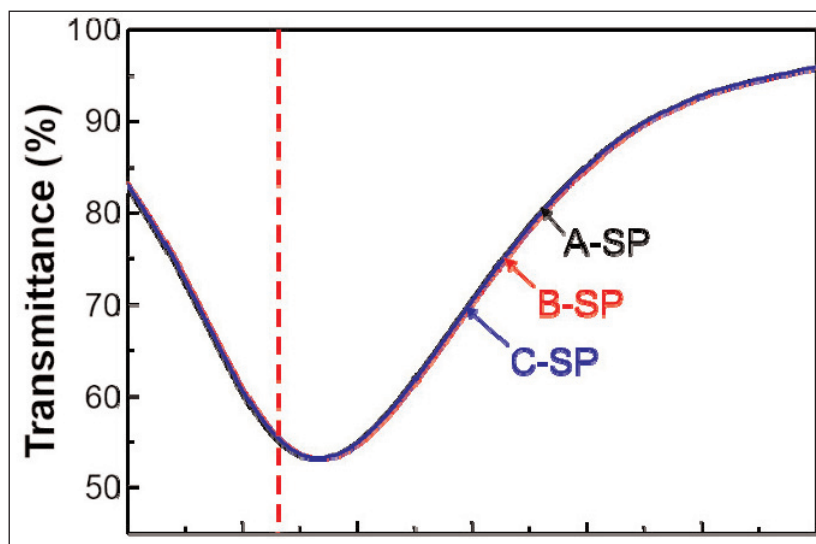
The researchers comment: "It is noted that the SP resonance peak in the current work does not well coincide with the QW emission wavelength, as shown in [Figure 2]. A careful adjustment of Ag NP size can blue-shift the SP resonance peak for further increasing the SP coupling strength at the designated QW emission wavelength (465nm). In this situation, the modulation bandwidth can be further increased."

The n-contacts of the LEDs consisted of 20nm/100nm titanium/gold.

The 970°C growth of the p-type layers also annealed the underlying InGaN single quantum well, reorganizing the indium-rich cluster structures that can lead to higher than expected internal quantum efficiency (IQE) through carrier localization. However, too much annealing can degrade the crystal structure in the quantum well, reducing IQE.

The IQE of the various devices was estimated by comparing the room-temperature photoluminescence (PL) with that at 10K (assumed to be 100% IQE). Shorter anneal times were found to result in higher IQEs (Table 1). The presence of Ag NPs gave significant SP enhancement, particularly with reduced distance to the QW. The decay of time-resolved PL was also faster with SP structures.

The improved IQE of the SP-LEDs resulted in brighter electroluminescence. The droop in wall-plug efficiency (WPE) from the peak value was also less severe in the SP devices. The researchers comment: "It is noted



**Figure 2. Transmission spectra of samples A-SP, B-SP, and C-SP. Vertical dashed line indicates QW emission wavelength around 465nm.**

that the injected current density for the maximum efficiencies in the samples under study ( $1\text{kA}/\text{cm}^2$ ) is generally higher than that usually reported in literature. This is so because the mesa size of the used samples is smaller at  $10\mu\text{m}$  in radius. The smaller device size leads to a weaker heating effect and hence reduces the droop behavior caused by heating."

The shorter PL decay time is reflected in higher modulation bandwidths, with the highest value higher than 600MHz: "In sample C-SP, we can reach the modulation bandwidth of 625.6MHz, which is believed to be the highest ever reported in a c-plane GaN-based surface-emitting LED (~100MHz higher than our previous record of 528.8MHz)." The improvement over the reference samples is close to the square-root of the enhanced decay rate in the PL studies. ■

<https://doi.org/10.1364/OE.25.021526>

Author: Mike Cooke

**Table 1. Structures and performance of LED samples.**

| Sample  | A-R          | A-SP         | B-R          | B-SP         | C-R          | C-SP         |
|---|--------------|--------------|--------------|--------------|--------------|--------------|
| p-GaN thickness   |              |              | 50nm         | 50nm         | 30nm         | 30nm         |
| Distance between Ag NPs and QW                              |              |              | —            | 108nm        | —            | 88nm         |
| High-temperature 970°C growth duration                      | 881s         | 881s         | 803s         | 803s         | 726s         | 726s         |
| IQE   | 26.4%        | 38.6         | 28.7         | 49.4         | 31.5         | 57.3         |
| SP IQE enhancement factor                                   | —            | 1.46         | —            | 1.72         | —            | 1.82         |
| PL decay time   | 2.88ms       | 1.35ms       | 2.76ms       | 1.20ms       | 2.63ms       | 1.02ms       |
| Square-root of SP decay enhancement                         | —            | 1.46         | —            | 1.52         | —            | 1.61         |
| Normalized output intensity at $3.185\text{kA}/\text{cm}^2$ | 1            | 1.67         | 1.19         | 2.06         | 1.30         | 2.48         |
| SP enhancement  | —            | 1.67         | —            | 1.73         | —            | 1.91         |
| Droop range at $3.185\text{kA}/\text{cm}^2$                 | 45.8%        | 27.1%        | 38.3%        | 22.1%        | 33.0%        | 16.2%        |
| SP change   | —            | -41%         | —            | -42%         | —            | -51%         |
| Resistance  | $44.8\Omega$ | $42.3\Omega$ | $45.6\Omega$ | $43.2\Omega$ | $46.5\Omega$ | $44.3\Omega$ |
| Modulation bandwidth at $9.555\text{kA}/\text{cm}^2$        | 349.7MHz     | 516.5MHz     | 367.2MHz     | 559.6MHz     | 385.7MHz     | 625.6MHz     |
| SP enhancement  | —            | 1.48         | —            | 1.52         | —            | 1.62         |

# InGaN quantum dot microcavity light emission

**Electrical pumping results in radiation wavelengths covering 129nm range from yellow-green to violet.**

**R**esearchers in China have developed tunable indium gallium nitride (InGaN) quantum dot (QD) microcavity (MC) visible light emitters with a 129nm wavelength range from yellow-green to violet from electrical pumping [Yang Mei et al, Appl. Phys. Lett., vol111, p121107, 2017]. The device included distributed Bragg reflectors (DBR) forming the Fabry-Perot cavity.

The team from Xiamen University, East China Normal University, Suzhou Institute of Nano-tech and Nanobionics (SINANO) and China Academy of Engineering Physics comment: "As the first electrically driven III-V nitride semiconductor based tunable MC light emitter with a tuning range of 129nm, the device is promising for applications such as in wide-gamut compact displays and projectors."

The researchers also believe that biomedical, mood-lighting, and broad-band communication applications could benefit from monolithic broadband and wavelength tunable light sources.

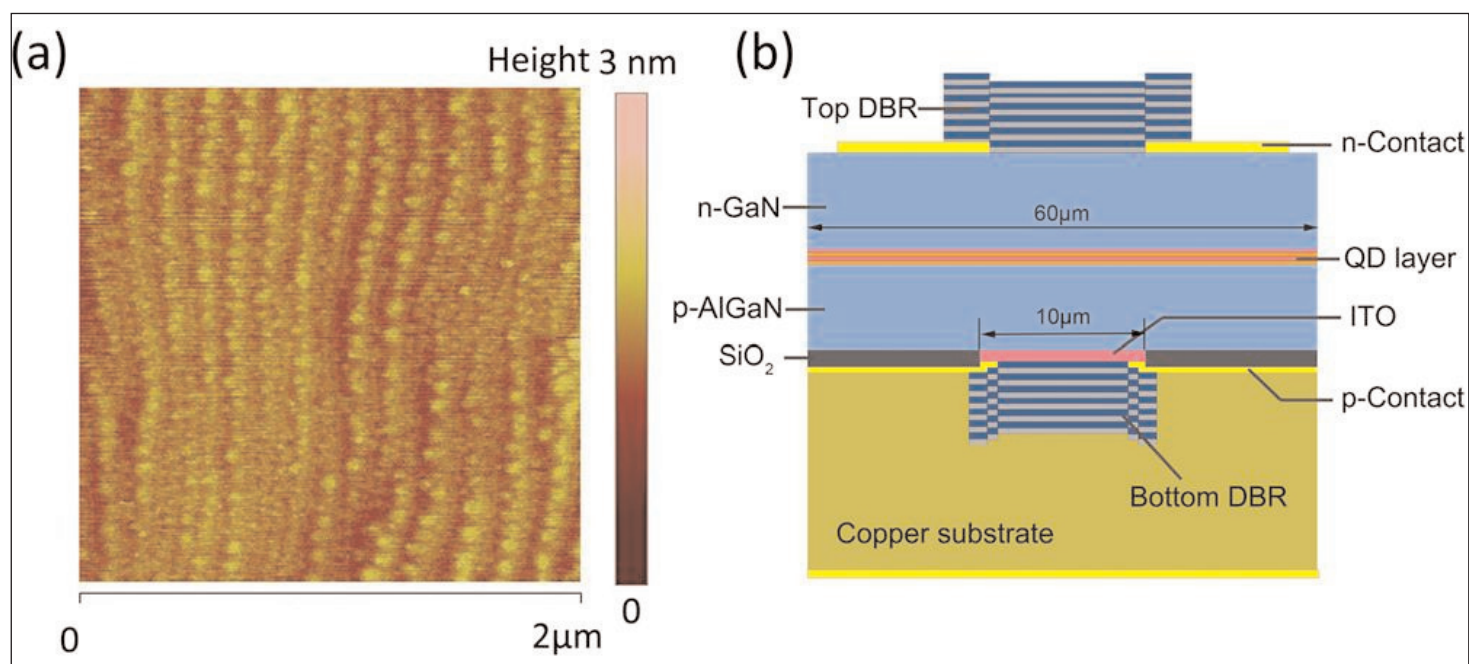
The semiconductor material (Table 1) was grown on (0001) c-plane sapphire using metal-organic chemical vapor deposition (MOCVD). The QD layer was grown in

