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semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

Vol. 13 • Issue 7 • September 2018

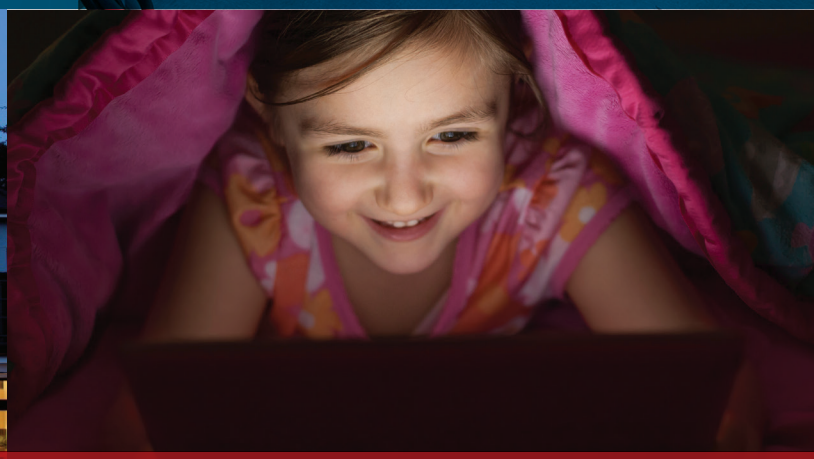
www.semiconductor-today.com

Gearing up for μLEDs

Nitride VCSELs

ST & Leti developing GaN-on-Si for power switching • News from ECOC
X-FAB expands Texas SiC foundry • Osram launches its first VCSEL

Lower Cost LEDs



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

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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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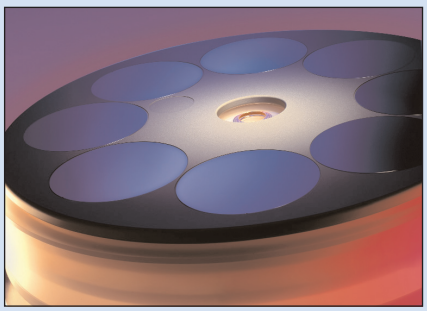
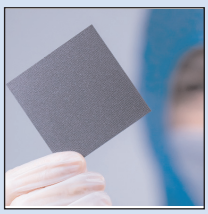
p15 Germany's X-FAB Silicon Foundries is doubling the 6" silicon carbide process capacity at its fab in Lubbock, Texas.



p29 Thermco Systems has acquired CSD Epitaxy, which makes the Epi-pro epitaxy batch reactor.

p48 CST Global has added the capability for in-house InP epi overgrowth for producing DFB lasers.



Cover: Lextar Electronics has unveiled its micro-LED chip capabilities (with a die size down to under 20μm and luminous efficiency of over 30%) including debuting two new technologies — R/G/B Micro LED chip and Color Conversion Micro LED chip — for different micro-LED mass transfer processes. **p40**

editorial

VCSEL and micro-LED developments

On pages 78–83 of this issue we cover the latest advances in research on III-nitride-based vertical-cavity surface-emitting lasers (VCSELs), including filling the 'green gap' not covered by established AlGaAs-based VCSELs (which are restricted to red-infrared wavelengths longer than 650nm).

Meanwhile, following its acquisition in May of US-based fabless VCSEL firm Vixar, Germany's Osram Opto Semiconductors has now launched its first VCSEL (emitting at the infrared wavelength of 940nm), enabling it to target new applications such as 3D sensing (facial recognition in consumer mobile devices etc) — see page 45.

Finisar cites VCSEL arrays for 3D sensing as an expected driver of its revenue growth from the September quarter onwards, especially as its new 6-inch wafer fab in Sherman, Texas ramps up, alleviating the capacity constraints of its existing 4-inch VCSEL fab in Allen, Texas (see page 64).

Epiwafer foundry IQE's first-half 2018 photonics revenue were up 30% year-on-year (on a constant-currency basis), despite its largest photonics customer being flat while inventory from the aggressive first mass-market ramp of VCSEL epiwafers in second-half 2017 was consumed in the supply chain (page 28). Revenue from other photonics customers rose 40% as capacity was diverted to more than 20 VCSEL chip manufacturer engagements applications (although profit margins have been reduced by qualification programs for new customers, as well as pre-production costs for IQE's new Newport Foundry). IQE's guidance for Photonics revenue growth is 35–50% for full-year 2018, accelerating to 40–60% for 2019.

Likewise, Germany's Aixtron has gained orders for AIX 2800G4-TM MOCVD systems for VCSEL production from Taiwan's HLJ Technology (expanding from 4" to 6" wafers) and from Sinosemic — the first all-Chinese manufacturer of VCSEL chips for face recognition (page 32–33).

Aixtron has also received orders from UK-based Plessey for an AIX G5+ C MOCVD system (configured for 8x6" or 5x8" wafers, with automatic cassette-to-cassette wafer transfer, supplementing Plessey's existing 7x6"/3x8" Aixtron reactors). Plessey will boost its manufacturing of gallium nitride on silicon (GaN-on-Si) wafers, targeting micro-LED displays that can compete with LCD and OLED displays. Plessey has also announced a partnership for its monolithic micro-LED displays to be driven by the silicon backplane of Jasper Display Corp (page 40). Meanwhile, Taiwan's Lextar has unveiled two technologies — R/G/B Micro LED chip and Color Conversion Micro LED chip — for different micro-LED mass transfer processes.

The variety of technologies proposed for micro-LED assembly and pixel structuring presents technical and economic barriers. "High-volume placement challenges need to be addressed prior to widespread market adoption of these emerging lighting solutions," says chip assembly & packaging equipment and materials supplier Kulicke & Soffa which, together with Rohinni (which has developed a proprietary method for transferring semiconductor devices) has launched the micro- and mini-LED high-speed die placement solution PIXALUX (see page 36).

However, according to Yole Développement, technology solutions should start converging by the end of 2019 (see pages 70-71). Micro-displays for augmented reality (AR) and head-up displays (HUD) will be the first commercial applications, followed by smartwatches, while TVs and smartphones could follow in 3–5 years.

Mark Telford, Editor

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

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

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news

Power module packaging materials market growing at 8.2% CAGR to almost $2bn in 2023

Innovations driven by EV/HEV and SiC & GaN technologies

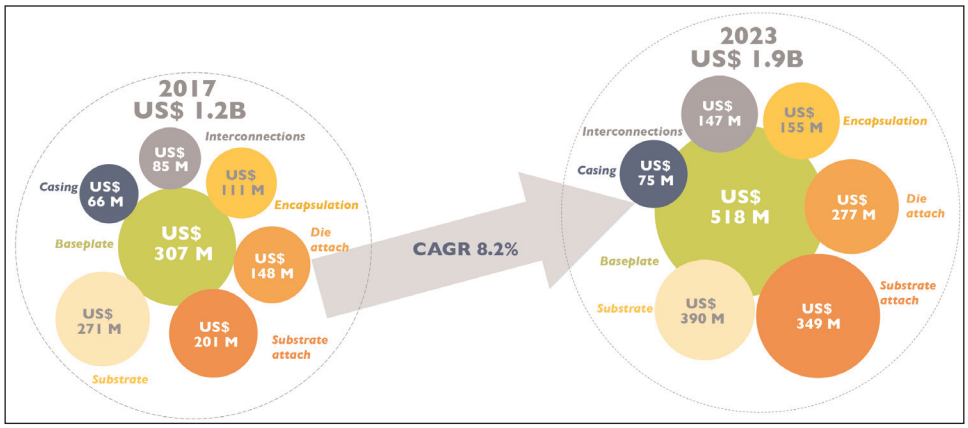
The power module packaging materials market is worth $1.2bn (just more than a third of the total power module market) and is rising at a compound annual growth rate (CAGR) of 8.2% during 2017–2023 to $1.9bn, forecasts market research and strategy consulting firm Yole Développement in its 'Power Module Packaging Report, 2018 edition'.

"It is a very dynamic market, where continuous innovations and material enhancements and a lot of R&D investment are needed," comments Alejandra Fuentes Suarez, technology & market analyst at Yole.

Technical innovations in power module packaging (such as silver sintering, new substrates and interconnection technologies) are driven mainly by the challenging system requirements of the booming electric/hybrid electric vehicle (EV/HEV) industry and the entrance of the wide-bandgap (WBG) semiconductors materials silicon carbide (SiC) and gallium nitride (GaN), which allow devices to work at higher switching frequencies and higher junction temperatures.

The EV/HEV industry's demand for high power density and mechatronics integration is driving many power electronics innovations with dedicated packaging solutions. New standards in terms of electrical devices and systems are becoming a reality, pushing electronic components to work in non-conventional environments for longer.

Step by step SiC technologies are hence becoming an essential solution to meet industrial requirements, with a market forecast growing at a 29% CAGR over 2017–2023. An example of WBG penetration is the latest Model3 inverter of car maker Tesla, showing the added-value of STMicroelectronics' SiC power module.



Power module packaging: 2017–2023 raw material market per packaging part.

The latter has been reverse engineered by Yole company System Plus Consulting, whose report 'Automotive Power Module Packaging Comparison 2018' details the physical composition and cost of ten modules for automotive applications from five different manufacturers. After reviewing the different topologies and techniques used for the module packaging, System Plus Consulting's analysts highlight the specificities of each solution, defined by the car makers. "There is not yet a standardized package in automotive application," concludes Farid Hamrani, cost engineer at System Plus Consulting.

With two major technical trends, over-molded double-side cooled modules for hybrid cars and single-side cooled modules with pin-fin baseplates for full electric cars, this industry is dominated by insulated-gate bipolar transistor (IGBT) power modules: "The IGBT power module market grew 18.1% in 2017," says Dr Milan Rosina, senior technology & market analyst, Power Electronics & Batteries, at Yole. "No doubt today that IGBT modules are driving the power module packaging materials business." Indeed, 2017 was an impressive year for the IGBT power module market. And 2018 perspectives are even better, with over 20% growth in first-half 2018, due mainly to the EV/HEV sector (especially in China).

It has also been an exceptional year for industrial motor drives in Asia. In parallel, other device modules (like those based on MOSFETs and bipolar transistors) show a slight decrease.

Consequently, the overall power module market is expected to grow to more than $5.5bn in 2023, directly benefitting the packaging material market.

Yole and System Plus Consulting are exhibiting in booth # A4667 at Semicon Europa 2018 and Electronica 2018 in Munich, Germany (13–16 November), where Yole is also presenting two key power electronics & compound semiconductor presentations on 15 November:

- 'How battery pack evolutions create opportunities for power electronics companies' (12:20pm, in the Battery Session);
- 'GaN power HEMT reliability research within the POWERBASE' (2pm, in the Power Electronics Session).

www.i-micronews.com/category-listing/product/power-module-packaging-2018-material-market-and-technology-trends.html

IR LED market growing at 15% CAGR to over $1bn by 2024

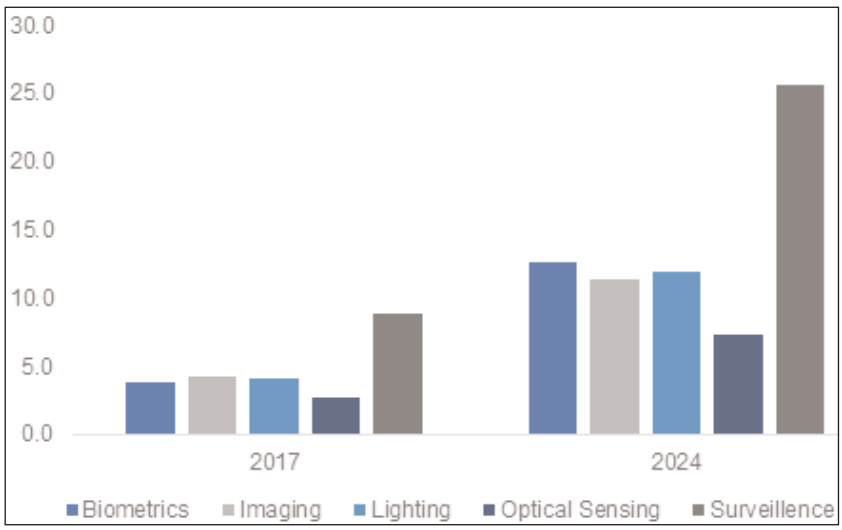
700–850nm and 850–940nm segments to grow at 17%

The infrared (IR) LED market will exceed $1bn by 2024, as shipments rise from over $400m in 2017 then at a compound annual growth rate (CAGR) of over 15% between 2018 and 2024 (to more than 8 billion units), forecasts a report by Global Market Insights Inc that covers wavelength ranges of 700–850nm, 850–940nm, 940–1020nm and 1020–1720nm.

The IR LED market is expected to see significant growth due to increasing demand for cameras with night-vision capabilities and remote sensing in the automotive and consumer electronics industries. Automotive demand has grown due to increasing usage in exterior and interior lighting. Moreover, the IR LED market has tremendous opportunities for future growth with integration into wearable devices such as augmented reality (AR)/virtual reality (VR) and with the emergence of Internet of Things (IoT)-enabled devices.

By wavelength range, the 700–850nm and 850–940nm segments are expected to grow at a CAGR of over 17%, due to increasing use in numerous applications, especially in the automotive and industrial sectors for 850–940nm.

A growth segment in the infrared LED market is the biometrics industry, due to increasing adoption of iris and facial recognition in electronic devices, driven by mobile payment services that create the need for secure and reliable authentication for users. Several LED makers are taking advantage of these opportunities and are launching advanced components for biometric applications. For example, Chinese electronics retailer GOME recently collaborated with German LED maker Osram Opto Semiconductors GmbH to integrate infrared components for iris recognition technology into all their smartphones. The growing global smartphone industry is projected to boost the IR LED market for iris and facial recognition.

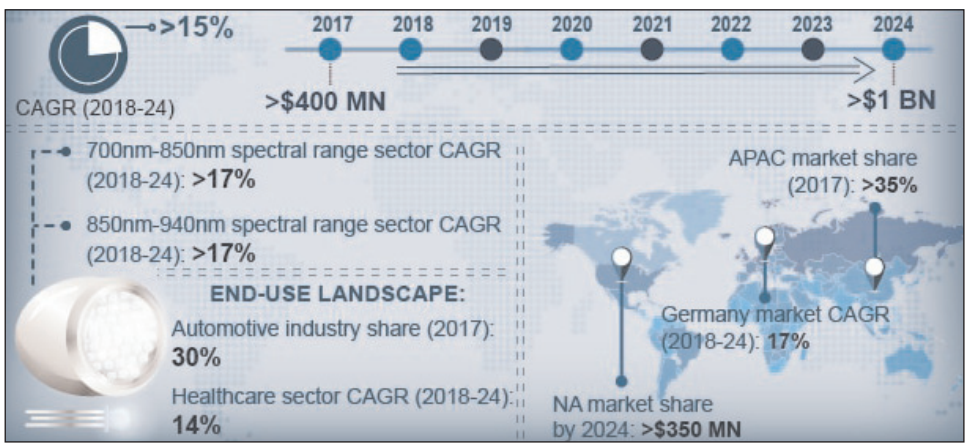


The North America IR LED market is expected to exceed $350m by 2024 due to increasing demand from the surveillance industry. The USA has been the main country adopting advanced surveillance technologies such as artificial intelligence, facial recognition and surveillance automation. Demand for such technologies is rising across airports, commercial buildings and other public buildings, particularly as surveillance is integral to the USA for law enforcement and is part of its critical national infrastructure.

Vendors in the infrared LED market space include Everlight, Vishay Intertechnology, Epistar, and Rohm Semiconductor. To cater to demand from growing applications in consumer electronics, the industry is seeing extensive investment in IR LEDs. To gain market share, players have been focusing on new product launches and targeting the consumer electronics segment. In 2018, Osram Opto Semiconductors has expanded its product portfolio by announcing six new IR LEDs (IREDs) for automotive use, including 850nm components for applications such as pedestrian protection, night vision and other exterior applications and 940nm components for applications such as gesture recognition, driver monitoring, and other interior applications.

Considering the demand and huge potential, several companies in the industry have shifted their focus to the infrared LED market. For example, in 2017 Everlight reported that IR LEDs contributed 25% of its total revenue. For Epistar, its market share in these LED chips was over 10% of all aluminium gallium indium phosphide (AlGaInP) chip output in 2015, the report notes.

www.gminsights.com/industry-analysis/infrared-ir-led-market



RF power amplifier market to grow at 12.2% to 2028

The approximately $3bn RF power amplifier market is poised to expand at a robust compound annual growth rate (CAGR) of 12.2% over 2018–2028, as the widening expansion of 5G cellular networks will remain the main driver of RF power amplifier market growth, in addition to the continuous penetration of smart devices and connected technology, according to the report 'RF Power Amplifier Market Forecast, Trend Analysis & Competition Tracking — Global Market insights 2018 to 2028' from Fact.MR.