**Table 1. Detailed structure of epitaxial wafer.**

| Layer structure           | Composition   | Thickness (nm) |
|---------------------------|---|----------------|
| Substrate                 | Flat sapphire   |                |
| u-GaN                     | u-GaN   | 1000           |
| n-GaN                     | n-GaN   | 4000           |
| Lower cladding layer      | n-Al <sub>0.1</sub> Ga <sub>0.9</sub> N                 | 800            |
| Lower waveguide layer     | n-In <sub>0.03</sub> Ga <sub>0.97</sub> N               | 130            |
| Active layers (2 periods) | In <sub>0.27</sub> Ga <sub>0.73</sub> N/GaN             | 2.5/10         |
| Upper waveguide layer     | p-In <sub>0.03</sub> Ga <sub>0.97</sub> N               | 85             |
| Electron-blocking layer   | p-Al <sub>0.2</sub> Ga <sub>0.8</sub> N                 | 25             |
| Upper cladding layer      | p-Al <sub>0.1</sub> Ga <sub>0.9</sub> N                 | 600            |
| Contacting layer          | p <sup>++</sup> In <sub>0.12</sub> Ga <sub>0.88</sub> N | 20             |

Stranski-Krastanov mode at 670°C for high indium content. The subsequent GaN barrier was applied in two steps: at 670°C as a 2nm-thick matrix for the QDs to inhibit indium desorption, and then ramped up to 850°C for the 8nm barrier material.

The QD density was  $\sim 1.5 \times 10^{10}/\text{cm}^2$ . The indium content was 27%. The dot diameters ranged between



**Figure 1. (a) Atomic force microscope  $2\mu\text{m} \times 2\mu\text{m}$  image of uncapped QDs. (b) Cross-sectional schematic of fabricated InGaN QD MC light emitter.**

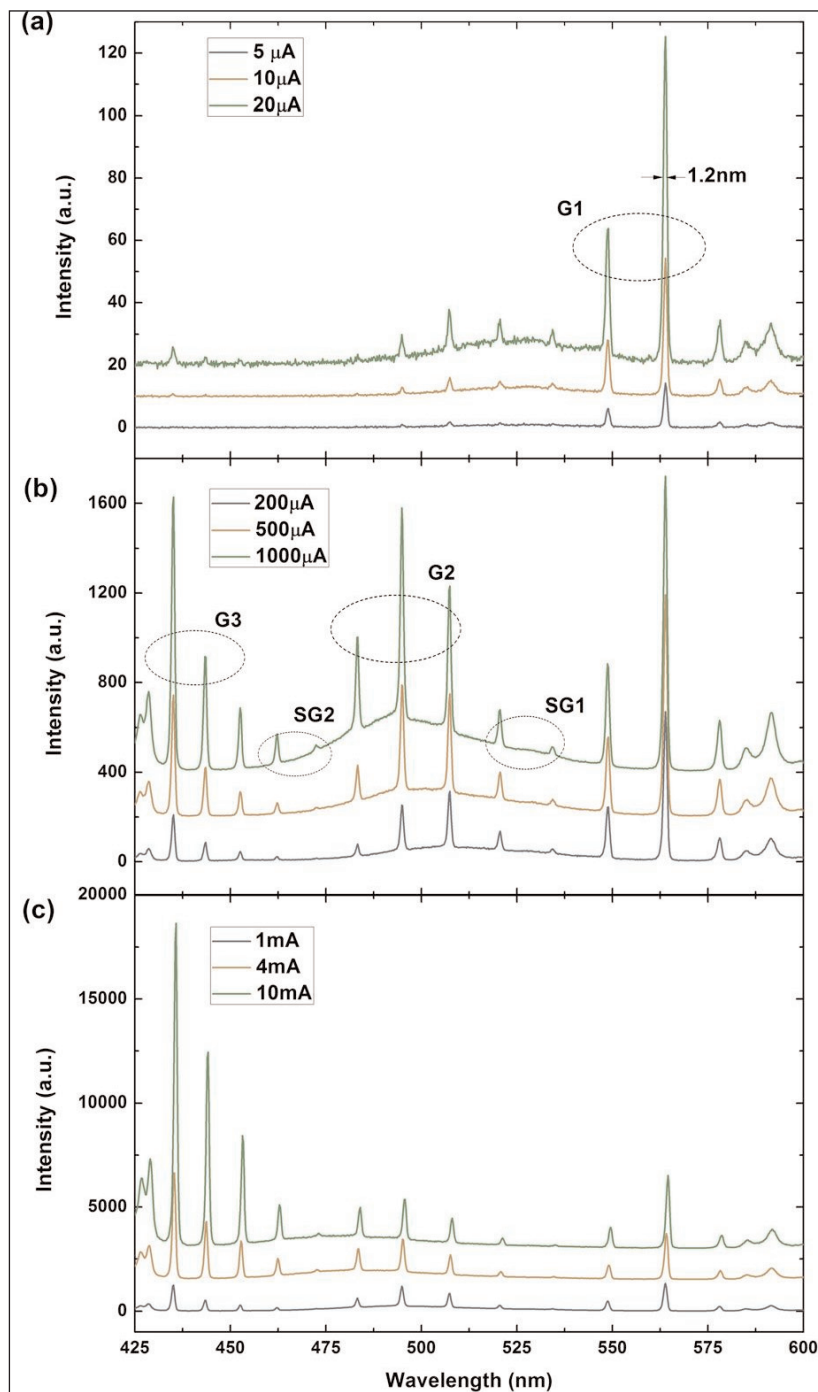
20nm and 60nm. The heights averaged  $\sim 2.5$ nm. Photoluminescence showed a broad spectrum with emissions between 420nm and 600nm wavelength. The spread is attributed to variations in dot size and InGaN composition. As the pump power increased there was a blue shift in the spectrum caused by broadening in the small-wavelength region. The researchers attribute this to band filling effects making the bandgap effectively wider.

The electrically pumped MC light emitter (Figure 1) was fabricated first by depositing a 30nm indium tin oxide (ITO) current/spreader layer and ohmic contact on the p-GaN surface of the semiconductor material. The ITO was patterned into a  $10\mu\text{m}$  circular disk to give a narrow current flow path. Silicon dioxide ( $\text{SiO}_2$ ) was applied to confine the current aperture to the ITO region. The p-contact electrode consisted of chromium/gold deposited on the  $\text{SiO}_2$  in a ring that contacted with the ITO. The p-side of the device was completed with 12.5-layer-pairs of tantalum oxide ( $\text{Ta}_2\text{O}_5$ ) and silicon dioxide formed into a  $15\mu\text{m}$ -diameter DBR and  $150\mu\text{m}$ -thick electro-plated copper.

The n-side was fabricated by removing the sapphire growth wafer through laser lift-off and thinning down to the n-GaN with inductively coupled plasma etch and chemical mechanical polishing (CMP). The n-contact electrode was again chromium gold. The top DBR consisted of 11.5-pairs of  $\text{Ta}_2\text{O}_5/\text{SiO}_2$ . The devices were singulated using inductively coupled plasma etch.

Electrical injection without the n-side DBR gave an emission spectrum that was modulated by interference from reflection between the bottom DBR and top GaN/air interface. At low current injection of  $\sim 20\mu\text{A}$ , the emission was dominated by longer wavelengths between 540nm and 570nm. At higher currents the dominant region blue-shifted to 480–520nm. The researchers attribute the changes to the carrier capture and emission properties of the dots with larger QDs dominating at low current and smaller ones at high current. There was a gap in the emissions in the range 530–540nm.

Cavity effect became more obvious when the second DBR was added. The linewidths were 1.14nm, close to the 1nm limit of the spectrometer. The mode spacings suggested a cavity length of  $4.5\mu\text{m}$ , around 18 wavelengths. The cavity's quality factor (Q) was around 495. The wavelength composition of the emissions at low current grouped around 560nm (G1, Figure 2). Shorter-wavelength components at  $\sim 500$ nm (G2) and  $\sim 440$ nm (G3) emerge at higher current. The three groups are approximately equal in intensity at around



**Figure 2. Electroluminescence spectra of MC light emitter at (a) low, (b) medium, and (c) high injected current. All spectra offset along y-axis for clarity.**

1mA injection. At 20mA, the emission from G3 was about 7x that from G1.

The 129nm tuning range covered the range from 564nm (yellow-green) to 435nm (violet). The emissions were suppressed around 530nm (SG1) and 470nm (SG2). Simulations suggest that the high emission regions G1-3 correspond to the active QD region being at anti-nodes of the standing waves in the cavity. By contrast, the suppressed groups SG1-2 correspond to the QDs being at nodes of the radiation field. ■

<http://dx.doi.org/10.1063/1.4994945>

Author: Mike Cooke

# Step-flow growth of green-emitting indium gallium nitride quantum wells

**Increased quantum efficiency reduces threshold current of laser diode structures.**

University of Chinese Academy of Sciences has improved green light internal quantum efficiency from indium gallium nitride (InGaN) quantum wells (QWs) by increasing the miscut angle of the gallium nitride template to encourage step-flow growth [Aiqin Tian et al, Appl. Phys. Lett., vol111, p112102, 2017].

The researchers claim that step-flow QWs have not been achieved up to now for green light-emitting InGaN. Instead, green InGaN QWs tend to be formed from two-dimensional (2D) island growth.

The team was partly motivated by the desire for improved green light performance in laser diodes (LDs) for pico-projectors and displays. Indeed, the work included the fabrication of laser diodes with reduced threshold current.

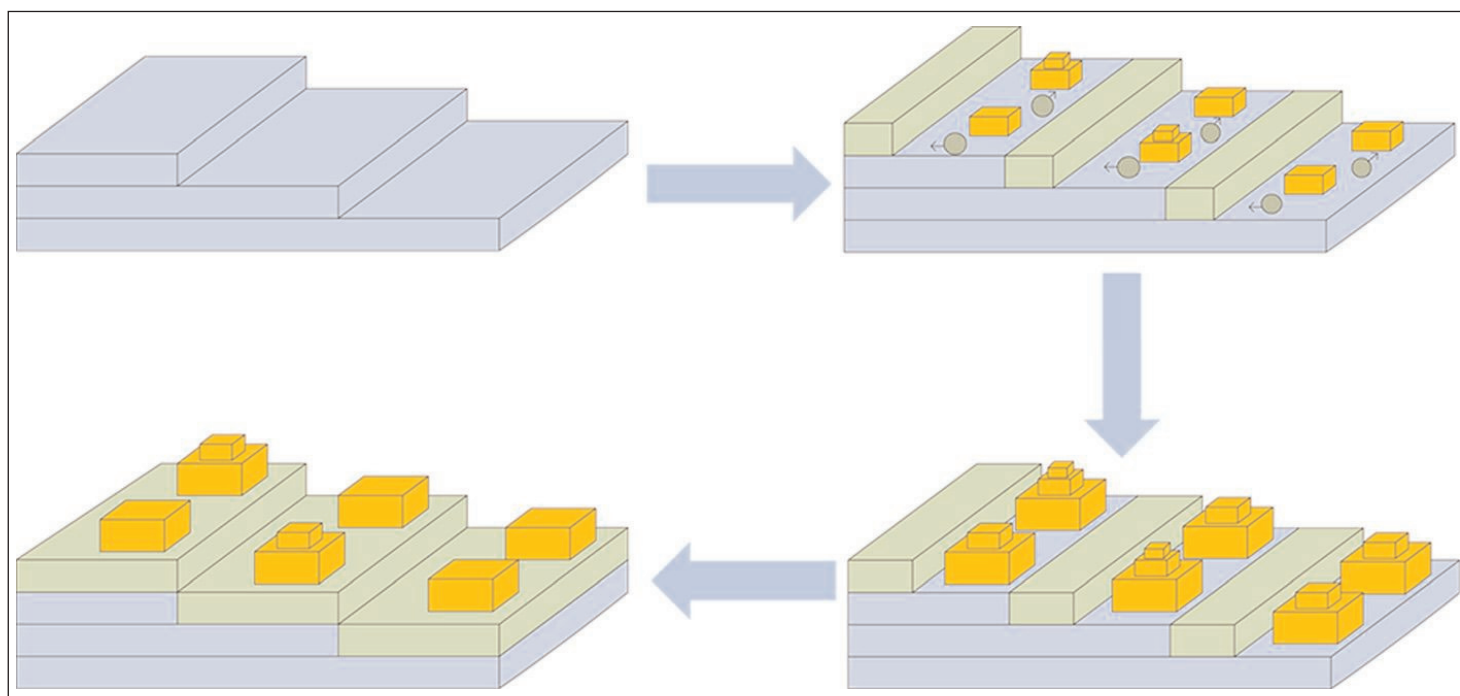
The InGaN QWs were grown on a  $2\mu\text{m}$  n-GaN buffer by low-pressure metal-organic chemical vapor deposition. The QWs consisted of 2.5nm InGaN layers grown at  $688^\circ\text{C}$ , while the separating GaN barriers were grown at  $850^\circ\text{C}$ .

Ammonia was used for the nitrogen precursor. The gallium component came from trimethyl-gallium for the barriers and buffer and triethyl-gallium for the wells. The indium source was trimethyl-indium.

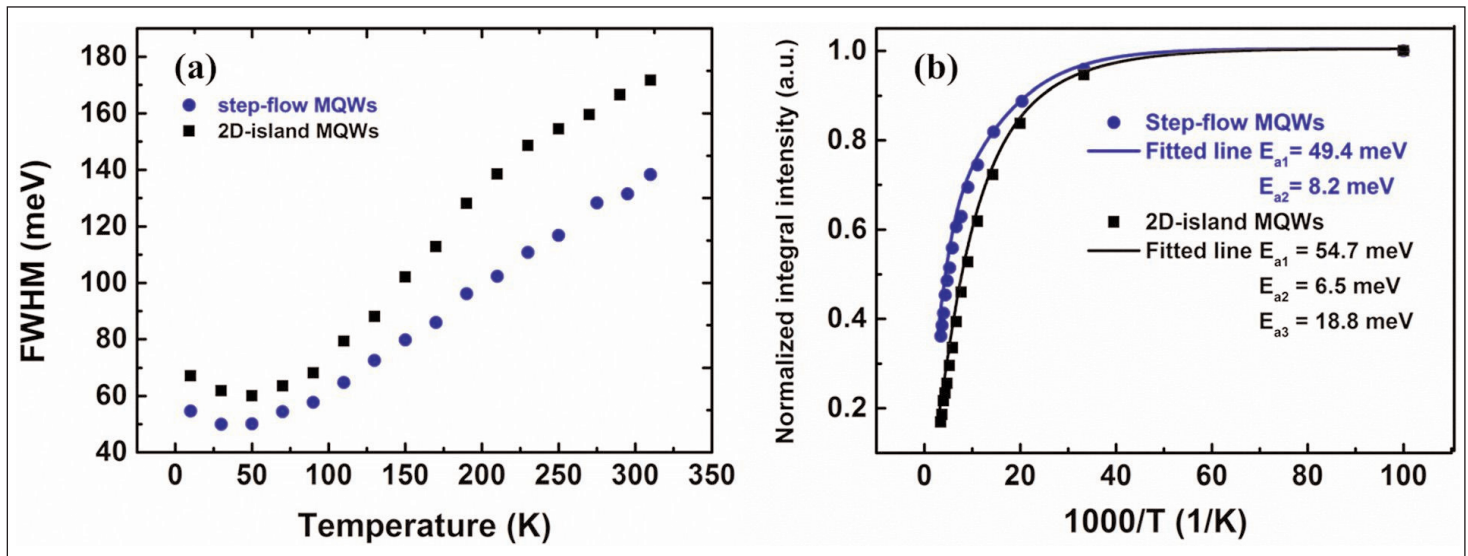
High-quality step-flow growth for 27%-indium-content green QWs was encouraged by increasing the miscut angle of the GaN/sapphire template from  $0.20^\circ$  to  $0.48^\circ$ . This reduced the step terrace width from  $\sim 80\text{nm}$  to  $\sim 30\text{nm}$ , respectively (Figure 1). This decreased the distance that adatoms had to diffuse on the surface before being incorporated into the step growth front.

The lower growth temperatures needed for high-indium-content InGaN reduces the diffusion distance of adatoms. Blue InGaN QWs with 16% In could be grown at  $710^\circ\text{C}$  and  $0.20^\circ$  miscut angle. Higher temperatures increase diffusion distances. Optimized GaN growth occurs at temperatures around  $1050^\circ\text{C}$ .

Low-temperature growth with insufficient miscut leads to two-dimensional island or even three-dimensional growth, which can be indicated through increased surface roughness.



**Figure 1. Schematic of 2D island InGaN QW growth on miscut template with large terraces.**



**Figure 2. (a) Temperature dependence of FWHM values of green MQW samples. (b) Normalized temperature-dependent integral PL intensity.**

Green InGaN 4-period multiple QWs (MQWs) had x-ray diffraction (0002) peak full widths at half maximum (FWHMs) of 351arcsec and 381arcsec for 0.48° and 0.20° miscuts, respectively. The narrower peak suggests sharper well/barrier interfaces from the higher crystal quality achieved through step-flow growth.

Room-temperature photoluminescence (PL) peaks were observed at 2.313eV and 2.309eV for 2D island and step-flow MQWs, respectively. The FWHMs of the peaks were temperature dependent (Figure 2), decreasing to a minimum as the temperature increased to 50K. The room-temperature FWHMs were 131meV for step-flow MQWs and 166meV for 2D island structures.