The APEJ region (Asia-Pacific, excluding Japan) currently accounts for a sizable share (<50%) of the RF power amplifier market, whereas North America holds over a quarter of the market.

The North American and European RF power amplifier markets are expected to exhibit high CAGRs, due mainly to the booming consumer electronics sector. However, the strong presence of some of the leading RF power amplifier manufacturers will maintain Asia Pacific (excluding Japan) as the largest market region through 2018–2028. With nearly 40% share of the market, APEJ is expected to be driven mainly by the developing telecom, industrial and wireless network sectors.

Burgeoning adoption of energy-efficient equipment, coupled with rapid progress in the semiconductor industry, will further accelerate RF power amplifier market growth in the APEJ region, the report forecasts. In terms of sustainable value generation in the RF power amplifier market, China, South Korea and India are expected to boost high-performance analog semiconductor components, increasing demand. Another strong factor driving growth in APEJ is consistently increasing deployment of next-generation wireless networks and LTE networks.

Established and new-entrant semiconductor manufacturers in certain regions, including China, India, Japan and the USA are expected to stimulate the development of new business models among RF power amplifier manufacturers by augmenting demand for advanced consumer electronics and network products — pushing the Internet of Things (IoT) and wireless infrastructure sectors further.

RF power amplifier manufacturers are focusing on increasing investments in technology upgrades, notes the report. The onus has shifted to revamping legacy models in order to improve operational efficiency. Evolving end-user demand has also meant that RF power amplifier manufacturers have to make consistent size/weight reductions while increasing the power density of amplifiers. Investment in R&D on the next generation of multi-mode RF power amplifiers will potentially play a pivotal role in enabling firms to address the challenge of adapting legacy platforms to support modern business operations, unlocking opportunities for RF power amplifier market growth in the near future, it is reckoned.

In March, US-based Cree Inc announced the acquisition of the assets of Radio Frequency (RF) Power business of Germany's Infineon Technologies AG, which should trigger expansion of Cree's existing product portfolio and customer base. Moreover, industry experts expect the acquisition to strengthen Cree's market position, particularly in RF GaN-on-SiC technologies. Also, MACOM has introduced the MAGM series of GaN-on-Si based monolithic microwave integrated circuit (MMIC) power amplifiers, specifically optimized for 5G wireless base-station infrastructure. More recently, NXP Semiconductors announced the launch of its 5G RF front-end portfolio for massive multiple-input-multiple-output (mMIMO) systems (the key part of 5G networks), notes the report.

www.factmr.com

5G mm-wave transceivers and beam-formers to ship in hundreds of millions of units annually within five years

The transceiver and beamforming components critical to 5G millimeter-wave systems will ship in hundreds of millions of units per year within five years, forecasts Strategy Analytics in its report '5G mm-Wave Systems, RF Front-end Components & Process Tech Forecast 2018 – 2024'.

"Each 5G millimetre-wave smartphone, base station and customer premise system will use multiple transceivers, beam-formers and antenna elements for antenna gain, capacity and coverage," says author Christopher Taylor. "System makers will use a mix of compound semiconductors, SiGe-BiCMOS and CMOS, depending on emitted power required, link budget and number of antenna elements in the system. Compound semiconductors and SiGe-BiCMOS have higher F_{max} for better design margins and efficiency, but the lower cost and higher integration capabilities of CMOS will put it ahead in terms of number of RF components shipped per year for 5G."

"Performance dictates that infrastructure will use more SiGe-BiCMOS for the RF than will user equipment, but much of this will eventually move to CMOS as well," says Eric Higham, director of the Strategy Analytics Advanced Semiconductor Applications service. "Compound semiconductors will play a role in those mm-wave infrastructure systems where electrical efficiency and system power consumption are critical," he adds. "Suppliers of RF chips for 5G mm-wave infrastructure systems using the different semiconductor process technologies include Anokiwave, Infineon, Qualcomm and Qorvo."

www.strategyanalytics.com

LED market growth in 2018 revised from 11% to 4%

Escalating trade war may aggravate oversupply and price declines

The LED market will grow to $18.796bn in 2018, up just 4% year-on-year (less than the earlier forecast of 11%), according to the report 'LED Industry Demand and Supply Data Base' by LEDinside (a division of TrendForce). The market is slowing down since oversupply is contributing to LED price declines, together with the impacts of escalating trade war on demand in the end market, notes the market research firm.

The massive production capacity expansion of Chinese LED makers has outpaced the growth in demand, triggering oversupply in the market, says LEDinside. The Chinese LED makers originally intend to raise their revenue and profits through production capacity expansion, but the falling average selling prices (ASPs) have made the market situation more difficult. First-half 2018 saw price declines of 20-30% for some LED chips. However, LEDinside does not expect a further sharp drop in prices in the short term, since price levels have almost approached the costs.

Taiwanese LED makers may move packaging facilities out of China

On the demand side, LED makers' export business to North America and other emerging markets has been influenced considerably by the trade war and currency depreciation. With the next wave of tariffs going into effect on 24 September, tariffs of 10% are being imposed on Chinese products, including more than 30 categories of LED lighting-related products. Accounting for around 70% of China's LED lighting exports, the $8bn worth of products will face even higher tariffs of 25% by 1 January 2019.

LEDinside believes that the tariffs may affect Chinese LED packaging companies and lighting product makers, because they may see a large decrease in orders from foreign customers. This will in turn reduce demand for LED chips upstream in the supply chain.

Despite the impacts of the trade war, which may result in a changing landscape in the global LED industry, LEDinside believes that lighting products will still be produced in China in the short term, with little change to supply chains, because the supply chains of components and electroplating processes are long established in China. Due to the imposed tariffs and cost increase, some US LED lighting manufacturers have already reported price rises for their products in the US market. Meanwhile, to avoid the tax, Taiwanese LED makers that have production facilities in China may move assembly back to Taiwan before exporting to North America. To maintain competitiveness in the long term, LED companies may relocate production to their facilities outside China in order to minimize the impacts of trade issues, concludes LEDinside.

www.ledinside.com

SemiGen boosts contract manufacturing capability

Firm invests $0.5m in new assembly & test equipment

SemiGen Inc of Manchester, NH, USA — an ISO- and ITAR-registered RF/microwave assembly, automated PCB manufacturing, and RF Supply Center — says that, after moving into its new facility, it has made an additional capital investment of over $0.5m in new production, wafer fab and testing equipment to support customer demand.

The new equipment consists of improvements across the firm's entire service platform and includes: a new Mycronic MY300 pick & place system; two new Westbond wire bonders, a new Centrotherm eutectic vacuum chamber, new HTOL/HTRB ovens; as well as a new Disco DAD3220 dicing saw. In addition, the firm has made upgrades in its high-frequency testing department, including several new pieces of performance testing and metrology tools.

"Our CEO, Jim Morgan, has said we must do our best to help our customers augment their design, assembly, and hi-rel testing and up-screening capabilities, and it feels great to see this new equipment getting up and running to do just that," says president Tim Filteau.

SemiGen offers outsourcing to OEMs in the RF/microwave, military, space, homeland security, optical, medical device and commercial wireless markets. Its services and products are designed to fill voids in the manufacturing supply chain and production floor. SemiGen's design and manufacturing center includes wire bonding to silicon (Si), gallium arsenide (GaAs) and gallium nitride (GaN) chips, RF/microwave and PCB assembly, mixed-signal digital and analog assembly, module repair, and high frequency testing and up-screening services.

In recent years, SemiGen has invested in coupling its services with in-stock product solutions by carrying the diodes, active and passive semiconductor devices, and bonding supplies needed for the production of several types of solid-state, multi-function assemblies (MFAs) and components. Bonding supplies are available for online purchase. The team helps with designs, builds prototypes, and handles volume production runs within its new 37,000ft^2 facility, which also includes a class 10,000 cleanroom. Manual to fully automatic assembly solutions are now available.

With its recent upgrades in place, the firm is also offering wafer processing of silicon wafers, as well as processing ceramic substrates. Processing services provided include any combination of photolithography, wet etch, dry etch, metallization, grinding, polishing and in-process metrology.

The recent investments in RF and microwave testing and environmental screening lab has also enabled the firm to offer high-reliability (hi-rel) screening of amplifiers, FETs, MMICs, transistors, diodes and other RF and microwave components operating up into millimeter-wave frequencies.

Tests can be performed and delivered with full documentation in adherence with MIL-PRF-19500, MIL-PRF-38534 and MIL-PRF-38535 requirements. Element evaluation and screening options from Class H, Class K, TX, TXV, S-level, as well as custom SCD driven requirements, are available.

RF and microwave engineers and OEM procurement agents seeking design for manufacturability (DFM) and purchasing consulting on outsourcing their assembly and test can submit their technical or operational related questions on the contact page of the firm's website.

www.semigen.net/contact

Skyworks launches GNSS low-noise amplifier front-end modules for Internet of Things applications

Skyworks Solutions Inc of Woburn, MA, USA (which makes analog and mixed-signal semiconductors) has launched the SKY65933-11 and SKY65943-11 as its latest GNSS low-noise amplifier (LNA) front-end modules (FEMs).

The turnkey GNSS connectivity solutions feature Skyworks' proprietary temperature-compensated (TC-SAW) filters, are designed specifically for Internet of Things (IoT) applications including smartwatches, action cameras, drones, asset trackers and personal navigation devices, and can be easily integrated by wireless module and IoT device makers, it is claimed.

Both modules come in a compact 2.5mm x 2.5mm multi-chip module (MCM) package with surface-mount technology and offer extremely low leakage current (1μA max) — a key benefit for battery-powered IoT devices. They also integrate a pre- and post-filter, LNA and matching to reduce PCB area (compared with a discrete implementation) as well as a single DC supply for design flexibility and simplicity.

The SKY65933-11 and SKY65943-11 are multi-GNSS compatible, spanning GPS, GLONASS, GALILEO, COMPASS (BeiDou) and QZSS receiver applications in the 1559–1606MHz range.

www.skyworksinc.com/Product/3578/SKY65933-11

www.skyworksinc.com/Product/3579/SKY65943-11

GlobalFoundries delivering 8SW RF SOI client chips on 300mm platform for next-gen mobile applications

At its annual Global Technology Conference (GTC), GlobalFoundries of Santa Clara, CA, USA says that its mobile-optimized 8SW 300mm RF silicon-on-insulator (SOI) technology platform has been qualified and is in production. Several clients are engaged for this RF SOI process, tailored to accommodate aggressive LTE and sub-6GHz standards for front-end module (FEM) applications, including 5G Internet of Things (IoT), mobile and wireless communications.

Leveraging the 300mm RF SOI process, 8SW delivers significant performance, integration and area advantages, with up to 70% power reduction and 20% smaller overall die size compared with the previous generation. GlobalFoundries says that the technology enables superior low-noise amplifiers (LNAs), switches and tuners by supplying higher voltage handling and a best-in-class on-resistance (R_{on}) and off-capacitance (C_{off}) for reduced insertion loss with high isolation. The optimized RF FEM platform helps designers to develop solutions that enable extremely fast downloads, higher-quality connections and reliable data connectivity for existing 4G/LTE Advanced operating frequencies and future sub-6GHz 5G mobile and wireless applications.

"GlobalFoundries has now delivered more than 40 billion RF SOI chips for the world's smart devices, and this latest generation of RF SOI technology is another proof point that we're poised to meet accelerating global demand for solutions that deliver seamless, reliable data connectivity everywhere," says Christine Dunbar, vice president of the RF business unit. "The mobile market continues to favor RF SOI, and GlobalFoundries' industry-leading 8SW process in 300mm manufacturing is specifically designed to help our clients take advantage of more frequency bands that will deliver ultra-reliable communications across high-band LTE and future 5G applications," she adds.

"We are proud to support GF's new advanced and differentiated 8SW technology on 300mm RF SOI substrates and to continue our long-term strategic engineering and manufacturing collaboration enabling next-generation connectivity solutions," comments Dr Bernard Aspar, executive VP at engineered substrate supplier Soitec. "We are ready to deliver the 300mm RF SOI substrates in high volumes to meet GF clients' growing market demands," he adds.

"SEH believes 300mm RF SOI products are an important technology, whose time has come," comments Nobuhiko Noto, general manager of SOI Division at Japan's Shin-Etsu Handotai (SHE). "SEH has been a long-time partner on RF technology and looks forward to supporting GF for their future generations of RF technologies as well. We will continue to be a supplier to the 300mm RF SOI market as it grows."

The 8SW technology is manufactured on GF's 300mm production line at Fab 10 in East Fishkill, NY, USA, enabling clients to take advantage of advanced tooling and processes for faster time-to-market with RF SOI. Qualified process design kits are available now.

www.globalfoundries.com

pSemi reorganizes and promotes two directors to VPs

Murata company pSemi Corp of San Diego, CA, USA (formerly Peregrine Semiconductor Corp) — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has announced several organizational changes, including the promotion of two directors to vice presidents, a simplified organizational structure and a change in role for CEO Stefan Wolff. These changes come amidst a record-breaking quarter as pSemi prepares for additional rapid growth. The firm is projected to end this quarter in September with revenue 15% higher than the prior record.

Wolff will step down as CEO on 1 October. Former CEO and current chief technology officer Jim Cable will serve as CEO pro tem. In order to support the transition, Wolff will remain as strategic advisor until December, when he will return to Germany to be closer to his family.

"pSemi is only beginning to harness and deliver its innovative products on a large scale," comments Wolff. "We have a fantastic team to deliver what the market needs next, a full design-win pipeline, an award-winning patent portfolio and outstanding support from our parent company, Murata," he adds. "Our team, our business and our product portfolio have grown substantially. With our simplified organizational structure and the addition of further industry expertise to our leadership team, I am confident pSemi can effectively scale the business to the next level and become Murata's center of excellence for RF, mixed-signal, power, optical and ASIC semiconductors."

The firm will promote Donna Fenn to vice president of HR and Anil Tata to vice president of IT, effective 1 October. Fenn joined pSemi in 2016 as director of HR and, under her leadership, headcount has grown to more than 580 staff. Tata joined pSemi in 2015 as director of IT, and he has effectively scaled the enterprise's systems. Both positions will report directly to the CEO and will support additional internal needs and more collaboration with Murata.

www.psemi.com

Custom MMIC awards 'Women in Engineering' scholars

Monolithic microwave integrated circuit developer Custom MMIC of Westford, MA, USA has awarded its inaugural 'Women In Engineering' scholarships, which were launched in spring — in partnership with the Greater Lowell Community Foundation — to provide full tuition and fees for undergraduate engineering degrees to three young female graduates of either Groton-Dunstable High School in Groton, MA or Westford Academy in Westford, MA. After receiving 11 outstanding applications for the award, and due to the quality of applicants, it has been decided to expand the scope of the scholarship.

Emma Fournier of Groton, MA (who will attend Tulane University to study Chemical Engineering) was awarded the full scholarship totaling about $112,000 over four years. Grace Remillard of Groton, MA (who will attend the University of Massachusetts Lowell to study Electrical Engineering) and Sarah McKinley of Westford, MA (who will attend Clarkson University to study Mechanical Engineering) were each awarded partial scholarships totaling $40,000 over four years.

"This has been a dream of mine for a few years now," says Custom MMIC's president & CEO Paul Blount. "The three women chosen were impressive in their past accomplishments and future goals," he adds. "We are also fortunate to have the Greater Lowell Community Foundation as our partner, for the logistical support they provide is a major reason we can offer these scholarships. We look forward to working with them for many years to come."

The firm plans to offer the scholarship again next spring, and will likely increase the application pool to include other nearby towns.

www.custommmic.com

Low-noise amplifier with 0.6dB noise figure and spanning 2–6GHz

Custom MMIC has launched a gallium arsenide low-noise amplifier (LNA) MMIC with broadband noise figure performance previously only achievable with discrete FET designs. The CMD283C3, with a noise figure of 0.6dB, is the first in a family of new ultra low-noise amplifiers.

The CMD283C3 LNA covers 2–6GHz with high mid-band gain of 27dB and output P1dB of 16dBm.

Housed in a leadless 3mm x 3mm surface-mount package, the new MMIC operates from a bias supply of +2V to +5V and draws a nominal 42mA in current.

The CMD283C3 is suitable for S- and C-band receivers requiring excellent sensitivity, and as a replacement for discrete FET LNA solutions.

www.custommmic.com/cmd283c3

TowerJazz addressing emerging 5G and mmWave markets with new SiGe and RF SOI technologies

At European Microwave Week (EuMW 2018) in Madrid, Spain (25–27 September), specialty foundry TowerJazz (which has fabrication plants at Tower Semiconductor Ltd in Migdal Haemek, Israel, and at its US subsidiaries Jazz Semiconductor Inc in Newport Beach, CA and TowerJazz Texas Inc in San Antonio, TX, and at TowerJazz Japan Ltd) showcased its RF silicon process capability including silicon germanium (SiGe) and RF silicon-on-insulator (SOI) technologies, addressing the emerging 5G and millimeter-wave (mmWave) markets and focusing on high-data-rate mobile and automotive applications.