The researchers comment: "The smaller FWHM value indicates better potential uniformity, which is beneficial for the improvement of the peak gain of green laser diodes and is believed to result partially from the sharper well/barrier interface, consistent with the XRD result. The indium composition homogeneity may also have improved as a result of the step-flow morphology, but this requires further study."

Comparing the PL at 10K and room temperature, the internal quantum efficiencies (IQEs) were estimated at

30% and 15% for the step-flow and 2D island samples, respectively. The researchers attribute the IQE improvement for step-flow growth to "better material quality and fewer non-radiative recombination centers in the step-flow MQW sample".

Temperature-dependent PL analysis suggested also three non-radiative recombination centers in the 2D island sample with activation energies of 54.7meV, 6.5meV and 18.8meV. For the step-flow growth, only two non-radiative recombination centers with 49.4meV and 8.2meV activation were sufficient to fit the data.

The centers with the highest activation energies were attributed to dislocations. The 6.5meV and 8.2meV centers were due to defect formation at the InGaN QW interface, it is suggested. Finally, the 18.8meV center in the 2D island sample is seen as being the factor that significantly reduces IQE.

Laser diodes fabricated from these materials demonstrated the benefit of step-flow growth with reduced threshold current at 300mA, compared with 500mA for the 2D island laser diodes. The researchers attribute this reduction to the improved IQE for step-flow material. ■

<http://dx.doi.org/10.1063/1.5001185>

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# Boosting speed & breakdown voltage performance of Schottky barrier diodes

**Mike Cooke** reports on recent developments with GaAs and III-nitride devices.

Schottky barrier diodes (SBDs) are often used in electronics circuits aiming to benefit from low turn-on voltages and high speed.

The fabrication of Schottky rather than pn diodes allows the turn-on voltage to be reduced significantly below that suggested by the bandgap energy. This particularly impacts gallium nitride (GaN) devices, since the large  $\sim 3\text{V}$  turn-on of pn diodes leads to large power losses in switching applications. However, Schottky diodes tend to have lower breakdown voltages and higher on-resistance than pn devices. Improving breakdown with thicker drift layers tends to increase on-resistance.

High speed arises from the domination of current flow by majority carriers so that switching does not have to wait for the recombination of electron and holes. However, as frequencies increase to the terahertz and sub-millimeter-wave-length level, fabrication becomes challenging due to the more restricted size of the device and high sensitivity to parasitic elements.

Here we look at recent research progress for GaAs (gallium arsenide) and GaN Schottky barrier diodes.

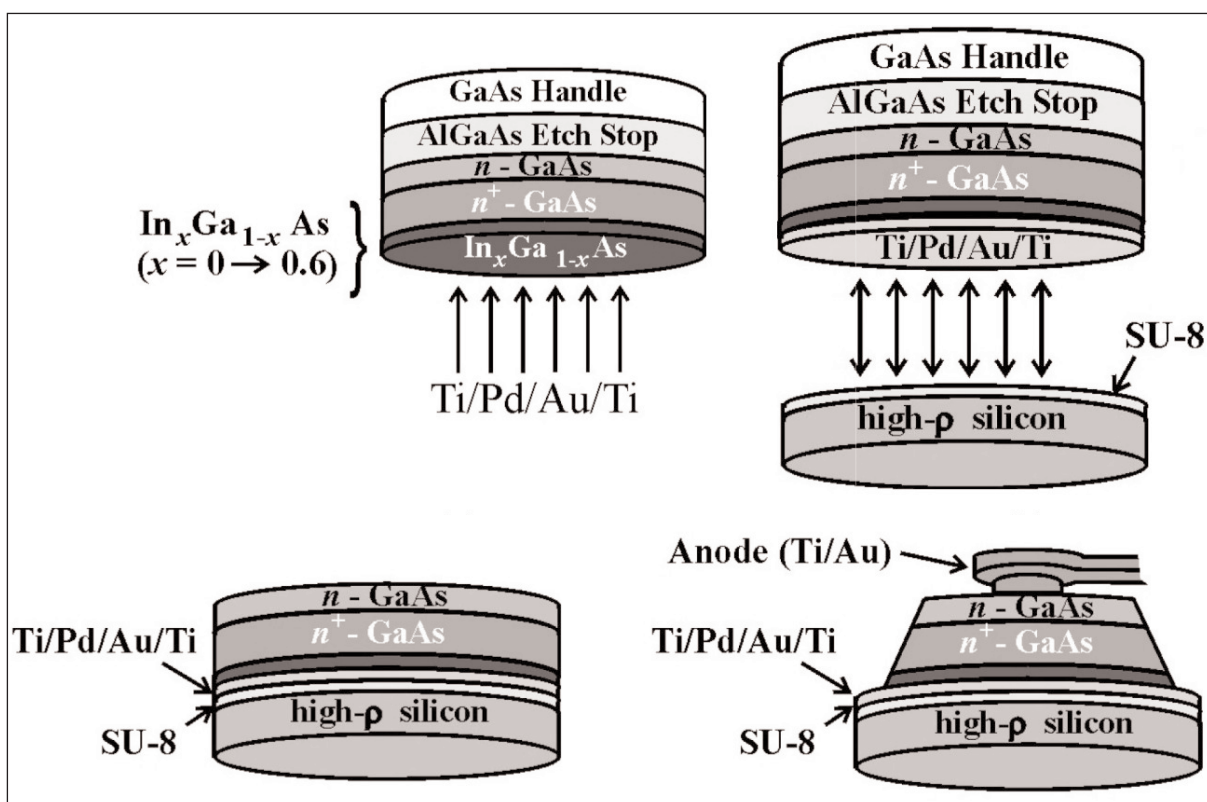
## SU-8 bonding GaAs to silicon

The University of Virginia and Dominion Micro-Probes Inc in the USA have reported the development of a submillimeter-

wave radio frequency (RF) GaAs quasi-vertical SBD on silicon [Linli Xie et al, IEEE Electron Device Letters, 26 September 2017]. The III-V epitaxial material was transferred to the silicon using SU-8 photoresist as a bonding material. The team worked to eliminate problems with previous methods such as wafer fracture and delamination, which seriously impacted yields.

The researchers comment: "Diodes fabricated with the new process and measured in the 325–500GHz range using on-wafer RF probes exhibit low parasitic capacitance and series resistance, achieving device characteristics comparable to prior state-of-the-art submillimeter-wave diodes."

The team sees the integration of III-V materials on silicon as "an effective approach for realizing novel devices that combine outstanding RF characteristics



**Figure 1. Quasi-vertical Schottky diode fabrication process: (a) Evaporation of Ti (20nm)/Pd (40nm)/Au (150nm)/Ti (20nm) ohmic contact. (b) Bonding of III-V epitaxial material to high-resistivity silicon. (c) Removal of GaAs handle and AlGaAs etch stop layers. (d) Etching of device mesa and formation of Schottky anode contact.**



with a mechanically robust and low-loss substrate". They add: "Integration processes have been shown to provide flexibility in engineering new device geometries and can be exploited to mitigate the electrical parasitics and thermal grounding bottlenecks that frequently limit the performance of terahertz components."

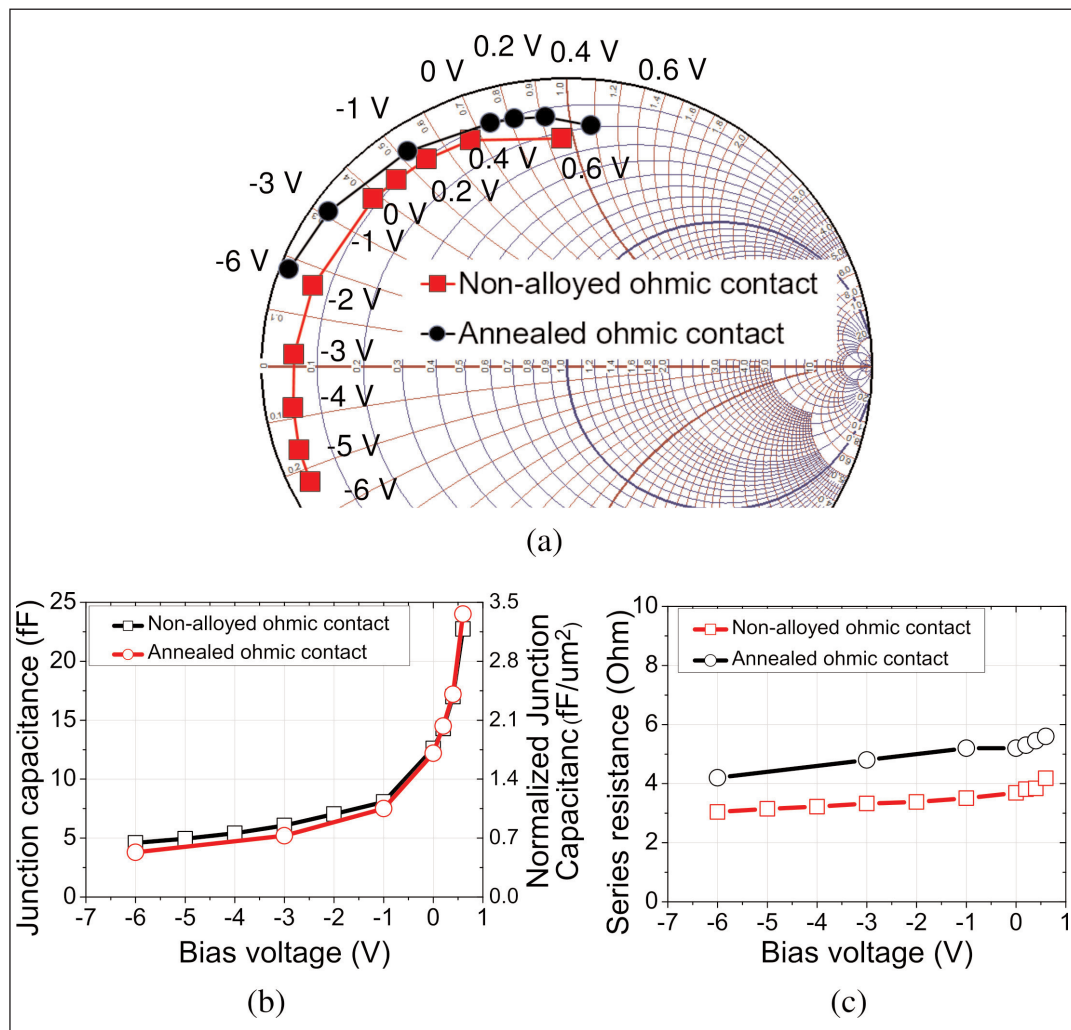
The researchers have developed a process that builds on previous work (Figure 1). The III-V epitaxial structure on the 650 $\mu\text{m}$ -thick GaAs handle wafer consisted of 1 $\mu\text{m}$  aluminium gallium arsenide (AlGaAs) etch stop, 280nm n-GaAs, 1 $\mu\text{m}$  n<sup>+</sup>-GaAs device, and highly doped indium gallium arsenide (InGaAs) cap layers. The cap ensured low-resistance ohmic contact with the titanium/palladium/gold/titanium (Ti/Pd/Au/Ti) metal stack. The cap consisted of 50nm graded-composition InGaAs and 40nm In<sub>0.6</sub>Ga<sub>0.4</sub>As.

The unannealed metal layers were evaporated over the whole InGaAs surface and were not patterned. By not annealing the metal, a smooth surface was achieved that avoided wafer fracture as a result of the bonding with high-resistivity silicon, which has been a problem with the group's previous work.

The bonding material was 250nm-thick SU-8 negative epoxy-based photoresist, replacing the spin-on glass used previously. "The relatively low curing temperature of SU-8 (100–140°C) compared to SOG (about 200°C or higher), coupled with its relatively lower percent volume shrinkage after cross-linking, results in a more robust epitaxy transfer," the team comments. The low-temperature curing avoided the need for transparent substrates in ultraviolet curing contexts. The bonding involved spin-coating the SU-8, a 1-minute 110°C soft-bake, an ultraviolet exposure, 40 minutes outgasing, and 40 minutes 140°C curing.

The GaAs handle wafer was etched away by 50°C etching in nitric acid and then citric acid solutions. The AlGaAs etch stop was removed by hydrochloric acid.

The diodes were fabricated by etching mesas down to the silicon with a combination of wet and dry etches:



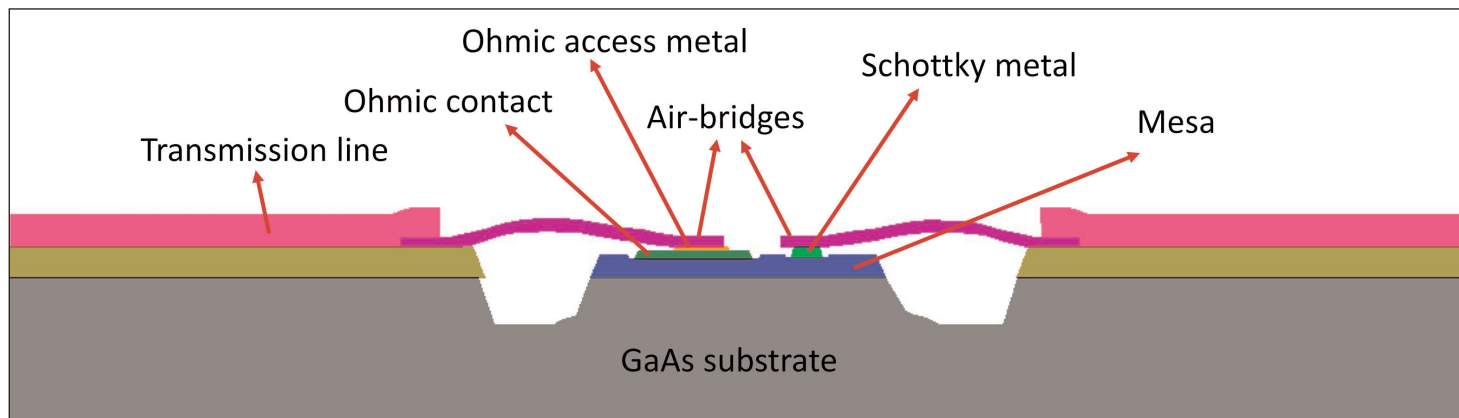
**Figure 2. WR-2.2 on-wafer measurement results: (a)  $S_{11}$  versus voltage at 425GHz. (b) Extracted junction capacitance. (c) Extracted series resistance.**

sulfuric acid and hydrogen peroxide in deionized water solution wet etch (GaAs); reactive ion etch (Ti, SU-8); sputter etch (Au); and wet chemical etch (Pd, Au). The GaAs mesa was further etched to give semiconductor material on a pedestal of exposed metal.

The further metalization of ohmic and air-bridge finger Schottky contacts, along with other circuit elements, were fabricated using standard techniques.

Direct-current measurements gave 1.19 ideality factor, 4.2 $\Omega$  resistance, 0.1pA saturation current, 33.7mS/ $\mu\text{m}^2$  normalized conductance, and 0.014pA/ $\mu\text{m}^2$  normalized saturation current. Reverse-bias breakdown occurred at 9.5V.

High-frequency characterization was carried out for operation in the WR-2.2 rectangular waveguide (0.570mmx0.285mm, 325–500GHz) band (Figure 2). S-parameter characterization focused on the  $S_{11}$  reflection coefficient. The zero-bias junction capacitance normalized to the anode area was 1.78fF/ $\mu\text{m}^2$ . The normalized series conductance was 38.4mS/ $\mu\text{m}^2$ . The unannealed ohmic contacts were found to have 1 $\Omega$  lower series resistance, compared with previous annealed devices.



**Figure 3. Schematic side view of fabricated diode.**

### Reducing costs

The University of Sherbrooke and École de Technologie Supérieure in Canada have developed a GaAs SBD fabrication technique aimed at low-cost submillimeter-wave performance [Sarvenaz Jenabi et al, *Semicond. Sci. Technol.*, vol32, p105006, 2017]. The researchers used photolithography rather than the more expensive electron-beam patterning that is often used. Also, the number of metalization steps was reduced from five to two, reducing lithography alignment complexities from eight steps to five.

A significant reduction in parasitic capacitance was achieved by the use of air-bridge connections to the transmission lines (Figure 3). The researchers report: "The proposed fabrication method with large stand-off height for the air-bridge, wide and deep trenches has reduced the parasitic capacitance to less than 0.7fF. We expect a practical cut-off frequency of 0.85 and 1.4THz for these diodes."

The researchers used a GaAs wafer designed for heterojunction bipolar transistors (HBTs), etching away unwanted layers to leave a lightly doped n-GaAs layer for the Schottky contact and a heavily doped n-GaAs ohmic contact region. The ohmic contact layer was 350nm thick.

The multi-step metalization (multi-SM) used wet mesa etching, germanium/gold/nickel/gold ohmic contact evaporation, rapid thermal annealing (RTA), and titanium/gold Schottky contact evaporation. The height of the ohmic contact was raised to that of the Schottky contact by depositing titanium/gold.

Air-bridge formation began with titanium/gold evaporation and deep trench etching around the mesa. The trench was filled with resist that was etched back with oxygen plasma until the air-bridge contact features appeared. Further deposition and patterning formed the titanium/gold air-bridge wiring and transmission lines, where the resist materials were removed in the lift-off process.

The researchers simplified this process into a 'double-step' process by combining the Schottky contact, air-bridge and transmission line metalization into a

single step. This needed the deep trench to be created before the Schottky metal deposition. Also, the trench filling material was changed so that it consisted of two resist types: a 'filling resist' and a 'cover resist'. The filling resist was chosen so that it was not affected by the cover resist developer. The filling resist also had a higher temperature tolerance.

The fill consisted of poly(methyl methacrylate) (PMMA) deposited in several layers. The lower part of the fill used low-concentration PMMA solution. The PMMA concentration was gradually increased for subsequent layers.

The thick cover resist was then spun onto the structure and patterned so that, after development, the cover resist was only found over the trench. The oxygen plasma etch rate for the cover resist was less than that of the PMMA so the final structure made an arch shape of resist over the trench. The non-trench surfaces were free of resist.

The researchers comment: "Unlike the multi-SM, this process is much less sensitive on the etching stop point, since another resist will be spun over to form and support the air bridges and T-shaped anode."