Specifically, TowerJazz presented its high-volume SiGe BiCMOS technology for 5G mobile transmit–receive chips with greater than 12Gbps data rates, with record performance in the 28GHz band (a more than ten-fold improvement in data rate versus 4G LTE, and meeting many other technical specification requirements of the emerging 5G standard).

The firm also highlighted its 5G RF SOI technology, which includes its newest 65nm process ramping on 300mm wafers with what is claimed to be best-in-class low-noise amplifier (LNA) and switch performance to address integration in the front-end module. The process can reduce losses in an RF switch, improving battery life and boosting data rates in handsets and Internet of Things (IoT) terminals.

Also, at the accompanying 48th European Microwave Conference (EuMC 2018), TowerJazz participated in a panel session to discuss RF semiconductor solutions for 5G systems.

www.eumweek.com
www.towerjazz.com

Anokiwave appoints Abhishek Kapoor as VP of sales

Anokiwave Inc of San Diego, CA, USA — which provides highly integrated silicon core chips and III–V front-end integrated circuits for millimeter-wave (mmW) markets and active antenna-based solutions — has appointed Abhishek Kapoor as VP of sales, based at the company's office in Billerica, MA. He joined Anokiwave in January, and is responsible for growing sales, increasing the firm's global footprint, building and managing the sales channel and distribution teams, and establishing a global brand presence.

"Abhishek has already greatly improved our sales channel operations and our SATCOM business, and we look forward to the even greater impact he can have across all sales functions and all three of our major markets," says chief operating officer Carl Frank. Over his career Kapoor has held various positions in sales, marketing, product management, business development and engineering, giving him a holistic view of the business, it is reckoned. He received his B.S. in electrical engineering from Virginia Tech in 2007 and M.B.A. from Kenan-Flagler Business School at University of North Carolina—Chapel Hill in 2013.

The firm says that the appointment comes at a strategic time for it, with opportunities for continued growth in the rapidly developing mmW 5G, SATCOM and aerospace & defense (A&D) markets.

"As we continue to develop our leadership in the mmWave markets, we remain committed to offering our customers the very best products, backed by market-leading levels of sales and service support," says Frank. "Abhishek's leadership, along with his product knowledge, and depth of sales and marketing experience, will lead Anokiwave to new heights in customer satisfaction and sales growth," he believes.

www.anokiwave.com

Anokiwave joins 5G O-RAN alliance as contributing member

Anokiwave has joined the O-RAN (Open Radio Access Network) alliance as a contributing member in support of its vision of open, interoperable interfaces that maximize the use of common off-the-shelf hardware.

Announced at the GSMA's Mobile World Congress (MWC 2018) in Barcelona, Spain at the end of February, O-RAN is an alliance formed by the major mobile operators such as AT&T, NTT DoCoMo, China Mobile, Orange and Deutsche Telekom to cooperate and to share 5G technology. The alliance aims to expand the 5G ecosystem by evolving Radio Access Network (RAN) towards using open, interoperable interface.

Anokiwave expects to participate in the O-RAN alliance by making technical contributions on hardware focusing on the mmWave active antenna for 5G, as well as the active antenna unit (AAU) and remote radio unit (RRU) specifications and interface definitions.

"This will help accelerate the adoption of off-the shelf mmWave hardware, thus further enabling the commercialization of active antennas for 5G," expects Alastair Upton, senior VP of business development. "In conjunction with our customers and business partners, our products are already in use by several O-RAN alliance network providers."

MACOM showcases RF & microwave portfolio at EuMW

At European Microwave Week (EuMW 2018) in Madrid, Spain (25–27 September), MACOM Technology Solutions Inc showcased its gallium nitride on silicon (GaN-on-Si) portfolio, lightwave antennas and other high-performance MMIC and diode products

Specifically, MACOM highlighted new products optimized for 5G, wireless base-stations, radar, test & measurement, and industrial, scientific & medical RF applications:

- *Lightwave antenna solutions*: combining RF coherent beam-forming and fiber-to-the-element optical transport to deliver wideband performance, low latency and improved spectral efficiency.
- *Enabling the next generation of wireless base-stations*: GaN-on-Si 60W average power Doherty module.
- *Front-end modules (FEMs)*: Delivering performance and reliability for wireless networking leveraging proprietary switching technology and integration.
- *RF Energy*: the industry's first GaN-on-Si-based RF energy toolkit.
- *GaN-on-Si*: GaN-on-Si technology in mainstream CMOS factories is expected to enable the scale capacity, cost structure and supply chain economics for mainstream base-stations and RF energy applications at scaled-volume production levels.
- *High-performance RF components*: showcasing MACOM's high-performance MMICs, limiter diode design, cross-reference tools and application-specific solutions.

MACOM experts also participated in various sessions at EuMW, including:

- Technical Session: 'Ka-Band P-I-N Diode Based Digital Phase Shifter' — presenter: Daniel Kramer;
- Technical Session: 'Characterization of Bond Wire Interconnects in QFN Packages' — presenter: Qun Xiao.

www.eumweek.com
www.macom.com

Delta begins US DOE-sponsored program to develop microgrid-capable solid-state transformer-based 400kW extreme fast chargers for electric vehicles

Partners include GM, DTE Energy, NextEnergy and CPES Virginia Tech

Power and thermal management solutions provider Delta has begun work on a three-year, $7m research program — with 50% cost-share by the US Department of Energy (DOE) — to develop a solid-state transformer (SST)-based extreme fast EV charger (XFC) with industry-leading capacity up to 400kW to provide capable EVs with a 180-mile range with less than 10 minutes of charging. Moreover, the proposed XFC design is expected to offer grid-to-vehicle efficiency up to 96.5%, four times less weight and half the size of conventional DC fast EV chargers (DCFC), as well as a high-voltage direct current (HVDC) port to utilize energy storage and renewable energy systems, minimizing demand on the power grid. All these unique features are intended to accelerate the ubiquitous adoption of EV charging.

The initiative will be supported and led by a program development team consisting of industry experts based at Delta's automotive division in the greater Detroit area (Livonia, MI) and researchers at the Delta Power Electronics Laboratory (DPEL) in North Carolina's Research Triangle Park. Project partners include General Motors LLC, DTE Energy, CPES Virginia Tech, NextEnergy, the Michigan Agency for Energy's Energy Office and the City of Detroit's Office of Sustainability.

"By utilizing solid-state transformer technology, we have the opportunity to create unprecedented charging speed and convenience that will ultimately help support the DOE's strategic goal of increasing EV adoption across the nation," says M.S. Huang, president of Delta Electronics (Americas).

The novel SST power cell topology directly utilizes medium-voltage alternating current (MVAC) at 4.8kV or 13.2kV, eliminating conventional line frequency transformer (LFT) technology, which converts low-voltage alternating current to a direct current (DC) to charge the high-voltage battery in an EV. Combined with a new silicon carbide (SiC) MOSFET device, the proposed SST enables a 3.5% improvement in grid-to-vehicle efficiency up to 96.5%, a 50% reduction in equipment footprint, and four times less weight than existing DCFC EV chargers. Moreover, the 400kW XFC prototype, which is expected to be ready in 2020, will have a power level enabling ground-breaking 3C charging speed on tomorrow's long-range EVs. With this technology, EV drivers will need close to 10 minutes to achieve an additional 50% of vehicle range on their vehicle. For example, a 360-mile EV could achieve a 180-mile range in about 10 minutes of charging.

Early data and results from the program should give automotive manufacturers, technology providers, cities and utilities a greater understanding of how fast charging can impact demand response efforts within specific circuits. The project will also provide insight into how renewable generation can be integrated to avoid infrastructure strain on the power grid associated with the wide deployment of XFCs.

www.deltaenergysystems.com

Delta uses Transphorm's HV GaN FETs to shrink power supply

Power electronics and thermal management solutions provider Delta Electronics says that its latest 80Plus Platinum 800W power supply unit (PSU) – which now offers a backup lithium-ion battery – benefits from the use of high-voltage (HV) GaN FETs from Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage power conversion applications.

Should a data center lose power, the PSU's battery will keep connected servers running for one minute — long enough to allow for a proper power-down sequence. The use of GaN enabled Delta to reduce the power system size by ~25%, allowing the inclusion of a battery within a CRPS form factor.

The design stems from Delta's experience working with GaN power semiconductors in an effort to equip customers with high-performing power solutions. The decision to use HV GaN devices depended partly on meeting new product reliability and power density objectives. Delta also sought to repurpose its existing PSU design — a standard PFC continuous-conduction mode (CCM) boost converter.

Market analyst firm Yole Développement projects that the use of GaN within server power supplies will grow to about $50m by 2022, comprising the third largest segment of the total GaN power device market (~$450m by 2022), behind broad industrial power supplies.

www.transphormusa.com/design-resources

X-FAB doubles 6" SiC foundry capacity at Lubbock fab

X-FAB Texas buys second heated ion implanter, for production from first-quarter 2019

In response to customer demand for high-efficiency power semiconductor devices, analog/mixed-signal and specialty foundry X-FAB Silicon Foundries SE of Erfurt, Germany plans to double the 6" silicon carbide (SiC) process capacity at its fab in Lubbock, TX, USA.

In preparation for manufacturing 6-inch SiC wafers, X-FAB Texas has purchased a second heated ion implanter, for delivery by the end of 2018 and production release in first-quarter 2019 (in time to meet projected near-term demand).

Claiming to have been the first wafer foundry to offer SiC manufacturing on 6" wafers, X-FAB says that its doubling in SiC process capacity demonstrates its commitment to SiC technology and the SiC foundry business model.

X-FAB says that advantages of its 6-inch SiC process capabilities for power semiconductors include superior high-voltage operation, significantly lower transistor on-resistance, much lower transmission and switching losses, extended high-temperature operation (as high as 400°F/204°C), higher thermal conductivity, very high-frequency operation, and lower parasitic capacitance. The firm's SiC process capabilities allow customers to realize high-efficiency power semiconductor devices including high-power MOSFETs, JFETs and Schottky diodes.

Systems with SiC power devices benefit from reduced system size and weight, notes X-FAB. Also, because they dissipate less heat, they are significantly more efficient compared with similar power semiconductor technologies. These features are important for switching power supplies and power converters found in electric vehicles (EVs), wind turbines and solar converters. High-temperature operation improves reliability, especially in hot industrial applications such as aircraft, EV racecars and train locomotives. Reduced system size and weight is important in portable medical equipment and hybrid EVs (PHEVs).

"With the rising popularity of SiC we understood, early on, that increasing our ion implant capability would be critical to our continued manufacturing success in the SiC marketplace," says X-FAB Texas' CEO Lloyd Whetzel. "This is just the first step in our overall capital plan for SiC-specific manufacturing process improvements. This step also enables X-FAB to demonstrate our commitment to the SiC industry."

X-FAB's 6" SiC process capabilities are available at its Lubbock, Texas manufacturing site, which is certified for automotive manufacturing according to the new IATF-16949: 2016 International Automotive Quality Management System (QMS).

The firm exhibited at the European Conference on Silicon Carbide and Related Materials (ECSCRM 2018) in Birmingham, UK (2–6 September).

https://warwick.ac.uk/fac/sci/eng/ecscrm2018
www.xfab.com

Advantech Wireless and Alga present at IBC 2018

Toronto-based wireless technology management firm Baylin Technologies Inc (which provides passive and active RF products and services) says that both its subsidies Advantech WirelessTechnologies Inc of Montreal, Canada and Alga Microwave of Kirkland, Quebec, Canada (acquired on 28 June) presented satellite solutions for broadcast applications at the IBC 2018 event in Amsterdam, The Netherlands (14–18 September).

Showcasing their Ultra HD-ready satellite solutions, the proprietary GaN-based solid-state power amplifiers (SSPAs) and block up-converters (BUCs) from Advantech and Alga deliver solutions for Digital Satellite News Gathering (DSNG).

In an Ultra HD broadcasting environment, additional power is required in order to transmit higher modulation at a lower cost. The new generation of GaN-based SSPAs from Advantech are designed for very high-order modulation transmission of up to 256 APSK in a single compact unit, making ultra HD 4K/8K broadcast over satellite more cost effective.

The GaN-based SSPAs are teleport-grade, designed for 4K/8K Ultra HD transmission and provide elevated linearity while supporting higher-modulation transmissions. The enhanced linearity comes with no increase in size, weight or energy consumption, maximizing efficiency and reducing operational costs.

www.baylintech.com
www.advantechwireless.com
www.alga.ca

Advantech receives million dollar order for X-band SSPAs and BUCs

Advantech Wireless Technologies has received an order from a NATO member country worth over $1m for its X-band line of GaN-based SSPAs and BUCs.

"These military-grade X-band solid-state power amplifiers and block up converters are designed and produced by Advantech to meet the stringent requirements of military standards for large data rates and wide-bandwidth applications," says Baylin's president & CEO Randy Dewey.

With high linearity and operating efficiency, the latest generation of X-band SSPAs is built to perform in the most challenging environments. The high-power X-band SSPAs are designed to provide very high throughput for large strategic military satellite teleports in any environmental condition.

"In the last few years we have seen a significant migration from the traditional way of designing large satellite uplinks," comments president John Restivo. "Our customers are adopting Advantech's solid-state technology and phasing out the old Klystrons and TWTs which are reaching end of life," he adds. "The new technology's advantages include massive OpEx reduction and increased teleport technological capabilities".

Mission receives SSPA orders and design wins

Mission Microwave Technologies LLC of Santa Fe Springs, CA, USA, which makes gallium nitride (GaN)-based solid-state power amplifiers (SSPAs) and block up-converters (BUCs), has received orders and design wins from top-tier system integrators in both government and commercial satellite communications markets.

"Since Mission Microwave was founded over four years ago, we have made steady progress winning the confidence and contracts of the leading suppliers of satellite communications (SATCOM) terminals for use in ground, air and maritime services," says president & CEO Francis Auricchio. "We can foresee building on this solid foundation of customer validation to expand the presence and availability of products to more markets segments that benefit from our products' superior performance and remarkable benefits in size, weight and power (SWaP)."

Customer wins include applications for Ku-band BUCs across the 25–400W range. These BUCs are used on lightweight fly-away and mobile terminals, including vehicular-mounted terminals that are part of a nationwide first-responder network. Other wins include system integrators of flat-panel antennas and lightweight deployable network terminals.

Mission continues to ship high-power Ka-band BUCs for fixed and mobile applications, with the Dart, Stinger, Javelin and Titan platforms bringing weight savings and performance to terminal designs for power ranges of 10–200W in both commercial and government bands. Recently, two suppliers of maritime terminals launched high-throughput 10W terminals compatible with Inmarsat's Global Xpress network that are based on Mission Microwave products. Other Ka-band wins include high-power BUCs for large gateway terminals for use in wideband global satellite networks.

"The satellite terminal market in X, Ku and Ka band increasingly demands the reliability of SSPAs to replace tube amplifiers across the entire range of mobile, fixed and transportable satellite terminals," says Auricchio. "Mission Microwave has proven its technology and ability to deliver and support the ground terminal market as it continues to expand in support of increased in-orbit capacity across a variety of global satellite network architectures."

www.missionmicrowave.com

5G GaN2 project developing 28GHz, 38GHz and 80GHz demonstrators for 5G cellular network base stations

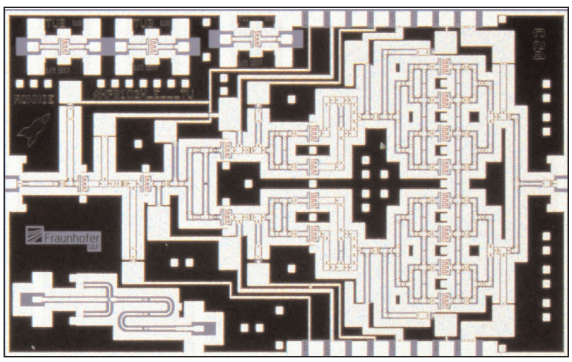
Fraunhofer IAF to develop E-band power amplifiers for 80GHz

The fifth-generation (5G) cellular network will enable data transmission between humans, devices and machines in real time, but so far no technology exists that allows for a reliable, fast and energy-efficient 5G network. In the European Union (EU) project '5G GaN2', 17 partners from research and industry have joined forces to develop cost-effective and high-performance technologies, based on gallium nitride, for the upcoming mobile communications standard. The consortium, which also includes the Fraunhofer Institute for Applied Solid State Physics (IAF) of Freiburg, Germany, started its work in July.

Besides Fraunhofer IAF, the project consortium partners include the complete value chain of mobile phone technology (wafer suppliers, semiconductor manufacturers and system integrators, together with universities and research institutes).

In the 5G cellular network, cars, devices and production machines will also transmit data in real time via the wireless radio network. In future, these high data rates will be covered by frequency bands in the millimeter-wave range (>24GHz), which provide a ten times higher bandwidth compared with currently available frequency bands (<3GHz) and have now been released internationally to significantly increase the bandwidth range.

However, these new frequency ranges cannot be served efficiently with existing mobile and antenna technology. "Therefore, it is necessary to improve the available output power and energy efficiency of the net infrastructure for these innovative frequency bands, through the use of advanced gallium nitride technology," says Dr Dirk Schwantuschke, who is managing the project on behalf of Fraunhofer IAF. In the '5G GaN2' project, components, parts and circuits for 5G base stations will be developed based on GaN. "The contribution of the Fraunhofer IAF to the overall project will be the development of power amplifiers in E-band, the frequency range around 80GHz," explains Schwantuschke.



The E-band amplifier chip developed at the Fraunhofer IAF measures only 4mm x 2.5mm.

GaN-based devices are especially well suited for powerful high-frequency amplifiers that are required for base stations and the infrastructure

Lowering cost and improving performance

To meet the demand for data transmission via millimeter-wave frequency bands in the future, base-station technologies need to fulfill two criteria: the output power needs to be improved while simultaneously keeping cost and energy consumption low. To achieve these goals, the '5G GaN2' project partners are counting on GaN-based technology and amplifier circuits. GaN-based electronic components and systems are much more energy efficient than conventional silicon-based components. GaN components can optionally be applied on cost-efficient silicon substrates. Another aspect of the project is the combination of various components in a single module, through innovative approaches regarding packaging technologies, in order to reduce costs.

Dr Dirk Schwantuschke, group manager in the microelectronics department and supervisor of the project '5G GaN2' on behalf of Fraunhofer IAF.

The project's aim is to realize demonstrators at 28GHz, 38GHz and 80GHz serving as key technologies for the development of a powerful and energy-efficient 5G cellular network based on GaN. The European Commission initiative ECSEL (Electronic Components and Systems for European Leadership) promotes the three-year joint project, consisting out of 17 project partners from seven countries. ECSEL supports development, research and innovation electronics by bringing various partners from industry, research and public sphere together.

Amplifier development Fraunhofer IAF

Fraunhofer IAF has particular expertise in developing GaN-based amplifiers. "GaN-based devices are especially well suited for powerful high-frequency amplifiers that are required for base stations and the infrastructure of the cellular network, as it allows [us] to provide high frequencies at high power," says Schwantuschke. "The amplifiers developed at the Fraunhofer IAF are capable of sending more data faster and more energy efficiently through the cellular network."

www.5ggan2.eu

PowerAmerica issues Call for Projects to help speed adoption of wide-bandgap technologies

The PowerAmerica institute — a member of Manufacturing USA — has issued its 2018 Call for Projects, which seeks projects spanning 1 July 2019 to 30 June 2020.

PowerAmerica aims to save energy and create US manufacturing jobs by accelerating the development and large-scale adoption of wide-bandgap (WBG) semiconductor technology made with silicon carbide (SiC) and gallium nitride (GaN) in power electronics systems. Located at North Carolina State University (NCSU) in Raleigh, NC, the institute is funded by the Department of Energy, industry partners and the state of North Carolina, and has a member portfolio representing over 45 leading companies in the wide-bandgap semiconductor field.

The 2018 Call for Projects is focused primarily on the manufacturing of SiC and GaN power semiconductor devices, wide-bandgap power electronics architectures and assemblies, and packaging and manufacturing processes with the potential to improve performance, lower cost, and create US manufacturing jobs. Demonstration of WBG devices in high-volume commercially viable power electronic applications is desired.

Teaming between companies, and between companies/national laboratories/universities is required. All projects require a 1:1 cost share.

The concept paper submission is due on 9 October (at 9pm EDT). The Full Proposal submission deadline is 4 December (at 9pm EST).

https://poweramericainstitute.org/2018-call-for-projects

US Air Force's GaN technology to be transferred to BAE Systems' Advanced Microwave Products Center

6-inch, 140nm MMIC process to be qualified by 2020, with products available to DoD suppliers through open foundry service

BAE Systems has signed a cooperative agreement with the US Air Force Research Laboratory (AFRL) for Phase 1 of a technical effort to transition gallium nitride (GaN) semiconductor technology developed by the US Air Force to its Advanced Microwave Products (AMP) Center in Nashua, NH, USA.

As part of the effort, BAE Systems will transfer and further enhance the technology, and scale it to 6-inch wafers to slash per-chip costs and improve accessibility of the defense-critical technology.

Since GaN technology provides broad frequency bandwidth, high efficiency and high transmit power in a small footprint, it is suitable for next-generation radar, electronic warfare (EW) and communications systems. Under the agreement, BAE Systems will work with AFRL to establish a 140nm GaN monolithic microwave integrated circuit (MMIC) process that will be qualified for production by 2020, with products available to Department of Defense (DoD) suppliers through an open foundry service.

"Millimeter-wave GaN technologies today are produced in research and development laboratories in low volumes at high associated costs or in captive foundries that are not broadly accessible to defense suppliers," says AMP director Scott Sweetland. "This effort will leverage AFRL's high-performance technology and BAE Systems' 6-inch manufacturing capability to advance the state of the art in GaN MMIC performance, reliability and affordability while providing broader access to this critical technology."

Work on the project will primarily take place in BAE Systems' 70,000ft^2 Microelectronics Center (MEC) in Nashua, NH, where it researches, develops and produces compound semiconductor materials, devices, circuits and modules for a wide range of microwave and millimeter-wave applications. The MEC has been an accredited DoD Category 1A Trusted Supplier since 2008, and fabricates integrated circuits in production quantities for critical DoD programs.

As part of the project, the AMP Center team will work closely with the firm's FAST Labs research organization and MMIC design experts from ENGIN-IC.

www.baesystems.com/en-us/product/amp-center

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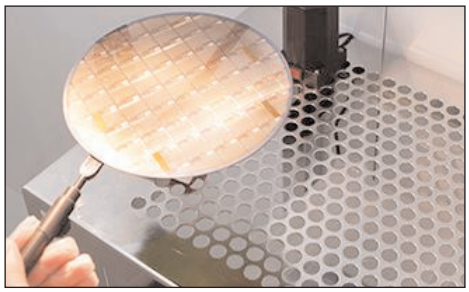
STMicroelectronics and Leti to co-develop GaN-on-Si diode and transistor architectures for power conversion

Process to be transferred from Leti's 200mm R&D line to ST-operated pilot line by 2020

STMicroelectronics of Geneva, Switzerland and micro/nanotechnology R&D center CEA-Leti of Grenoble, France are cooperating to develop and industrialize gallium nitride-on-silicon (GaN-on-Si) technologies for power switching devices, which will enable ST to address high-efficiency, high-power applications, including automotive on-board chargers for hybrid and electric vehicles (HEVs/EVs), wireless charging, and servers.

The collaboration focuses on developing and qualifying power GaN-on-Si diode and transistor architectures on 200mm wafers, a market that research firm IHS Markit forecasts will rise at a compound annual growth rate (CAGR) of more than 20% from 2019 to 2024.

In the framework of Grenoble-based Technological Research Institute Nanoelec (IRT Nanoelec) — an R&D consortium headed by CEA-Leti focused on information and communication technologies (ICT) using micro- and nanoelectronics — ST and Leti are co-developing the process on Leti's 200mm R&D line and expect to have validated engineering samples in 2019. In parallel, ST will set up a fully qualified



manufacturing line, including GaN/Si hetero-epitaxy, for initial production running in ST's front-end wafer fab in Tours, France, by 2020.

In addition, given the attractiveness of GaN-on-Si technology for power applications, Leti and ST are assessing advanced techniques to improve device packaging for the assembly of high-power-density power modules.

"Recognizing the incredible value of wide-bandgap semiconductors, ST's contributions in power GaN-on-Si manufacturing and packaging technologies with CEA-Leti move to arm us with the industry's most complete portfolio of GaN and SiC products and capabilities, on top of our proven competence to manufacture high-quality, reliable products in volume," says Marco Monti, president of STMicroelectronics' Automotive and Discrete Group.

"Leveraging Leti's 200mm generic platform, Leti's team is fully committed to supporting ST's strategic GaN-on-Si power-electronics roadmap and is ready to transfer the technology onto ST's dedicated GaN-on-Si manufacturing line in Tours," says Leti's CEO Emmanuel Sabonnadiere. "This co-development, involving teams from both sides, leverages the IRT Nanoelec framework program to broaden the required expertise and innovate from the start at device and system levels."

In February, ST also announced another development of GaN-on-Si for RF applications with MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications), for MACOM's use across a broad range of RF applications and for ST's own use in non-telecom markets. The RF GaN-on-Si is — for now, at least — better suited to 150mm wafers. Because they produce low switching losses, GaN technologies suit higher-frequency applications.

www.st.com
www.leti.fr

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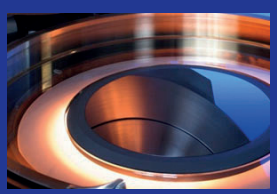
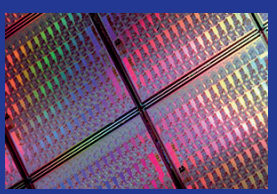
GaP-on-Si templates with high crystalline perfection for high-end applications





For today´s high-end applications we all strive to achieve a supreme performance. The challenging question is this: how to boost the efficiency of Si wafers to get one step ahead?

Our solution for you: NAsP III/V

Our technology has mastered the first challenge for the integration of a variety of III/V semiconductor materials and device heterostructures on 300 mm CMOS compatible (001) Si wafers. For this purpose, we have developed a proprietary nucleation process for the deposition of thin GaP layers on such Si substrates with high crystalline perfection.

Curious? For further information, please contact us at **NAsP.de**

Teledyne e2v HiRel launches highest-voltage 650V/60A bottom-side-cooled GaN FET

Teledyne e2v HiRel Electronics of Milpitas, CA, USA (a business unit of the Teledyne Defense Electronics Group that provides solutions, sub-systems and components to the space, transportation, defense and industrial markets) has launched a 650V/60A gallium nitride (GaN) field-effect transistor (FET) device dedicated to demanding high-reliability (HiRel) applications. The new 650V/60A enhancement-mode power transistor is claimed to be the highest-voltage GaN FET on the market.

Fabricated in a GaN-on-silicon process, the TDG650E60 is packaged in GaN System's GaNPX package, which enables very low inductance and thermal resistance in a small 11mm x 9mm outline. The package is bottom-side cooled to offer very low junction-to-case thermal resistance. GaN System's patented 'Island' technology is key to enabling high voltage, current and efficiency.

The plastic-packaged GaN FET is the first 650V product released from the new Teledyne e2v HiRel Enhanced Product (EP) series that addresses the concerns of applications where ceramic packages are not required. In such applications, the cost and earliest availability of newer technologies are the highest priorities for design engineers.

Teledyne e2v HiRel GaN screening, baseline control and a 10 year longevity support program will give reliability and availability assurance for demanding military, space, avionics, and related HiRel applications, says the firm.

"Releasing a HiRel 650V GaN FET is an industry milestone, giving design engineers more margin in the most demanding space and military COTS applications," says Mont Taylor, VP of business development. "The non-ceramic package will allow customers to benefit from the low-weight and efficient GaNPX package for the best performance in these stringent applications."

For demanding high-power applications, GaN power FET technology is the newest, most efficient solution, says the firm. The new 650V FET builds on this by offering additional benefits, including:

- very high switching frequency;
- SWaP (the device is a offered in a very small package);
- high voltage and high current;
- high energy density; and
- modular flexibility (the parts can be used in parallel to increase current).

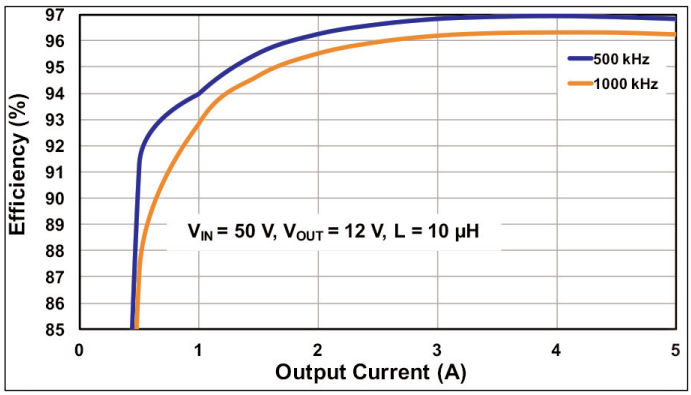
Teledyne HiRel Electronics is able to offer samples of the new device available for review. Shipping will begin in November.

www.gansystems.com
www.e2v.com/products/semiconductors/power-solutions

EPC launches 100V, 25mΩ eGaN power transistor

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 launched the EPC2051, a 100V GaN transistor with a maximum $R_{DS(on)}$ of 25mΩ and a 37A pulsed output current for high-efficiency power conversion in a small footprint.

The EPC2051 measures just 1.30mm x 0.85mm (1.1mm^2) — 30 times smaller than a comparable silicon MOSFET — so applications demanding higher efficiency and power density no longer have to choose between size and performance, says the firm. Despite the small footprint of the chip-scale package, operating in a 50V–12V buck converter the EPC2051 achieves 97% efficiency at a 4A output while switching at 500kHz.



In addition, the low cost of the EPC2051 brings the performance of GaN FETs at a price comparable to silicon MOSFETs.

Applications benefiting from this performance, small size and low cost include 48V input power converters for computing and telecom systems, LiDAR, LED lighting and Class-D audio.

"The ability of eGaN-based power devices to operate efficiently at high frequency widens the performance and cost gap with silicon," says CEO Alex Lidow.

The EPC9091 development board is a 100V maximum-device-voltage half-bridge featuring the EPC2051, and the UP1966A gate driver from uPI Semiconductor. This 2"x2" (50.8mm x 50.8mm) board is designed for optimal switching performance and contains all critical components for easy evaluation of the 100V EPC2051 eGaN FET.

The EPC2051 eGaN FET is priced at $0.67 each in 1000-unit quantities and $0.37 in 100,000-unit quantities. The EPC9091 development board is priced at $118.75 each. Both products are available for immediate delivery from distributor Digi-Key Corp.

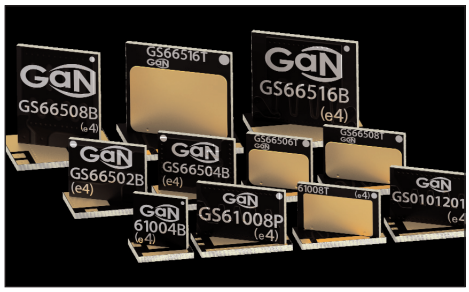
www.epc-co.com

GaN Systems appoints Arrow Electronics as distributor in EMEA

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) says that distributor Arrow Electronics is now supplying its range of GaN transistors in Europe, Middle East and Africa (EMEA).

GaN Systems says that its 100V and 650V transistor product families offer high efficiency, small sizes and open up opportunities in areas from data centres, electric vehicles and renewable energy to industrial motor drives and consumer electronics.

"This agreement further extends customer access and support to our industry-leading capabilities in power GaN transistors," says Tony Astley, director EMEA sales at GaN Systems. "As the demand for GaN technology grows worldwide, Arrow's extensive power team that



combines technical and commercial experience provides the perfect platform for bringing GaN Systems' innovative technology to engineers in EMEA," he adds.

"For some applications, engineers need to look beyond established solutions if they are to create ground-breaking products," comments Matthias Hutter, VP of product management & supplier marketing, EMEA at Arrow Electronics. "GaN technology can deliver significant efficiency savings and GaN Systems offers a range of products to help make this happen."

www.arrow.com

GaN Systems showcases GaN power transistor products and design tools at ECCE 2018

At the 10th annual IEEE Energy Conversion Congress & Expo (ECCE 2018) in Portland, OR, USA (23–27 September), GaN Systems exhibited the latest products and design tools that extend the capabilities of its GaN power transistors. These include the 100V, 120A, 5mΩ GaN E-HEMT device (claimed to be the highest-current and most power-efficient 100V GaN power transistor); 650V, 120A, 12mΩ GaN E-HEMT (said to be the world's highest-current-rated GaN power transistor); and wireless power amplifiers (100W and 300W) for wireless charging in high-power consumer, industrial and transport applications. In addition, reference designs and evaluation kits that ease the design process will be shown.

The firm also provided a wide range of customer and application demonstrations focused on industrial, automotive, and renewable energy applications.