The T-shaped anode and air-bridge wiring was patterned through deep-ultraviolet lithography on a three-layer resist for metal lift-off processing. The bottom layer was poly-methyl-glutar-imide (PMGI). The top layer was from Shipley. The middle 'undercut' layer was chosen so that its developer would not affect the bottom PMGI layer. The PMGI layer enabled the formation of the tall-neck T-shaped anode. The titanium/gold metal was deposited after cleaning and passivation. The lift-off process then gives the Schottky contact (anode), air bridges, and transmission-line circuitry.

The capacitance of diodes with 1.5 $\mu\text{m}$ - and 1 $\mu\text{m}$ -diameter anodes were extracted as 7.1fF and 3.3fF, respectively. These values were based on S-parameter measurements between 2GHz and 40GHz. DC measurements (Figure 4) gave  $5 \times 10^{-16}\text{A}$  saturation current, 1.13 ideality, 0.817eV Schottky barrier height, and 34 $\Omega$  diode resistance between 8mA and 10mA high current.

The diode was in the middle of a co-planar waveguide

(CPW) structure. The team reports: "The measurement results are valid for diodes fabricated by using both presented fabrication process since a single design was used in both processes."

### Aluminium nitride SBDs with 1kV+ breakdown

Arizona State University (ASU) in the USA have claimed the first demonstration of 1kV-class aluminium nitride (AlN) SBDs [Houqiang Fu et al, IEEE Electron Device Letters, 5 July 2017] and record low turn-on voltage, less than 0.6V, for its latest vertical GaN-on-GaN SBDs [Houqiang Fu et al, Appl. Phys. Lett., vol111, p152102, 2017].

AlN has an ultra-wide bandgap of 6.2eV. Wide bandgaps are associated with the large critical fields (12.5MV/cm in AlN) that are needed in compact power handling devices.

Other semiconductor materials used in or proposed for power devices have narrower bandgaps: 3.3eV for silicon carbide, 3.4eV for GaN, 4.8eV for beta-gallium oxide, and 5.5eV for diamond. AlN also has a large thermal conductivity of 340W/mK, which is also an attractive feature for power applications.

AlN's advantages have not led so far to commercial devices since there are material and fabrication challenges.

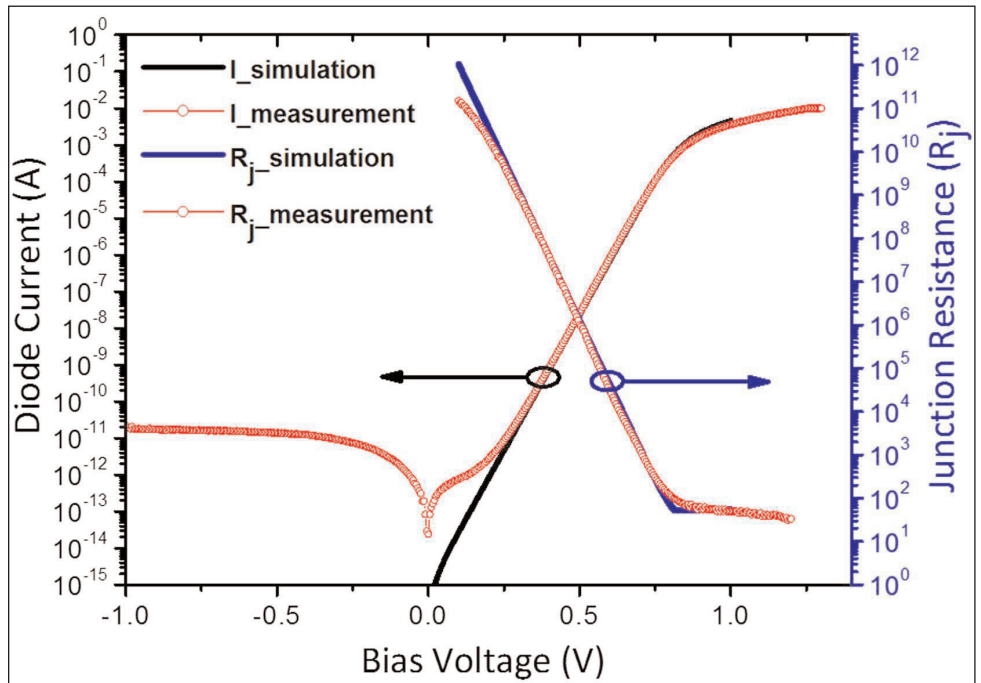
ASU's AlN material was grown by metal-organic chemical vapor deposition (MOCVD) on single-side-polished (0001) sapphire substrate off-cut 0.2°. The SBD structure (Figure 5) included 1µm unintentionally doped (UID) AlN underlayer (UL), 300nm silicon-doped n-AlN, and 2nm UID GaN cap.

According to the researchers, the device structure mimics silicon-on-insulator (SOI) technology, with a thin n-AlN epilayer active region on the thick resistive AlN underlayer. The purpose of the cap was to protect the underlying layers from oxidation, which can negatively impact device performance.

The researchers report that the AlN material demonstrated among the narrowest reported full-width at half maximum (FWHM) x-ray peaks for MOCVD AlN on sapphire — 46.8arcsec for the (0002) rocking curve and 159.1arcsec for (20 $\bar{2}$ 4). These figures suggest dislocation densities of the order 10<sup>8</sup>/cm<sup>2</sup>.

The SBD was fabricated with 20nm/100nm/20nm/50nm Ti/Al/Ti/Au ohmic and 30nm/120nm platinum/gold (Pt/Au) Schottky contacts. The ohmic metal was patterned as a 400µm-diameter circular disk.

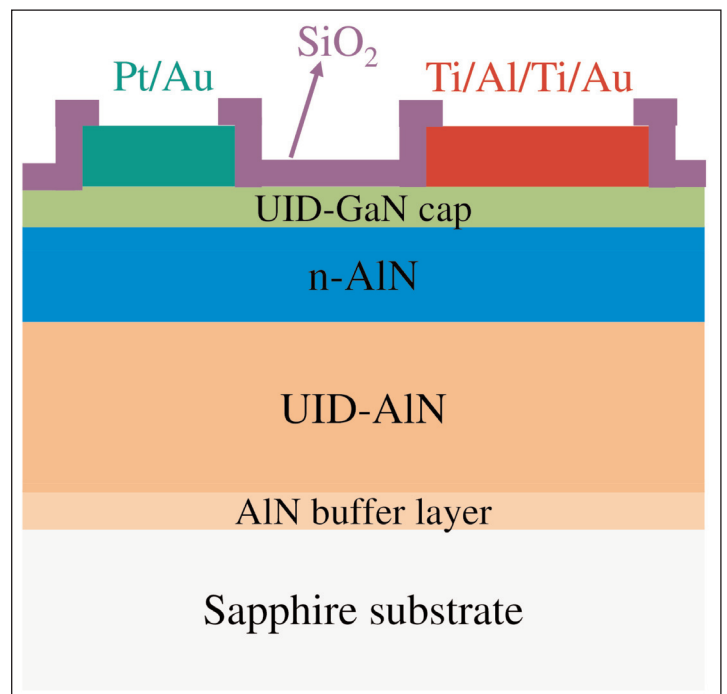
Two types of Schottky contact were made: a 100µm-diameter circular disk and 100µm-side square. The



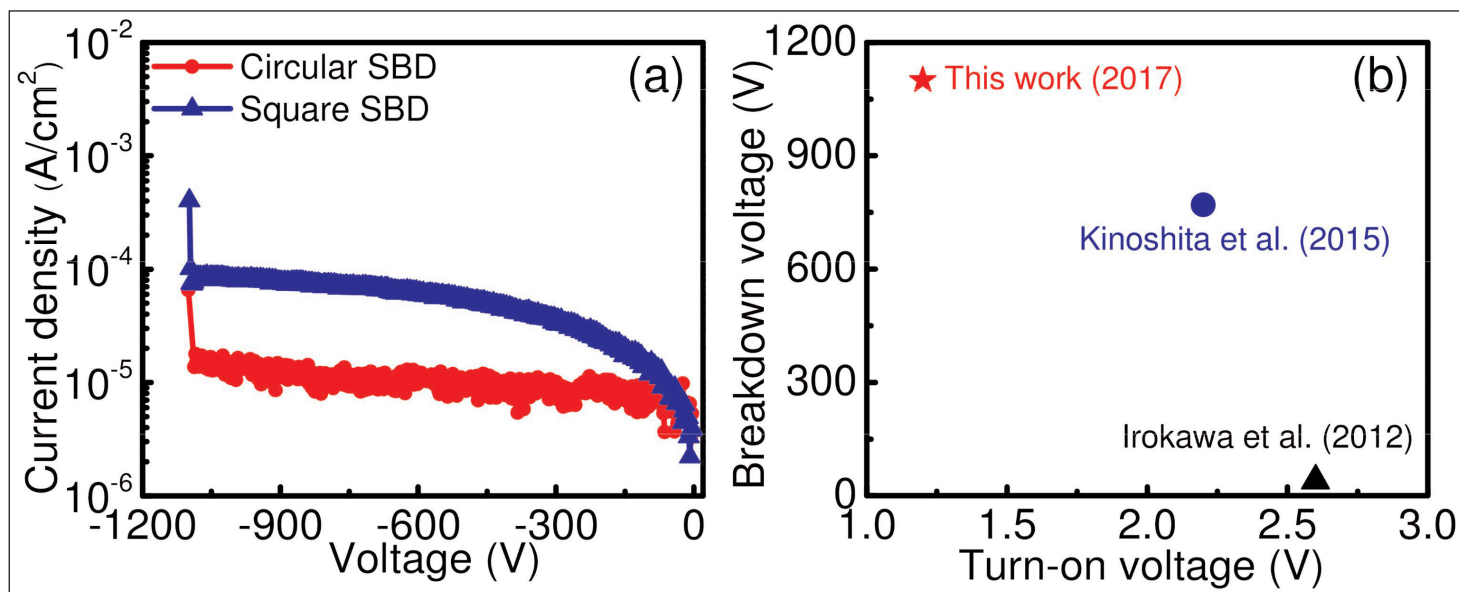
**Figure 4. Simulated and measured current versus voltage bias of diode (left axis), and junction resistance versus voltage bias (right axis) for 1.5µm anode radius.**

distance between contacts was 200µm. Surface passivation consisted of 200nm plasma-enhanced CVD silicon dioxide (SiO<sub>2</sub>). There was no edge termination structure.