In the poster session of the conference, GaN Systems experts presented two posters providing engineers best practices in taking advantage of GaN power transistors in designing improved and innovative power systems:

- 'An Ultrafast Discrete Short-Circuit/ Over-Current Protection Circuit for GaN HEMTs' by Ruoyu Hou, Juncheng Lu and Di Chen; and
- 'Paralleled GaN HEMTs Loss Distribution Analysis for High-power Applications' by Juncheng(Lu) Lu, Ruoyu Hou and Di Chen.

www.ieee-ecce.org/2018
https://gansystems.com/ecce2018

EpiGaN showcases GaN epiwafer solutions for 5G

In the booth of its local agent APEC at SEMICON Taiwan 2018 in Taipei (5–7 September) and at European Microwave Week (EuMW) in Madrid, Spain (23–28 September), EpiGaN of Hasselt, Belgium — which supplies gallium nitride on silicon (GaN-on-Si) and gallium nitride on silicon carbide (GaN-on-SiC) epitaxial wafers for power switching, RF and sensor applications — highlighted its latest GaN epiwafer developments tailored to 5G applications.

As well as enabling smaller, lighter and higher-performance systems with added functionality for power conversion and sensor applications, GaN is being readied to enable key features of new-standard 5G cellular wireless networks, which require exceptionally high-speed connections for multimedia streaming, virtual reality, M2M or autonomous driving applications.

For 5G, EpiGaN has released large-diameter versions of its HVRF (high-voltage radio frequency) GaN-on-Si as well as GaN-on-SiC epiwafer product families. Customers can choose from various optimized top structures to best serve their specific RF device needs — AlGaN, AlN or InAlN barriers combined with GaN or in-situ SiN caps — on silicon substrates up to 200mm and on SiC up to 150mm diameter. EpiGaN claims that its HVRF products enable excellent dynamic behavior, the highest power densities at mmW frequencies and the lowest RF losses (<0.8dB/mm up to 110GHz).

For ultimate RF performance in the 30GHz and 40GHz millimeter-wave bands assigned to 5G, EpiGaN has developed high-electron-mobility transistor (HEMT) heterostructures featuring ultra-thin AlN barrier layers in combination with an in-situ SiN capping layer. These allow the transistor's gate to be located very close to the densely populated channel, maximizing electrostatic coupling between them. This results in far superior RF transistor characteristics, as needed for 5G MMICs. HEMT structures with lattice-matched InAlN barriers exhibit sheet resistivities below 250Ω/sq and enable the highest transistor current densities.

"We are noticing an increasing demand in the market for our RF GaN product solutions optimized for 5G systems," says co-founder & CEO Dr Marianne Germain. EpiGaN offers a "broad portfolio of RF GaN epiwafer products that enables our global customer base to develop differentiated 5G cellular network solutions with industry-leading performance."

www.semicontaiwan.org/en
www.eumweek.com
www.epigan.com

Silvaco and Purdue to co-develop scalable atomistic TCAD for next-generation devices and materials

Purdue's NEMO tool suite to be linked with Silvaco's Virtual Wafer Fab to provide ab-initio to circuit level integrated co-optimization design platform

Silvaco Inc of Santa Clara, CA, USA (which provides electronic design automation and IP software tools for process and device development), Purdue University and Purdue Research Foundation have formed a partnership to extend Moore's law by modeling and simulating transistors and new memory technologies that approach atomistic scale in next-generation semiconductor processes and materials.

Silvaco will license Purdue University intellectual property from the Purdue Research Foundation, a private, non-profit foundation created to advance the university's mission, sponsor research and open an office in the Purdue Technology Center.

For more than 20 years Silvaco has been providing TCAD (technology computer-aided design) tools for semiconductor device and process simulation, and its latest Victory TCAD tools are deployed at leading semiconductor companies worldwide. The agreement involves the commercialization of the NEMO tool suite, an atomistic nanoelectronics modeling and simulation tool that has been used by semiconductor companies for the investigation of advanced physics phenomena aimed at extending Moore's law. The goal of the collaboration is to link NEMO with Silvaco's Virtual Wafer Fab to provide the market with a true ab-initio to circuit level integrated co-optimization design platform.

"We are very excited to bring together the strong research expertise of the Purdue team in atomistic simulation along with Silvaco's strong background in TCAD, modeling and circuit simulation," says Eric Guichard, VP of the TCAD division at Silvaco. "The partnership will result in a powerful solution that enables path finding of advanced semiconductors well before running silicon, which ultimately saves time-to-market and hundreds of millions of dollars in development costs," he adds.

Signing of the agreement between Silvaco and Purdue.

"The NEMO tool suite represents the spearhead of nanotechnology modeling — both for well-controlled experimental conditions as well as large-scale fabrication reality," comments Tillmann Kubis, a research assistant professor in Purdue's School of Electrical and Computer Engineering, in charge of the NEMO project. "Its commercial version, customized to industrial needs and infrastructure, will have high societal impact," he believes. "I also think the fact that Silvaco is interested in Purdue intellectual property, sponsoring further research and plan to open an office here is a strong endorsement of the innovation and collaboration ecosystem at Purdue."

www.silvaco.com
https://engineering.purdue.edu/ECE
www.prf.org

Compound Semiconductor Applications Catapult secures first commercial agreement

CSA Catapult to provide analysis of potential market for University of Bristol's TherMap technology

The Compound Semiconductor Applications (CSA) Catapult has secured its first commercial agreement, with the University of Bristol.

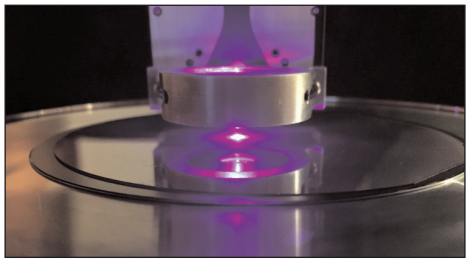
The Compound Semiconductor Applications Catapult is a not-for-profit organization (headquartered in South Wales) focused on accelerating the adoption of compound semiconductors and on bringing applications to life. It works across the UK within a range of industry sectors from automotive to medical, and from digital communications to aerospace.

The university has developed technology called TherMap, which uses a non-destructive technique to measure the thermal properties of semiconductor wafers and other multi-layer structures. The technique is suitable for most wide-bandgap layer structures, such as gallium nitride on silicon carbide (GaN on SiC), and can be used for in-line process monitoring and yield optimization.

The University of Bristol has commissioned the CSA Catapult to provide an analysis of the potential market for this technology in order to inform the commercialization roadmap. The Catapult will interview potential users of the technology to establish their current approach to wafer characterization and inform them about TherMap.

The university is also offering a free trial service to wafer fabs and device manufacturers around the world, and the Catapult is fielding enquiries from interested fabs.

The CSA Catapult works collaboratively and has built relationships with key players across the UK wafer fabrication industry. This outreach to CSA Catapult's network will enable it to advise the university on how its TherMap technology could be used in innovative applications within the compound semiconductor industry.



"This innovation could potentially make a huge difference to the compound semiconductor industry globally by enabling it to assess the quality of semiconductor wafers, improve yield and improve its processes," comments CSA Catapult CEO Stephen Doran. "We are delighted to be a part of bringing this impressive innovation closer to market and marking a milestone for the Catapult in being truly open for business," he adds.

"TherMap is a development of Bristol's CDTR labs for innovative thermal wafer mapping, the result of many years' of research which we aim to translate into an industry product," says professor Martin Kuball of Bristol University's Center for Device Thermography and Reliability (CDTR) Labs.

Building up the Compound Semiconductor Applications Catapult

Currently in start-up mode to build its full technology capability, CSA Catapult will initially focus on three technology areas: Photonics, Power Electronics and RF & Microwave.

The Photonics section can offer firms access to a range of services to assist with Photonics application development. Its integrated approach supports the whole design lifecycle from optical system and optoelectronic package design through to packaging, test and characterization, and qualification testing for harsh environments. The Photonics section offers the development of high-reliability optical systems while ensuring a design for manufacture and scalability. The team has expertise in optical modelling and simulation, spectroscopy, sensors and telemetry.

Power Electronics activities are focused initially on the transportation sector, covering, for example, automotive vehicle electrification and more electric aircraft. The power electronics facilities at the new CSA Catapult Innovation Centre cover converter and power module modeling, PCB and package design, simulation, system evaluation and reliability testing. The equipment includes programmable AC and DC sources and loads to 500kW, and an electro-magnetic compatibility (EMC) anechoic chamber for pre-compliance radiated emissions and immunity assessment. The team has expertise in system design, simulation and modelling, as well as system-level test and evaluation.

The RF & Microwave section can offer companies a range of collaborative R&D and commercial opportunities spanning design, modeling and simulation of semiconductor devices, circuits and systems, packaging and assembly through to test, evaluation and qualification. The team will have expertise covering device physics and modeling, MMIC/RFIC design, antenna design, RF packaging and assembly and systems integration.

The Catapult is actively looking to fill positions across all levels of the organization and in particular its three technology sections. Working with the Catapult can provide the opportunity to contribute and shape a business in its early stages. It says it has a collaborative, supportive and inclusive culture that will be reflected in its Innovation Centre, which has agile workspaces and settings for different types of working behaviour. The Catapult also boasts the benefit of a fast-moving entrepreneurial culture and a five-year delivery plan.

www.csa.catapult.org.uk

Presto extends test beyond 100GHz

At European Microwave Week (EuMW 2018) in Madrid, Spain (23–28 September), Presto Engineering Inc of San Jose, CA, USA — which provides outsourced operations to semiconductor and Internet of Things (IoT) device firms (including developing industrial solutions for RF, analog, mixed-signal and secured applications, from tape-out to delivery of finished goods) — highlighted that it can now provide high-volume testing of semiconductor devices up to 100GHz and beyond.

Applications using GHz frequencies, i.e. millimeter wavelengths (mmW), are increasing rapidly and hence driving the need for high-volume device testing, says the firm, for example for Internet over satellite connections, car ADAS systems, and other high-speed data transfer solutions with a projected volume of more than a billion units by 2020.

"Commercial test equipment does not test much about 50GHz," says chief operating officer Cédric Mayor. "The current method used by most customers is in-house bench testing by hand, which is slow and expensive. This is because testing equipment above 50GHz becomes increasingly expensive as the frequency increases as it is non-standard," he adds. "To solve this problem, we have created custom interfaces that step the test frequencies down into the range that commercial testers operate in. This enables us to provide a cost-effective testing service for ultra-high-frequency or mmW devices and builds on our existing services for high-frequency device testing."

Another challenge of mmW devices is that the substrate used is often much more brittle than the usual CMOS, such as gallium arsenide or gallium nitride. The wafers are hence much more susceptible to breakage in transit and handling. To reduce the possibility of breakage, they are usually cut into quadrants once manufactured. A broken quadrant means fewer damaged parts compared to a whole broken wafer. However, the standard handling and test equipment is designed for circular wafers, so Presto has developed its own quadrant handling adapters for its test equipment.

It is also key to be able to maintain good correlation during the test and during the self-heating of the pulsed test methods, where continuous-wave measurement is normally used. In this case, all the fixturing must be able to control temperature and heat dissipation as well as include RF systematic error compensation for the measurements and maintain the correct reproducibility during production.

Among mmW applications already implemented or under consideration are short-range wireless backhaul, connecting small-cell wireless; data-center interconnect (DCI) for cloud servers; radar (mainly automotive); body scanners for airport security; chip-to-chip communications on printed circuit boards (where even short runs of wires or cables attenuate signals at these frequencies); and wireless communication protocols, such as 5G cellular, WiGig (802.11ad) and Wireless HD.

For convenience, the markets can be considered in three segments: communications, automotive and cellular/consumer, as shown in the table, which includes estimates of the potential served available market (SAM) and unit volumes. The first two of these are in now. Communications, driven by expansion in small-cell backhaul and cloud computing, has annual unit volumes for 2020 projected to be in the millions; and Automotive, driven by assisted driving (with autonomous driving on the horizon), has projected volumes in the tens of millions. The third vertical segment, Cellular & Consumer, driven by WiGig and 5G mobile, is in development now, with 2020 annual unit volumes projected to exceed 1 billion.

www.eumweek.com
www.presto-eng.com

IQE's first-half 2018 revenue growth driven by Photonics segment

Gross margin hit by pre-production costs for Newport Foundry and product development for new VCSEL customers

For first-half 2018, epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has reported revenue of £73.4m, up 4% on first-half 2017's £70.6m (or up 5.4% on £69.6m from wafer sales, excluding first-half 2017's £0.95m of license income from joint ventures).

Wireless revenue fell slightly from £48.1m to £47.8m. CMOS++ revenue rose from £0.7m to £0.83m. Photonics revenue grew by 24% from £15.2m to £18.9m (rising from 21.9% to 25.8% of wafer sales), remaining IQE's most rapidly growing business segment.

However, overall revenue growth was despite a currency headwind of about 10%, reflecting strong sales growth in each of the firm's main business sectors. On constant-currency basis, Wireless sales were up 11%, InfraRed sales were up 11%, and Photonics sales were up 30%.

Wireless inventory channels, depleted as a consequence of the rapid ramp of VCSELs in second-half 2017, were partially replenished during first-half 2018.

Photonics revenue growth was despite revenue from the largest photonics customer being flat while inventory from the aggressive first mass-market ramp of vertical-cavity surface-emitting laser (VCSEL) epiwafers in second-half 2017 was consumed in the supply chain. Demonstrating the breadth and depth of photonics engagements, revenue from other photonics customers hence rose 40% as photonics capacity was directed to satisfy more than 20 VCSEL chip manufacturer engagements in order to significantly broaden IQE's global reach in the rapidly growing markets for 3D sensing in consumer and other high-growth applications.

Wafer gross margin contracted from 24.7% to 23.3%. Specifically, Photonics gross margin was adversely impacted by pre-production costs for Newport Foundry of £0.9m (recruitment, increased headcount and training to support 24/7 operation) and low-margin customer-funded product development (primarily new VCSEL customers) reducing photonics margins by a further £0.6m.

IQE has taken the opportunity during first-half 2018 to accelerate and expand its qualification activities for the fast-growing VCSEL market for consumer applications

Operating profit (from wafers) has fallen from £9.7m (excluding £1m from license income) to £7.6m, with operating margin falling from 13.8% to 10.4%. Specifically, Wireless operating margin fell from 15.6% to 13.9% due to conversion costs for switching reactors from Photonics to Wireless production during first-half 2018. Photonics operating margin fell from 41.6% to 25.8% due to the high level of low-margin photonics customer qualifications in first-half 2018 and the pre-production costs expensed in relation to the new Newport Foundry. Taking into account the Newport Foundry pre-production costs and the investment in qualification programs for new VCSEL customers, the underlying Photonics operating margin was 33.4%. Photonics margins will return to 35% for H2 2018 as production efficiencies of the ramp in output are realised.

Profit before tax rose from £5.6m to £6.6m, depressed by about £3.5m: £2m from the impact of the ForEx headwind and £1.5m from the Newport Foundry pre-production costs and VCSEL qualifications. Without these, profit before tax would have risen from £9.7m to £11.1m.

Operating cash generation fell from £11.2m to £7.6m (from 105% to 100%) after funding a £6.6m increase in working capital (from £4.5m in first-half 2017) as a consequence of an increase in both trade and other receivables and inventories since end-2017.

Investment in capital expenditure (CapEx) and product development was £13m. Specifically, capitalized R&D expenditure relating to VCSELs, gallium nitride (GaN), cREO (crystalline rare-earth oxide, for which an option was exercised in March to acquire the technology and IP portfolio from Translucent Inc for $5m) and dilute nitride developments was £6.4m. Spending on property plant & equipment (associated predominantly with the new Newport Foundry) was £6.3m. This was funded through organic cash generation and from surplus cash reserves following the share placing in November 2017.

Net cash at end-June 2018 was £40.6m, down from £45.6m at the end of 2017 but a reversal from net debt of £41.9m at end-June 2017 due to the placing completed in November, raising more than £90m to repay debt and fund capacity expansion.

"The Newport, UK foundry construction and fit out is proceeding well," says president & CEO Dr Drew Nelson. Five reactors had been installed by the end of first-half 2018 and a further two have been delivered in August. Three more are scheduled for second-half 2018, bringing the total to ten reactors. Commissioning and qualifications are ongoing and initial

production is expected to begin in the latter part of second-half 2018.

"IQE has taken the opportunity during first-half 2018 to accelerate and expand its qualification activities for the fast-growing VCSEL market for consumer applications, and is now successfully engaged with over 20 companies in this arena," notes Nelson. "Coupled with the installation, staffing and run up of the initial high-volume production tools in our flagship Newport Epi-Foundry, these activities represent major steps forward in securing and further strengthening IQE's leading position in the global supply of VCSEL wafers for multiple consumer and industrial 3D sensing applications. Although the costs of these investments have impacted first-half profitability, we are confident they will be pivotal in delivering strong increases in revenue, margin expansion and profitability as 3D sensing is widely adopted in global mobile platforms and other large-volume applications," he adds.

"Together with the renewal of our long-term supply agreement with our largest tier-1 wireless customer [securing an extended range of products and increased share of their epiwafer requirements, through to September 2019] and the manufacturing milestone reached with our first nano-imprint lithography (NIL) edge-emitting distributed feedback (DFB) laser production order [worth $250,000], this demonstrates both the strength of our existing core business and the new opportunities that we are creating as we continue to bring our unique innovative material capabilities and associated nanoscale fabrication technologies to market."

A healthy wireless business and VCSEL engagements with more than 20 chip companies for sensing, mobile, industrial and data communications demonstrates the breadth and depth of customer engagements across a range of technologies and applications and sets the scene for increasing revenue diversity and growth through second-quarter 2018 and beyond, believes IQE.

"As we transition our business model from being the global leading supplier of advanced semiconductor wafers to a global leader in advanced material solutions, we already see significant engagements for our other core technologies, including GaN-on-silicon, cREO and QPC (Quasi Photonic Crystals)," says Nelson. "We look forward to the rest of 2018 and in particular the further multi-customer ramp which is expected in 2019, with considerable anticipation."

IQE's updated guidance for wafer revenue compound annual growth rate (on a constant-currency basis) for full-year 2018 is up to 5% for Wireless, 5–15% for InfraRed and 35–50% for Photonics.

Initial guidance for 2019 is given as up to 5% for Wireless, 5–15% for InfraRed and 40-60% for Photonics.

The 3–5 year CAGR forecast is up to 10% for Wireless, 5–15% for InfraRed and 40–60% for Photonics.

www.iqep.com

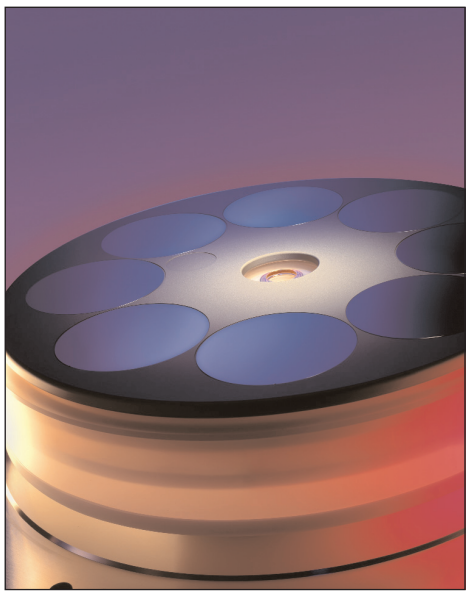
Thermco Systems expands global operations with acquisition of CSD Epitaxy

Furnace manufacturer adds batch epi reactor maker

Thermco Systems (a division of Tetreon Technologies Ltd of Washington, West Sussex, UK) has acquired CSD Epitaxy Inc of Fremont, CA, USA, which makes the Epi-pro epitaxy batch reactor.

Founded in 1962 and having one of the largest installed bases of over 30,000 horizontal tubes worldwide, Thermco Systems manufactures atmospheric and LPCVD furnaces for the semiconductor, power, MEMS, nanotechnology, LED and photovoltaic markets

The acquisition is part of Thermco's longer-term strategy to extend its global footprint and the capabilities it can now provide to its global customer base throughout the UK, Europe, USA and China. Customers can now benefit from a wider range of semiconductor



manufacturing solutions, including horizontal and vertical thermal reactors, batch-epitaxy reactors, chemical wet-benches, batch-ashers, four-point probe, gas cabinets and next-generation control systems.

"Our customers recognise the high quality of our products, our innovation and the attention to detail we apply during the manufacturing process, together with the high level of customer service we deliver," claims Thermco Systems' managing director Andrew Conning. "Our growth ambitions are focused on strengthening this proposition. Expanding our operations through acquisitions of businesses such as CSD-Epitaxy allows us to build our relevance to our customers in parallel with our capability to deliver a full range of high-end solutions."

www.thermcosystems.com
www.csd-epi.com

Veeco's president Bill Miller to become CEO

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that chairman & CEO John Peeler will transition to the role of executive chairman, effective 1 October. Current president William J. Miller will become CEO and will join the board of directors, bringing its size to eight. Additionally, Shubham (Sam) Maheshwari will be named chief operating officer and will continue in his role as chief financial officer.

Peeler joined Veeco in 2007 as CEO and became chairman of the board in 2012. As executive chairman, he will work with Miller and the board to ensure an effective transition of management.

"With his impressive background and track record of notable achievements across strategic, product development and operational assignments, there is no one better suited than Bill to take over the helm as Veeco looks forward to its next chapter," believes Peeler.

Over the last 16 years, Miller has held a variety of roles within Veeco. He became president in 2016, overseeing all of Veeco's global business units. Previously, he guided the strategic direction and product development for the MOCVD and Ion Beam product lines and was responsible for the global operations organization. Prior to joining Veeco, Miller held engineering and operations leadership roles with Advanced Energy and Exxon Corp. He holds BS, MS and PhD degrees in mechanical engineering from the University of Pennsylvania.

"I want to thank John for his guidance and building such a strong leadership team," says Miller. "I intend to build on this legacy while discovering new opportunities to leverage the company's outstanding technology and unmatched talent," he adds.

"When John joined the company in 2007, Veeco was considered a data storage and metrology company," notes lead independent director Richard D'Amore. "John's vision and focus on execution transformed Veeco to be on the leading edge of the compound semiconductor and advanced packaging markets… Bill will build upon his progress."

Maheshwari joined Veeco in 2014 with more than 20 years of experience in finance. He previously held senior and executive level positions in the semiconductor industry at KLA-Tencor, Spansion and OnCore. Maheshwari holds BS and MS degrees in chemical engineering and an MBA from the Wharton School of Business. Working side-by-side with Miller, he will be charged with advancing Veeco's operations, customer satisfaction and profitability.

www.veeco.com

SINANO uses Picosun's RPEALD to yield high-quality titanium nitride

Collaboration targets HEMTs and laser diodes

Atomic layer deposition (ALD) thin-film technology firm Picosun of Espoo, Finland and China's Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO) have reported what are claimed to be excellent quality titanium nitride (TiN) deposited using Picosun's plasma-ALD technology.

In microelectronic component manufacturing, the ohmic contact between metallic and semiconducting material layers is critical regarding component functionality and lifetime. Typically, pure metals such as titanium have been employed as the metallic material, but they have certain drawbacks, which is why titanium nitride has been proposed as a substitute. TiN is metallic too, and its conductivity and thermal stability are better than those of pure titanium metal. But, to obtain high-quality TiN films, the manufacturing method and conditions are critical, says Picosun.

Using Picosun's remote-plasma ALD (RPEALD) technology, the plasma source is located a high enough distance from the substrate so that, instead of aggressive ion bombardment, highly reactive radicals react at the substrate surface. This allows low process temperatures without thermal stress or physical ion damage to the substrate and enables the deposition of conductive materials too without the risk of short-circuiting or of gas back-diffusion into the plasma source. The right selection of precursor chemicals and plasma gases guarantees high-purity TiN films with very low oxygen content and work function, low sheet resistivity, exact stoichiometry, and high uniformity, says Picosun. Further, the process window is wide regarding the process parameters and temperature, enabling the process to be introduced on a large variety of substrate materials.

"TiN is a central material in their applications, especially in components manufactured on gallium nitride (GaN) and on small, up to 200mm diameter silicon wafers," say Edwin Wu, CEO of Picosun Asia Pte Ltd and Jurgen Yeh, CTO of Picosun China Co Ltd. "Picosun is specially dedicated to providing cost-efficient, turn-key production solutions for up to 200mm wafer markets.

"The quality of their ALD equipment is outstanding and enables us to develop cutting-edge ALD processes to be introduced to our other collaboration partners in the industries," comments professor Sunan Ding of SINANO's Nano-X lab. "An immensely important benefit in using Picosun ALD tools is also the smooth scalability of the processes to production scale, as all Picosun ALD systems - from R&D units to full-scale industrial production platforms - share the same core design and operating principles," he adds.

SINANO and Picosun have been collaborating since the beginning of 2017. The goal is to develop micro- and optoelectronic components such as high-electron-mobility transistors (HEMTs) and laser diodes, and lithium ion batteries utilizing ALD in their joint lab in Suzhou (which is equipped with several Picosun ALD systems). The collaboration is further supported by Picosun's local subsidiary Picosun China Co Ltd of Suzhou.

Picosun is exhibiting at the 4th International Conference on ALD Applications & 2018 China ALD Conference in Shenzhen (14–17 October), where it is again a platinum sponsor.

www.c-ald.com
https://avs.scitation.org/doi/10.1116/1.5025557
www.picosun.com
http://english.sinano.cas.cn

IN BRIEF

Quantum Matter Institute chooses Veeco's GENxplor R&D MBE system for 2D materials

Veeco Instruments Inc of Plainview, NY, USA says that a dual GENxplor R&D molecular beam epitaxy (MBE) system has been ordered by the Stewart Blusson Quantum Matter Institute (SBQMI) at the University of British Columbia (UBC) for research into exploring and controling the properties of new materials.

"This is a primary focus for our R&D team at SBQMI, and we're confident that the flexibility, precision and quality provided by Veeco's MBE expertise will aid in our efforts to achieve scientific breakthroughs utilizing the diverse properties of 2D crystal materials," says Ke Zou, assistant professor of physics and astronomy at UBC.

Veeco says that GENxplor is the industry's first fully integrated MBE system for the compound semiconductor R&D market. Due to its process flexibility, GENxplor is suitable for a broad range of MBE applications such as high-efficiency solar cells and high-temperature superconductors. Accordingly, the system can enable the advancement of 2D materials (crucial for the development of next-generation nanotechnologies and digital electronics).

"UBC is renowned for its work researching the complex quantum phenomena emerging in novel engineered materials," comments Gerry Blumenstock, VP & general manager of MBE and ALD products at Veeco. "As the institute's researchers expand R&D efforts, we're excited to support UBC's exploration of 2D materials through MBE."

http://qmi.ubc.ca
www.veeco.com/products/genxplor-randd-mbe-system

Plessey orders Aixtron AIX G5+ C MOCVD system for GaN-on-Si monolithic micro-LEDs

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has received an order for an AIX G5+ C Planetary Reactor metal-organic chemical vapor deposition (MOCVD) system from UK-based Plessey Semiconductors to boost its manufacturing capability for gallium nitride on silicon (GaN-on-Si) wafers targeting next-generation micro-LED applications.

With an automatic cassette-to-cassette (C2C) wafer transfer module, the new reactor will be installed and operational during first-quarter 2019 at Plessey's 270,000ft^2 fabrication facility in Plymouth, UK. The AIX G5+ C MOCVD system has two separate chamber set-up options, which enables configurations of 8x6" or 5x8" GaN-on-Si wafers to be automatically loaded and removed from the system in an enclosed cassette environment. The system will be an addition to the firm's existing MOCVD reactors, also supplied by Aixtron, which provide configurations of 7x6" or 3x8" with manual loading.

Productivity is further enhanced by the new reactor's automated self-cleaning technology, which helps to deliver a very low level of wafer defects by ensuring that the reactor is clean on every run, significantly reducing downtime for maintenance. The new equipment also provides faster ramp and cool down, along with a high susceptor unload temperature to reduce the recipe time.

The AIX G5+ C reactor will support Plessey's extensive production roadmap to increase R&D capacity of its monolithic micro-LEDs based on its proprietary GaN-on-Si technology. Plessey's micro-LEDs are said to offer extremely low power consumption, high brightness and very high pixel density, creating the potential for disruption in many existing application areas that use conventional display technologies such as LCD and OLED.

Plessey is developing illuminators for display engines and full-field emissive micro-LED displays. The complex devices combine very high-density RGB pixel arrays with high-performance CMOS backplanes to produce very high-brightness, low-power and high-frame-rate image sources for head-mounted displays, and wearable electronics devices for augmented reality (AR) and virtual reality (VR) systems.

"Our continued and valuable relationship with Aixtron allows Plessey to rapidly bring to market its monolithic micro-LEDs," says Plessey's chief operating officer Mike Snaith. "To help us achieve this, our latest acquisition of Aixtron's AIX G5+ C planetary system combines outstanding on-wafer uniformity and run-to-run performance at the lowest cost of ownership — aspects that are critical for efficient high-volume GaN-on-Si micro-LED displays," he comments.

"The AIX G5+ C will support Plessey's requirements in the best way possible to address the most stringent requirements for micro-LED production," believes Dr Frank Schulte, VP of Aixtron Europe. "While offering more productive configurations, the tool meets the toughest requirements from the silicon industry in terms of uniformity and particles."

Addressing all of the challenges involved in manufacturing micro-LEDs, including high-volume and cost-effective production capability, Plessey says that it is actively engaging with potential customers to use its production-ready micro-LED technology platform.

www.plesseysemiconductors.com/led-plessey-semiconductors.php

Sinosemic orders its first AIX 2800G4-TM for VCSEL production

Sino-Semiconductor Integrated Optoelectronics Cooperation (Sinosemic) — the first all-Chinese developer and manufacturer of vertical-cavity surface-emitting laser (VCSEL) chips for face recognition — has ordered an Aixtron AIX 2800G4-TM MOCVD system for the production of laser diodes. The firm will receive its first Aixtron tool in fourth-quarter 2018. The fully automated Planetary Reactor manufacturing system will be shipped in 8x6"-wafer configuration.

The AIX 2800G4-TM has established itself as the leading tool for high-volume production of VCSELs for 3D sensors and other diode lasers, claims Aixtron. The Planetary Reactor concept not only allows for maximum yield of devices at the highest performance level, but also for unparalleled productivity and uniformity of the epitaxial wafers. As well as the reproducibility of each individual system, there is also good repeatability among systems, adds the firm. The AIX 2800G4-TM also provides high efficiency in handling chemicals used for MOCVD processes for the production of laser devices.

"In recent years the AIX 2800G4-TM platform has already succeeded in the market for the production of VCSELs or datacom lasers," comments Sinosemic's general manager Ling Yong Peng. "This is the first time we order an MOCVD system from Aixtron and we are very much looking forward to benefit from the excellent performance of the AIX 2800G4-TM platform in terms of wafer homogeneity and maximum flexibility."

www.sinosemic.com
www.aixtron.com

HLJ orders Aixtron AIX 2800G4-TM MOCVD systems to expand VCSEL production capacity and epiwafer size

Deposition equipment maker Aixtron SE of Herzogenrath, Germany says that new customer HLJ Technology Co Ltd of Hsinchu Industrial Park, Taiwan — which was founded in 2001 and manufactures vertical-cavity surface-emitting laser (VCSEL) epitaxial wafers and chips — has ordered multiple AIX 2800G4-TM metal-organic chemical vapor deposition (MOCVD) systems to increase the capacity and wafer size (from 4" to 6") of its production line. Aixtron's fully automated Planetary Reactor systems will be supplied in 8x6-inch configuration in fourth-quarter 2018 and beyond.

"To meet fast-growing market demand for VCSEL both at epiwafer and chip levels, we decided to expand to 6" epiwafer manufacturing," says HLJ's general manager Dr Larry Lai. "Starting from Q4/2018, two sets of newly ordered Aixtron MOCVD systems are scheduled to arrive at HLJ. In Q2/2019, the first complete high-volume VCSEL production line will be ready," he adds.

"Looking forward to our cooperation with HLJ, we will support the company in the alignment of their production processes to our equipment technology," comments Aixtron's president Dr Bernd Schulte.

www.hlj.com.tw
www.aixtron.com

CVD Equipment creates post of lead independent director

CVD Equipment Corp of Central Islip, NY, USA (a designer and maker of chemical vapor deposition, gas control, and other equipment for developing and manufacturing materials and coatings) says that its board of directors has established the new position of lead independent director, and the firm's independent directors have unanimously elected Lawrence J. Waldman to the newly created position.

Waldman's responsibilities will include coordinating the activities of the independent directors and serving as a liaison between the president/CEO and the other independent directors, and helping to facilitate the board's oversight and shareholder responsiveness.

"We are committed to good corporate governance practices and believe that the addition of a lead independent director will help to enhance corporate oversight," says president, CEO & chairman Leonard A. Rosenbaum. "As Larry takes on this new role, his broad experience should prove valuable to CVD."

www.cvdequipment.com

Canon to distribute ClassOne equipment in Japan

ClassOne Technology of Kalispell, MT, USA (which manufactures electroplating and wet-chemical process systems for ≤200mm wafers) has signed an exclusive distribution agreement with Canon Marketing Japan Inc (CMJ), which will start receiving orders for Solstice ECD (electrochemical deposition) systems in 2018 and will provide technical and field support for ClassOne products after system delivery.

The Solstice platform delivers high-quality plating of gold (Au), nickel (Ni) and copper (Cu) at low cost, as well as variety of wet process functionality, such as metal lift-off, resist strip, Au de-plating, under-bump metal (UBM) etch, and anodization.