The ~10<sup>5</sup> on-off ratio of the devices is described by the team as being comparable to AlN devices on AlN substrates. The turn-on voltage of 1.2V (1.1V for square contacts) is smaller than previously reported values (more than 2V), according to ASU. ▶



**Figure 5. Schematic view of fabricated AlN SBDs on sapphire by MOCVD. Ohmic and Schottky contacts are in red and green, respectively.**



**Figure 6. (a) Reverse current–voltage characteristics of circular and square AlN SBDs. (b) Comparison of breakdown and turn-on voltages of reported AlN SBDs.**

The temperature dependence of the device performance suggests that the forward current was limited by thermionic emission. Schottky barrier height increased from 0.9eV to 1.6eV between 20°C (room temperature – RT) and 200°C. At the same time, ideality decreased from 5.5 (5.3 for square contact) to 2.2. Previous reported idealities of AlN SBDs have been greater than 8.

The researchers attribute the ideality behavior to “lateral inhomogeneity of the Schottky barrier interface”. They add: “Note that the RT ideality factors ( $n = 5.5$  and 5.3 for circular and square SBDs, respectively) obtained in this work were 2~3 times smaller than previous results, possibly due to improved material quality and metal/semiconductor interface.”

Under reverse bias, the SBDs broke down only after 1kV, beating previous reports of ~700V for devices produced on free-standing AlN substrate by Japan- and US-based researchers (Figure 6). The ASU devices showed catastrophic damage at the edge of the Schottky contacts that was attributed to edge electric field crowding.

The team comments: “Improvement in the breakdown capability of the devices can be further expected by employing field-plate and/or edge termination. In addition, improving the material quality of n-AlN, increasing the resistivity of the UID AlN UL by Fe or C doping and optimizing the passivation strategies can also help to increase the breakdown voltage of the devices.”

Reverse-bias leakage was generally less than 1nA.

### GaN single and double drift layers

The ASU researchers also developed a double drift layer to increase the breakdown voltage in GaN-on-GaN SBDs.

Vertical devices have recently been developed on free-standing or bulk GaN substrates for power applications. The use of free-standing/bulk substrates avoids generating high threading dislocation densities (more than

10<sup>9</sup>/cm<sup>2</sup> on sapphire) that provide unwanted leakage paths, reducing breakdown voltages.

The researchers used n<sup>+</sup>-GaN bulk substrates from Sumitomo Electric Industries Ltd for MOCVD of the SBD materials (Figure 7). A conventional single-drift-layer diode, A, was compared with a double-drift-layer structure, B. Simulations suggested that diode B should be able to support much higher reverse biasing for the same peak electric field at the metal/semiconductor interface.

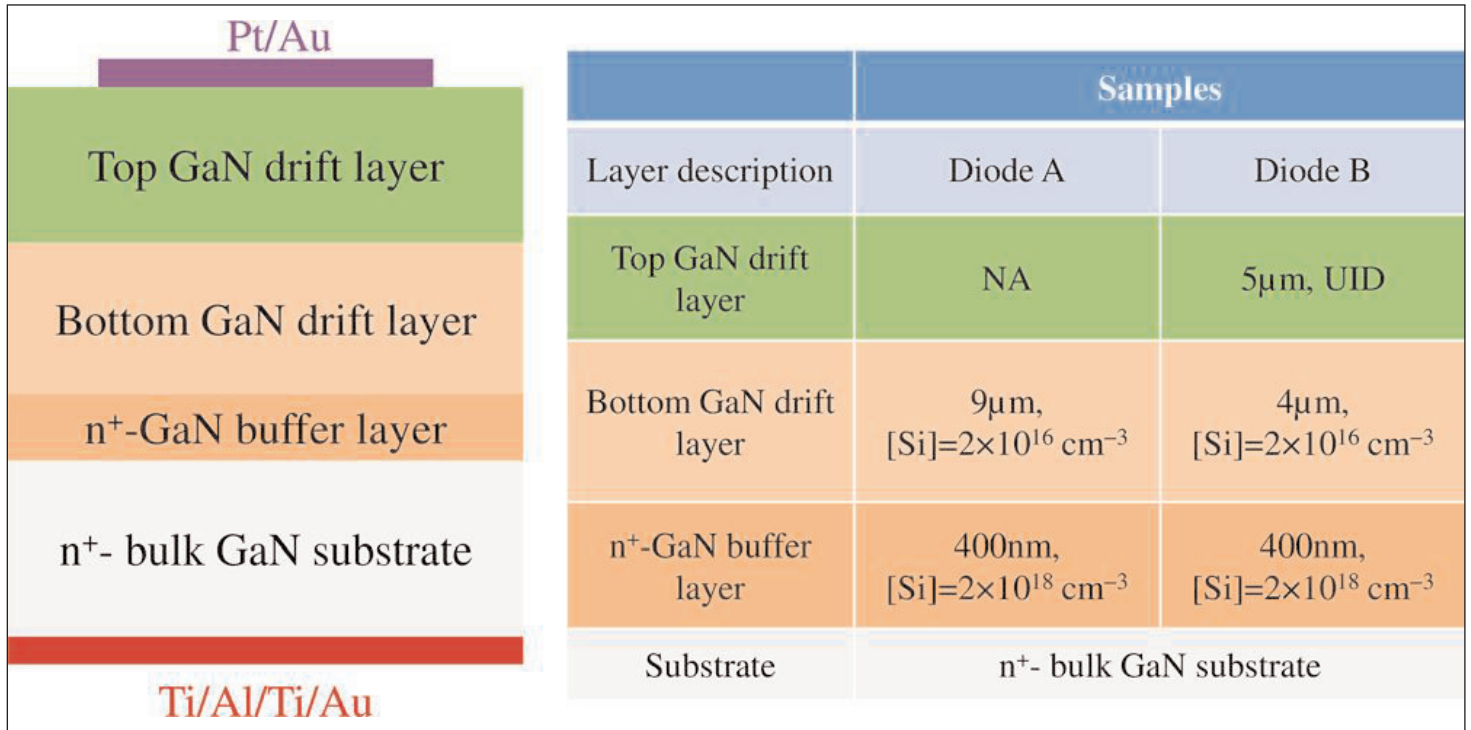
Using x-ray analysis the researchers estimated that the dislocation densities were in the low 10<sup>6</sup>/cm<sup>2</sup> range in both samples - “significantly lower than that of typical GaN devices grown on sapphire (>10<sup>9</sup>/cm<sup>2</sup>),” they add.

Fabrication involved cleaning, inductively coupled plasma mesa etch, and the deposition of Schottky Pt/Au and ohmic Ti/Al/Ti/Au ohmic contacts. There was no passivation, field plate (FP) or edge termination.

The turn-on voltages were 0.52V and 0.59V for diodes A and B, respectively. This gave corresponding forward voltages for 0.1mA current flow of 1.0V and 1.2V. The turn-on voltages are described as record lows for vertical GaN-on-GaN diodes. The diode B had an ideality of 1.04, compared with 1.06 for diode A. These values are described as nearly ideal (i.e. unity factor) for GaN SBDs.

The off-current density, the measurement of which was hampered by the 0.1nA lower limit of the test equipment, was below 10<sup>-7</sup>A/cm<sup>2</sup> for both diodes. The on/off current ratio was about 10<sup>10</sup>, “among the highest values demonstrated in vertical GaN power diodes,” says the team.