Solstice is available in 2-, 4- and 8-chamber variants, and provides what is claimed to be industry-leading uniformity and throughput with the smallest footprint, automation capability, controllability and lowest cost of ownership. Solstice is suited to growing customers who need to move from <200mm wet bench processing to high-volume automated single-wafer production.

The agreement with ClassOne Technology should assist Canon Marketing Japan in expanding its business in the high-growth segment of high-speed optical communication, 3D sensing including time-of-flight (ToF), high-frequency power devices, and related device markets.

www.classone.com/products
https://cweb.canon.jp/eng/corporate

Edwards acquiring Brooks Automation's cryogenic unit

Through its US entity Edwards Vacuum LLC (acquired with vacuum product and exhaust-abatement equipment maker Edwards Ltd of Burgess Hill, West Sussex, UK in 2013), industrial productivity solutions provider Atlas Copco Group of Stockholm, Sweden has agreed to acquire the cryogenic business of Brooks Automation Inc. Once the deal is completed (which is expected in first-quarter 2019) it will expand Edwards' offering to the global semiconductor industry.

Brooks Automation of Chelmsford, MA, USA provides cryopumps and associated products for the semiconductor industry through its CTI-Cryogenics and Polycold brands.

The acquisition includes cryopump operations in Chelmsford, MA and Monterrey, Mexico as well as a worldwide network of sales and service centres. Brooks Automation's 50% shareholding in Japan-based joint venture company Ulvac Cryogenics Inc is also part of the deal.

The acquired business will become part of the Semiconductor and Semiconductor Service divisions within Atlas Copco's Vacuum Technique business area and will expand Edwards' range of chamber solutions for the semiconductor industry.

"The acquisition of Brooks Automation's cryogenic business will help us cement our position as a trusted partner to the world's leading semiconductor OEMs by enabling the expansion of our current chamber solutions offering through the addition of new technologies and products," says Paul Rawlings, president of the Semiconductor division. The planned acquisition is subject to regulatory approvals.

www.edwardsvacuum.com
www.atlascopcogroup.com

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Kulicke & Soffa and Rohinni launch PIXALUX micro-LED and mini-LED die placement solution

Singapore-based chip assembly & packaging equipment and materials supplier Kulicke and Soffa Industries Inc (K&S) and Rohinni LLC of Coeur d'Alene, ID, USA (which has developed a proprietary method for transferring semiconductor devices) have launched PIXALUX, K&S's micro- and mini-LED advanced high-speed die placement solution that was developed with Rohinni.

Such next-generation LED technologies have the potential to further enhance performance, improve efficiency and reduce the size of existing lighting technologies, says K&S. High-volume end-markets including automotive, display, consumer electronics and general lighting are expected to drive adoption and benefit from the emerging technology. While micro- and mini-LED benefits are compelling, high-volume placement challenges needed to be addressed prior to widespread market adoption of these emerging lighting solutions, the firm adds.

In May, K&S announced a joint development partnership with Rohinni to directly address this challenge. Rohinni's proprietary robotic process supersedes complex LED manufacture by placing mini- and micro-LEDs directly on virtually any substrate at high speed, in high volumes, and at what is claimed to be greatly reduced cost. With a combination of high-throughput and high-accuracy placement supporting extremely small-die applications, the resultant PIXALUX offers:

- high productivity and yield via its ultrafast placement head design;
- placement accuracy and speed on multiple types of substrates;
- support for placement of LED and IC dies;
- a wafer magazine with 10 wafer carriers; and
- ease of use with one-step automatic wafer loading.

"An example of one of the applications we anticipate PIXALUX initially enabling is the development of 2D LCD display backlighting, which means thinner and lighter display products that will provide better performance, dynamic range (HDR) and efficiency," says Chan Pin Chong, senior VP of Kulicke & Soffa's Wedge Bond & EA/APMR business unit.

"Our partnership with K&S is another big step forward for the Rohinni team and our technology," believes Rohinni's CEO Matt Gerber. "The scale, capabilities and reach of K&S coupled with Rohinni's advanced mini-LED placement technology means customers around the world now have a viable path to develop and manufacture next-generation mini-LED-based products."

Customer evaluation of the PIXALUX bonder will begin in October.

www.kns.com
www.rohinni.com

MRSI unveils one-stop shop die bonding solutions

In the booth of partner CYCAD Century Science and Technology at the 20th China International Optoelectronic Exposition (CIOE 2018) in Shenzhen (5–8 September), MRSI Systems of North Billerica, MA, USA (which manufactures fully automated, high-precision eutectic and epoxy die bonding systems) demonstrated its 'One Stop Shop' capabilities.

The biggest challenge facing photonics manufacturing is how to handle high-volume and high-mix production, says MRSI. Solving this problem requires flexible high-speed automation, it adds. The firm is therefore unveiling its 'One Stop Shop' die bonding solutions.

During the year MRSI has expanded its die bonder product family with additional configurations. Providing the flexibility for true multi-die, multi-process, multi-product high-volume high-mix production, the high-speed products deliver what is claimed to be industry-leading speed without sacrificing flexibility, precision or reliability:

- the ultra-flexible MRSI-705 and MRSI-M3 can be used for R&D prototyping to low/medium volume;
- the ultra-fast MRSI-HVM3 and MRSI-H3 can meet high-volume requirements for all key die bonding applications in photonics manufacturing with what is claimed to be superior flexibility for multi-dies, multi-process and multi-products through one machine;

The ultra-fast product families deliver <3μm placement accuracy for next-generation products.

"Our 'One Stop Shop' solutions will help our customers to enable just-in-time supply and fast-pace innovations of critical photonic component for high-growth market segments such as hyper-scale data centers, photonic sensors and 5G wireless," reckons Dr Yi Qian, VP product management.

"MRSI Systems has been serving optoelectronic and microelectronic customers for the past 34 years and understands their requirement to scale efficiently in today's fast-paced marketplace," says president Michael Chalsen.

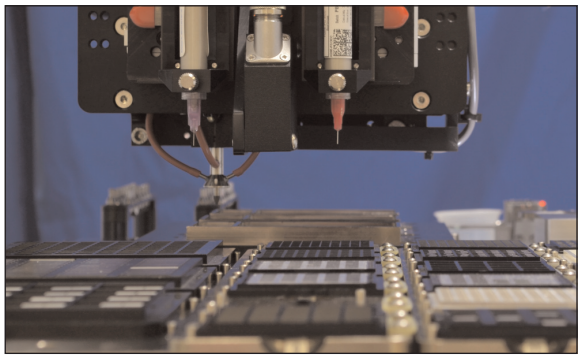
MRSI Systems also exhibited at the 44th European Conference on Optical Communications (ECOC 2018) in Rome, Italy (24–26 September).

www.cioe.cn/en
www.ecocexhibition.com
www.mrsisystems.com

MRSI introduces MRSI-H3LD die bonder for the high-power diode laser market

MRSI Systems of North Billerica, MA, USA (which manufactures fully automated, high-precision eutectic and epoxy die bonding systems) has launched the MRSI-H3LD, a new 3μm high-speed die bonder, optimized for bonding large dies for high-power diode lasers used in photonics applications such as industrial lasers, optical fiber amplifications, lighting and sensors.

High-power diode lasers are critical components for multiple markets and have seen a significant, continual rise in adoption with the explosion in new applications, says the firm. The MRSI-H3LD is equipped for speed with an 'on-the-fly' auto tool changer integrated on the bonding head for zero-time tool change-over with an ultrafast-ramp eutectic station for reduced cycle



time. Combining both, the MRSI-H3LD demonstrates what is claimed to be the industry's highest throughput for high-power diode laser die bonding.

"The new MRSI-H3LD product carries key technological building blocks from our field-proven flexible high-speed MRSI-HVM3 platform for industry-leading throughput, superior flexibility, and future-proven 3μm placement accuracy," says MRSI's VP of product management Dr Yi Qian. "It enables our high power diode laser and other photonics customers to scale up their business," he adds.

The MRSI-H3LD has a placement accuracy of <3μm (±3s). The precision is achieved without sacrificing high speed or flexibility and it helps high-power diode laser manufacturing to achieve smaller offset between the front facets of laser diode and the front end surface of the submount. It is also equipped with self-leveling collets designed specially for large high-power laser dies to achieve co-planarity between two bonded interfaces.

www.mrsisystems.com

MRSI launches MRSI-H3TO die bonding product family targeted at 5G wireless network supply chain

MRSI Systems has launched the MRSI-H3TO, a new 3μm high-speed die bonder that will be the first of its kind to address the multi-die and multi-process requirements, delivering what is claimed to be industry-leading throughput, superior flexibility, and future-proven 3μm placement accuracy.

The MRSI-H3TO is tailored for WDM/EML-TO or other multi-die multi-processing TO-can photonic devices to support the upcoming 5G wireless network, enabling photonics customers to meet their manufacturing challenges by allowing them to stay competitive in such a high-volume and high-mix production environment.

The upcoming 5G wireless deployment will need higher bandwidth in signal transportation through front-haul and back-haul fiber-optic systems within the fiber-to-home/premise (FTTH/P) network. As a result, WDM and EML types of lasers and other multi-die optical receivers in TO-can packages are required. MRSI says that these new TO-can based devices demand a new class of high-speed die bonder that is capable of multi-die and multi-process production in one machine, in order to achieve the best throughput.

The new MRSI-H3TO builds on the key technological building blocks featured in the field-proven high-speed MRSI-HVM3 platform, including a dual-head motion system that performs TO pick-and-place/handling and die bonding in parallel. In addition, it encompasses MRSI's on the 'on-the-fly' auto tool changer that has 12 vacuum tips/collets integrated on the bonding head for zero-time tool change between dies.

"The new MRSI-H3TO is exactly the type of die bonder our customers were demanding to manufacture the next generation of TO-can photonic devices, such as WDM and EML-TOs," says MRSI's VP of product management Dr Yi Qian. "It has the industry-leading throughput without sacrificing flexibility, accuracy or reliability," he claims.

"MRSI is pleased to meet the new market needs to support 5G wireless deployment with the launch of our new high-speed, flexible die bonder for high-volume manufacturing of TO-can based photonic packaging," says MRSI's president Michael Chalsen.

MRSI Systems exhibited at the 20th China International Optoelectronic Expo (CIOE 2018) with its partner CYCAD Century Science and Technology in Shenzhen (5–8 September) and at the 44th European Conference on Optical Communications (ECOC 2018) in Rome, Italy (24–26 September).

www.cioe.cn/en
www.ecocexhibition.com
www.mrsisystems.com

SETi files patent lawsuit against UV LED sterilizer firm

Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA — which manufactures UV-A, UV-B and UV-C ultraviolet LED products emitting at wavelengths less than 365nm — has filed a patent infringement lawsuit in the US District Court for the Northern District of California asserting that both Bolb Inc and Quantum Egg Inc (Q-egg). Bolb and Q-Egg are selling UV LED sterilizer devices that infringe on six of its patents covering fundamental UV LED technology, encompassing UV LED sterilizer structures and drivers, chip fabrication, and epitaxial layer growth.

Since its establishment in 1999, SETi has been dedicated to R&D on patented UV LED technologies. Its expertise has been recognized with government project grants focused on UV LED technology, including for the US Defense Advanced Research Projects Agency (DARPA).

SETi has also collaborated with South Korean UV LED maker Seoul Viosys Co Ltd (SVC), resulting in the development of Violeds technology for UV LED-based disinfection, deodorization, phototherapy and curing. Violeds technology has also been used by the US National Aeronautics and Space Administration (NASA) aboard the International Space Station (ISS).

The UV LED market was estimated to be $223m in 2017 and is projected to grow at more than 33% per year to $1.224bn by 2022. The UV LED appliance market has similarly expanded to many fields, including curing machines, medical devices and purification devices. In particular, the sterilization and purification market is projected to grow significantly over the next few years.

"It is important that such growth is accompanied by fair competition, including respect of intellectual property," SETi says. "An increasing number of products in the marketplace infringe on SETi's established patents," it believes. To protect its intellectual property, SETi has committed to monitoring the market for patent infringement and engaging in enforcement activities.

"SETi strongly opposes the distribution of products in the market that infringe our patents. For this reason, our company will be undertaking enforcement actions against suspected infringers where appropriate and necessary," the firm concludes.

www.s-et.com

Seoul Semi wins LED bulb patent litigation against Philcor

The US Federal District Court for Nevada has issued a judgment in favor of South Korean LED maker Seoul Semiconductor says that in its lawsuit alleging infringement of eight LED patents by LED lighting product retailer Philcor T.V. & Electronic Leasing Inc (trading as energyavenue.com).

According to Seoul Semiconductor, Philcor acknowledged that LED products used in the accused products were manufactured by several third-party suppliers and, although previously unknown to Philcor, it did not dispute that those products infringed Seoul Semiconductor's patents. Philcor also did not dispute the validity of Seoul Semiconductor's patents and agreed to pay past damages, as well as a license fee, in order to affirm its commitment to respecting the intellectual property of patents in technologies for high-voltage operation (Acrich driver), Acrich MJT (multi-junction technology; over-6V high-power chip), filament LED bulb structure, LED packaging, LED epitaxial growth, and LED chip fabrication.

Other enforcement actions against LED lighting retailers

Seoul says that it is continuing a series of enforcement actions to prevent the distribution of suspected infringing products in the LED lighting market.

On 2 March, it filed litigation in the Texas Northern District federal court alleging infringement of 10 LED patents by Service Lighting Electrical Supplies Inc – the operator of America's largest online retail channel for LED bulbs (1000bulbs.com).

On 8 May, Seoul initiated a lawsuit in the California Central District federal court alleging infringement of eight LED patents by Bed Bath & Beyond Inc, an American chain of big-box retail stores with 1550 stores. The accused products include various LED bulbs supplied by Feit Electric.

At the end of August, Seoul filed a lawsuit in the Texas Eastern District federal court alleging infringement of 15 LED patents by retailer Fry's Electronics — accusing UCD technology (KSF, which enables significant improvement of color gamut in LCD displays such as TVs and smartphones) as well as optical lens technology.

Seoul has also delivered notices to manufacturers of various LED lighting products (as well as their distributors) where it suspects infringement of its patents, warning them that they need to stop using LEDs and any other components that may infringe upon Seoul's patented technology.

"To create fair competition in the market and make sure that intellectual property rights are respected, manufacturers as well as distributors should take active precautionary measures not to manufacture or sell infringing products," says Nam Ki-bum, executive VP of the Lighting Department at Seoul. "We will do our best to encourage a fair-competition environment, in which young entrepreneurs and small entities can succeed in the business world, relying on fair competition in the market and respecting hard-earned patented technology."

www.SeoulSemicon.com

RayVio ships mid- and high-power UV-C LEDs

Health and hygiene company RayVio Corp of Haywood, CA, USA, which is commercializing deep-ultraviolet (UV) LEDs and consumer disinfection solutions, is volume shipping its new 280nm XD mid-power and XR high-power UV-C LEDs, and has established 10,000 hour benchmarks for lifetime reliability — critical to the success of consumer and medical-grade products. Both the XD and XR Series are available globally (in-stock at distributor Digi-Key Corp) as standard 3535-packaged emitters or mounted on star boards for easy test development and product integration.

"We are already stocking both the XD and XR Series and are well equipped to help our customers from a technical standpoint as the demand for UV-C continues to grow," says Nick Olson, manager, Semiconductor Product Group, at Digi-Key Electronics.

For what is claimed to be the first time in the industry, RayVio is introducing documented lifetime ratings at multiple currents for both the XD and XR devices. This allows designers to engineer solutions for optimum performance, lifetime and reliability characteristics for their particular application.

"These are the most cost-effective UV-C LEDs available and that means more opportunity to develop new solutions," claims CEO Dr Robert C. Walker. "For applications where cost is the primary driver, the XD mid-power Series is optimum, and when milliwatt-power is the priority our XR Series — with up to 12mW of power — is superior and yet very cost effective on a $/mW basis."

RayVio says that, regardless of drive current, its UV-C LEDs have demonstrated Sterility Assurance Levels of 10-6 (99.9999%) and can be applied to applications from surface and water disinfection to medical-grade sterilization.

www.rayvio.com

Seoul Semiconductor sues big-box TV retailer

Together with its affiliate Seoul Viosys Co Ltd, South Korean LED maker Seoul Semiconductor Co Ltd has filed a patent infringement lawsuit in the United States District Court for the Eastern District of Texas against consumer electronics retail company Fry's Electronics concerning sales of various LED television products.

With 17 mega-stores in California and 14,000 staff, Fry's is one of the largest big-box retailer of consumer electronics in the USA, offering over 300 LED TV models featuring 25 different global TV brands.