The on-resistance at 0.1A current was 1.39mΩ-cm<sup>2</sup> for diode A and 1.65mΩ-cm<sup>2</sup> for B. The slightly higher on-resistance of diode B is attributed to a lack of electrons in the top undoped drift layer. Subtracting out the effect of the substrate, the researchers estimate the drift-layer mobility to be 886.1cm<sup>2</sup>/V-s and 1045.2cm<sup>2</sup>/V-s



**Figure 7. Cross section of GaN SBDs (left) and detailed descriptions of layers (right) for diode A and diode B.**

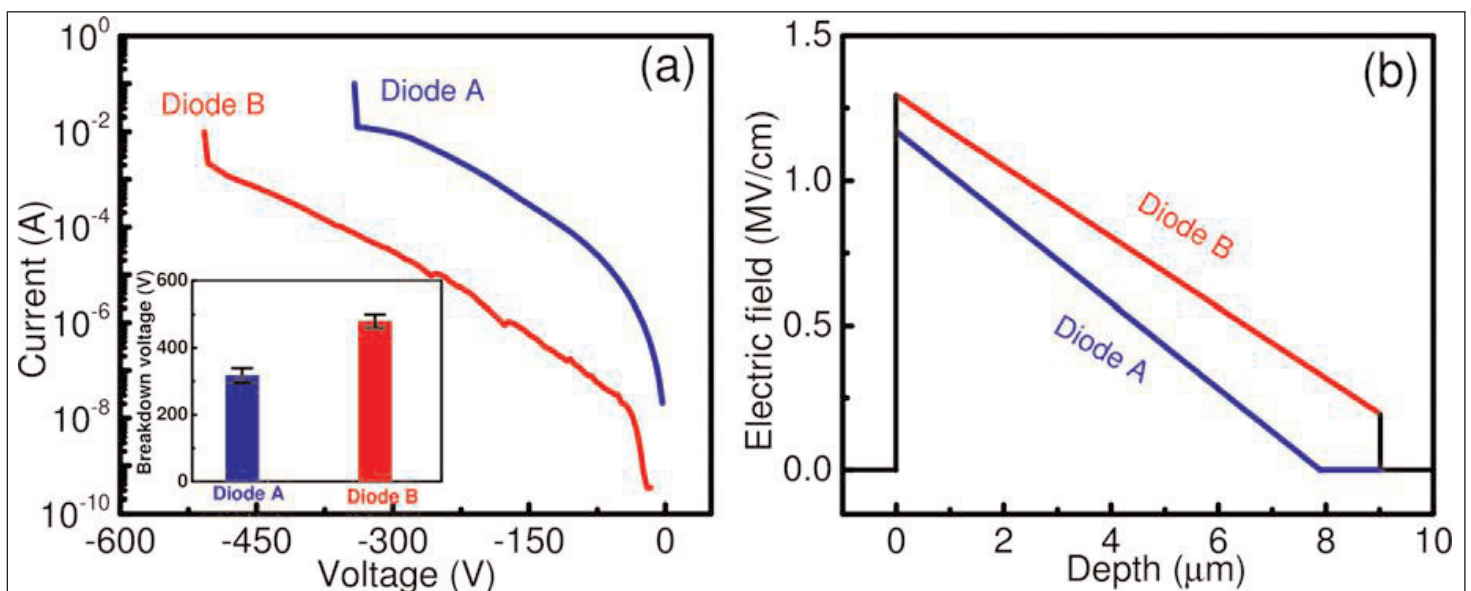
for diodes A and B, respectively. The team comments: "Diode A had a lower electron mobility possibly due to stronger impurity scattering from silicon dopants."

The reverse-bias breakdowns for diodes A and B were, respectively, 340V and 503V (Figure 8). These values gave critical fields (1.17MV/cm and 1.30MV/cm, respectively) that were somewhat lower than the expected values based on the critical field of GaN ( $\sim 3.0\text{MV/cm}$ ). The team reports: "Since we did not employ FP or edge termination, the breakdown was expected to be determined by the device edge breakdown. Optical microscopy examination confirmed that the catastrophic damages of the GaN SBDs indeed

occurred at the edge of Schottky contacts possibly due to severe edge electric field crowding."

Varying the temperature allowed extraction of the Schottky barrier heights ( $\Phi_B$ ): 0.69eV for diode A and 0.70eV for B. The team comments; "The low  $\Phi_B$  values are partly responsible for the obtained record-low  $V_{ON}$  in forward bias. The measured  $\Phi_B$  values are less than the theoretical values, which demands further investigations. Possible explanations include surface roughness, non-uniform current distribution, and so on." ■

*Author: Mike Cooke is a freelance technology journalist working in semiconductor & advanced technology sectors since 1997.*



**Figure 8. Reverse current–voltage characteristics of diodes A and B. Inset: measured breakdown voltages. (b) Electric field profiles along vertical direction of diodes.**

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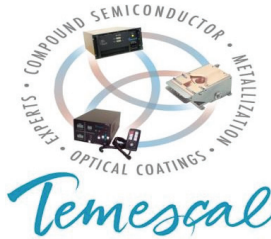
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 Tel: +1 617 965 5511  
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(see section 5 for full contact details)

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[www.cambridge-fluid.com](http://www.cambridge-fluid.com)**CS CLEAN SOLUTIONS AG**

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## 12 Inspection equipment

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[www.bruker-axs.de](http://www.bruker-axs.de)

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

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## 15 Assembly/packaging materials

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**Wafer World Inc**  
(see section 3 for full contact details)

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

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

**Palomar Technologies Inc**  
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## 17 Assembly/packaging foundry

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

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**Compound Semiconductor Technologies Ltd**  
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Fax: +44 141 579 3040  
[www.compoundsemi.co.uk](http://www.compoundsemi.co.uk)

**United Monolithic Semiconductors**  
Route departementale 128, BP46, Orsay, 91401, France  
Tel: +33 1 69 33 04 72  
Fax: +33 169 33 02 92  
[www.ums-gaas.com](http://www.ums-gaas.com)

## 19 Facility equipment

**MEI, LLC**  
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Fax: +1 541 917 3623  
[www.marlerenterprises.net](http://www.marlerenterprises.net)

## 20 Facility consumables

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

### Crosslight Software Inc

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Canada  
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[www.crosslight.com](http://www.crosslight.com)

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## 22 Used equipment

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

### M+W Zander Holding AG

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## 24 Consulting

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

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**E-mail:** [poweramerica@ncsu.edu](mailto:poweramerica@ncsu.edu)

[www.poweramericainstitute.org/shortcourse](http://www.poweramericainstitute.org/shortcourse)

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Tektronix, Santa Clara, CA, USA

**E-mail:** [erik@7pennies.com](mailto:erik@7pennies.com)

[www.7pennies.com/news-events/pic-training-silicon-valley-2017](http://www.7pennies.com/news-events/pic-training-silicon-valley-2017)

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

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**E-mail:** [info@ieee-iedm.org](mailto:info@ieee-iedm.org)

[www.ieee-iedm.org](http://www.ieee-iedm.org)

**5–7 December 2017**

## 9th PV Performance Modeling and Monitoring Collaborative Workshop 2017 (PVP-9)

Solar Research Institute of HIT, Weihai, China

**E-mail:** [pvpmc@hitwh.edu.cn](mailto:pvpmc@hitwh.edu.cn)

<http://pvpmc.hitwh.edu.cn>

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## 48th IEEE Semiconductor Interface Specialists Conference (SISC 2017)

San Francisco, CA USA

**E-mail:** [pmcintyre@ieeesisc.org](mailto:pmcintyre@ieeesisc.org)

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

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## SEMICON Japan 2017

Tokyo Big Sight, Tokyo, Japan

**E-mail:** [jcustomer@semi.org](mailto:jcustomer@semi.org)

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

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## SPIE Photonics West 2018

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San Francisco, California, USA

**E-mail:** [customerservice@spie.org](mailto:customerservice@spie.org)

<http://spie.org/SPIE-PHOTONICS-WEST-conference>

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## IEEE International Solid-State Circuits Conference (ISSCC 2018)

San Francisco, CA, USA

**E-mail:** [Issccinfo@yesevents.com](mailto:Issccinfo@yesevents.com)

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

**13–15 February 2018**

## Strategies in Light/The LED Show 2018

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[www.iuva.org/BerlinConference](http://www.iuva.org/BerlinConference)

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[http://spie.org/SPIE\\_Photonics\\_Europe\\_Conference](http://spie.org/SPIE_Photonics_Europe_Conference)

**13–17 May 2018**

**30th IEEE International Symposium on Power Semiconductor Devices and ICs (ISPSD 2018)**

Palmer House Hilton Hotel, Chicago, IL USA

**E-mail:** [info@ispsd.org](mailto:info@ispsd.org)

[www.ispsd2018.org](http://www.ispsd2018.org)

**5–7 June 2018**

**PCIM Europe (Power conversion and Intelligent Motion) 2018**

Nuremberg Messe, Germany

**E-mail:** [daniela.kaeser@mesago.com](mailto:daniela.kaeser@mesago.com)

[www.mesago.de/en/PCIM/main.htm](http://www.mesago.de/en/PCIM/main.htm)

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

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**IEEE 45th Photovoltaic Specialists Conference (PVSC 2018)**

Washington, DC, USA

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**13th European Microwave Integrated Circuits Conference (EuMIC 2018), part of 21st European Microwave Week (EuMW 2018)**

IFEMA, Madrid, Spain

**E-mail:** [eumwreg@itnint.com](mailto:eumwreg@itnint.com)

[www.eumweek.com/conferences/eumic.html](http://www.eumweek.com/conferences/eumic.html)

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Hilton San Francisco and Towers, CA, USA

**E-mail:** [iedm@his.com](mailto:iedm@his.com)

[www.ieee.org/conference/iedm](http://www.ieee.org/conference/iedm)

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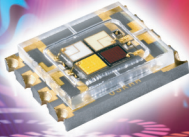


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