Seoul asserts that certain LED TV products in Fry's stores infringe 15 of Seoul's LED patents relating to manufacturing processes for LED backlight units. Seoul's patented technologies cover LED TV backlight unit structures, LED backlight lenses for providing uniform illumination of LED lights, UCD technology for high-color-gamut displays, LED packaging, LED chip fabrication, and LED epitaxy. These are said to be significant technologies for improving the color, brightness and duration time of all LCD light sources such as smartphones, laptops, tablet PCs and monitors as well as TVs.

In particular, Seoul says that optical lens technology for offering uniform light distribution on TV or monitor displays is one of the most significant LED backlight technologies that it has developed since the earliest days of LCD backlights.

Seoul says that, to protect that patented technology, it actively enforces its patent rights against suspected infringers. In 2016, it prevailed in US federal court against Japanese lens maker Enplas, with a judgment finding that Enplas willfully infringed one of Seoul's LED backlight lens patents as well as one of its LED backlight system patents. Over the past few years, Seoul has also pursued patent litigation for infringement of LED backlight lens and other components patents against North America TV maker Craig Electronics and Curtis International, obtaining patent royalties from both companies.

UCD technology (KSF) is another of Seoul's core LED backlight technologies (enabling improvement in the color gamut of LCD displays such as TVs and smartphones) which has been co-developed with a Japanese firm over a long period. By enabling green and red light generated with KSF phosphors, UCD technology delivers 92–93% NTSC (higher than that of OLEDs).

Prior to the filing of its most recent litigation, Seoul delivered notices of patent infringement to various global TV brand makers, as well as their suppliers who manufacture TV modules or TV sets in various regions of Asia, including China and Taiwan, through OEM or ODM. Seoul advised these TV makers and manufacturers that they needed to stop using LEDs and/or other components that likely infringe Seoul's LED backlight lens and UCD technology patents.

"For young entrepreneurs and small business entities to develop innovative products under fair competition culture, it is necessary for market participants to respect other companies' intellectual property rights," says Sam Ryu, Seoul's vice president of IT Business. "To prevent distribution of suspected infringing products, we are thoroughly investigating various global TV brand products that may infringe our patents. If these companies continue to use products that are suspected of infringement, despite our requests to stop, we will take all the necessary legal actions to the end."

www.SeoulSemicon.com

Plessey and Jasper Display collaborate on tailored backplane for monolithic micro-LED displays

Plessey Semiconductors Ltd of Plymouth, UK has announced a strategic partnership for its own monolithic micro-LED displays — manufactured on its proprietary gallium nitride on silicon (GaN-on-Si) wafers — to be driven by the silicon backplane of Jasper Display Corp (JDC).

Unveiled by JDC at January's Consumer Electronics Show (CES 2018) in Las Vegas, the eSP70 silicon backplane is tailored for the needs of micro-LED devices. The full-colour-capable active matrix backplane features a resolution of 1920x1080, a pixel pitch of 8µm and offers what is claimed to be excellent current uniformity via a proprietary current-source pixel as well as flexible addressing.

Making displays brighter for portable augmented reality (AR) and virtual reality (VR) battery-powered devices is increasingly challenging, says Plessey. Using existing technologies that require high power output is a serious design limitation as the compact devices have limited space to house on-board power sources. Using JDC's eSP70 backplane will give Plessey the flexibility to utilize its GaN-on-Si platform for micro-LEDs, delivering high brightness with moderate power consumption or run with low power while maintaining daylight-usable brightness levels.

"Plessey's monolithic micro-LED array is a great match to JDC's high-density silicon backplane," believes JDC's VP marketing & product management T.I. Lin. "Our JD27E series demonstrates our ability to deliver what our valuable partner Plessey and the wider industry has been waiting for — silicon that has been designed with their micro-LED needs in mind. Our X-on-Silicon backplane technology for micro-LED can be customized on a per-project basis, allowing us to make specialized silicon suiting needs ranging from low-power AR headsets all the way to automotive headlights," he adds.

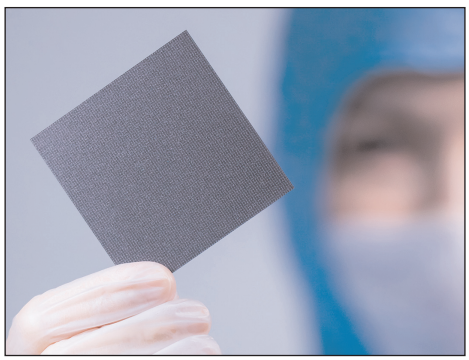
"JDC's micro-LED-specific silicon backplane allows Plessey to rapidly bring to market our monolithic full-colour micro-LED array at our entry-level 8µm pixel size," says Plessey's chief technology officer Dr Keith Strickland. "We have overcome the significant challenges involved in accurately aligning and bonding the micro-LED array with the backplane. We are looking forward to partnering with JDC as we continue our development, reducing pixel and display size."

www.plesseysemiconductors.com/products/microleds

Lextar debuting micro-LED chip technologies and UFP I-Mini RGB display module

At the Touch Taiwan 2018 exhibition in Taipei (29–31 August), vertically integrated LED firm Lextar Electronics Corp of Hsinchu Science Park, Taiwan unveiled its micro-LED chip capabilities (with a die size down to under 20µm and luminous efficiency reaching over 30%) including debuting two new micro-LED chip technologies — R/G/B Micro LED chip and Color Conversion Micro LED chip — which can meet different micro-LED mass transfer processes.

The firm reckons that it is one of the few in the industry manufacturing flip-chip, lateral and vertical micro-LED chips. Applied in displays, micro-LEDs have the advantages of high resolution, high brightness, fast response time and long life, as well as being slim and compact, suiting wearable devices, smart phones, virtual reality (VR) and automotive displays.



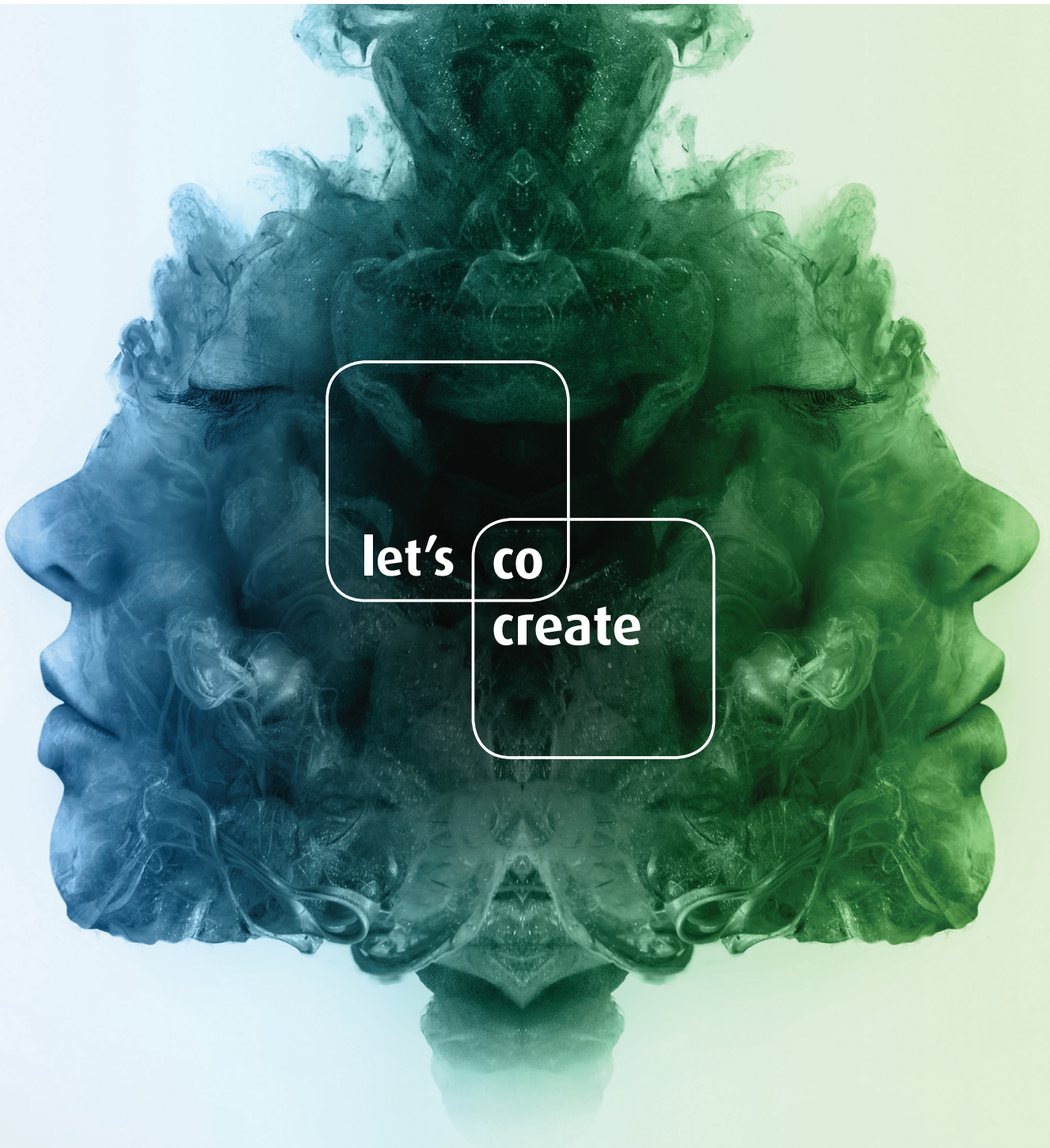
Lextar's UFP I-Mini RGB display module.

Lextar also debuted a series of Mini LED products, including the next-generation UFP I-Mini RGB display module and mass-produced slim Mini LED light board products that can be used in panel backlights.

The ultra-fine-pitch integrated mini RGB display module incorporates small RGB chips transferred onto drive circuit substrates. This combines not only traditional SMT and UFP CSP chip-level packaging technology but also integrated control circuit and LED display chips. The UFP I-Mini RGB display module can realize a minimal pitch to 0.3mm, allowing smoother image quality performance as well as simplified processing. With its high-brightness and high-contrast features, it is suitable for indoor and semi-outdoor applications.

For backlighting, Lextar exhibited mini-LED light boards for 32-inch and 15.6-inch panels, in which the 15.6-inch panel splits the mini-LED backlight into 240 control zones. It can achieve HDR 1000nits high dynamic contrast, and makes panels significantly slimmer, reducing the OD area to under 0.3mm, suitable for high-end notebooks, gaming monitors and automotive panels.

www.lextar.com



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Lumileds launches LUXEON V2 high-power LED

LED maker Lumileds of San Jose, CA, USA has launched the LUXEON V2 LED (available in a variety of color temperature and CRI options), which is claimed to have the highest performance in its class for output and efficacy, enabling DLC Premium performance at the system level.

"LUXEON V2 is designed such that 99% of the light is forward directed, resulting in the industry's most usable light from a compact source [using a 2mm x 2mm chip-scale package (CSP) in a 3.5mm x 3.5mm standard package]," says product line director Jennifer Holland.

At a correlated color temperature of 4000K and a color rendering index (CRI) of 70, typical output is

315lm at a luminous efficiency of 160lm/W when driven at 700mA. In addition, the versatility of the CSP die offers high drive current capability (up to 2.4A) while still maintaining high efficiency across the operating range. At 1A, the LUXEON V2 delivers 150lm/W and over 10% more flux than similar 2mm² LEDs on the market, it is reckoned. What is claimed to be the industry's lowest thermal resistance substrate (2.6ºC/W) simplifies the thermal design of the fixture, from streetlights through high-bay/low-bay fixtures to sports stadiums and portable applications.

The LUXEON V2 has a Lambertian radiation pattern profile, making it possible to leverage the existing optics ecosystem. "Fixture manufacturers can rapidly accelerate time to market while dramatically improving performance," says Holland. LUXEON V2 also delivers superior color over angle (COA) than competing LEDs, it is claimed, ensuring the best color consistency across the beam.

www.lumileds.com/products/high-power-leds/luxeon-v2

Cree launches highest-efficacy 90 CRI chip-on-board LEDs

LED chip, lamp and lighting maker Cree Inc of Durham, NC, USA has launched XLamp eTone LEDs, a set of chip-on-board (COB) LEDs that delivers 90 color rendering index (CRI) light quality at the same efficacy as standard 80 CRI LEDs.

Delivering up to 155 lumens per watt (LPW) at a correlated color temperature (CCT) of 3000K (at 85°C), the new eTone COB LEDs are claimed to provide the highest efficacy available compared with competing COB LEDs of the same size and color. The firm adds that the enhanced performance can transform the output, efficacy and size of LED luminaires in applications that need high-quality light, including retail, museum, high-end commercial and medical.

"Cree is enabling us to create 80 CRI and 90 CRI lights that share the same intensity, beam angle and power consumption with just one product design," comments Massimo Parravicini, R&D director of Reggiani Lighting. "This no-compromise COB solution gives us the industry's top performance, the excellent light quality that our customers require and the LED form factors that will drop right into our existing designs," he adds.

For many indoor lighting applications, the typical guideline for light quality is a minimum CRI of 80. Lower CRI values tend to distort colors and are generally unpleasing, while higher CRI values of 90 mean higher fidelity or accuracy, indicating better light quality, says Cree. LEDs with 90 CRI values are primarily used in settings where color quality is critical, such as retail and museum lighting. LEDs have been available in 90 CRI versions for many years but, until now, this light quality has come at a significant penalty to light output and efficacy compared with lower-light-quality 70 or 80 CRI versions. Cree says that its new eTone LEDs overcome this penalty by delivering an upgrade in LED efficacy of up to 17% over existing 90 CRI LEDs without sacrificing color quality.

"Two years ago, Cree achieved an LED industry first with our lab demonstration of a single high-power LED that hit an extraordinary 134LPW at 1587lm, 85°C and 90 CRI," says Dave Emerson, Cree LEDs executive VP & general manager. "Cree is committed to turning our industry-first R&D results into viable commercial products that offer customer-ready LED solutions where others do not," he adds. "Today's release of our eTone LEDs that deliver 90 CRI at the same efficacy as 80 CRI means that lighting manufacturers no longer have to sacrifice top-tier efficacy to achieve excellent color quality for indoor lighting applications."

Available in both the ceramic-based XLamp CXA2 Standard Density and the metal-based XLamp CMA & CMT High Current chip-on-board (COB) LED families, all eTone LEDs share the same mechanical and electrical characteristics as the standard versions, so lighting designers will be able to quickly upgrade their designs with minimal redesign effort. Additionally, LM-80 data coverage is available immediately to reduce the time for lighting manufacturers to receive DesignLights Consortium qualifications on their products.

The eTone LEDs will be available in 4000–2700K CCTs at minimum 90 CRI. Product samples of eTone LEDs are available now and production quantities are available with standard lead times.

www.cree.com/xlamp-etone

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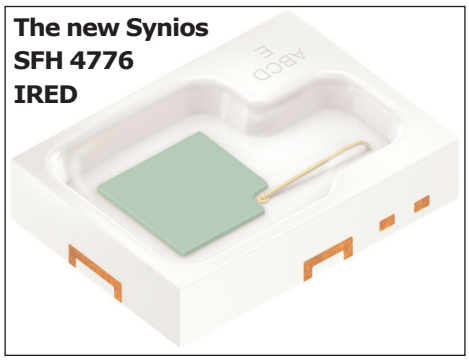
FerroTec

Osram launches compact broadband infrared LED for integrating spectroscopy into smartphones

Osram Opto Semiconductors GmbH of Regensburg, Germany has added the compact Synios SFH 4776 LED to its product portfolio for spectroscopy applications

Due to the development of broadband infrared LEDs (IREDs) that emit in a wide wavelength range, consumers will soon be able to use their smartphones to check how fresh supermarket food is, measure the calories in canteen meals, and verify whether the tablet in their hand really is a painkiller. Osram Opto says that its Oslon Black Flat SFH 4735 (launched at the end of 2016) opened up the consumer sector to this technology. To date, the firm is the only one to offer such IREDs, it is claimed. With the compact SFH 4776, spectroscopy applications can be integrated into smartphones.

Near-infrared spectroscopy enables things such as the water, fat, sugar and protein content of food to be measured using the characteristic absorption behavior of certain molecular compounds. If a defined light spectrum is directed at a sample, it is possible to determine the presence and quantity of certain ingredients from the wavelength distribution of the reflected light. An IRED such as the SFH 4776 acts as a compact light source for the spectrometer.



The new Synios SFH 4776 IRED

The Synios package of the SFH 4776 is only 0.6mm high and has a particularly space-saving footprint of 2.75mm x 2.0mm, making it suitable for use in smartphones. With the development of SFH 4776 Osram Opto is therefore addressing the latest trends such as technology-based fitness monitoring and the gradual spread of electronic aids in the health sector.

Like the SFH 4735, SFH 4776 is based on a highly efficient, blue-emitting ThinGaN chip in UX:3 technology. A phosphor converter specially developed for spectroscopy converts blue light into infrared light with a broad wavelength range of 650–1050nm. By making improvements to the phosphor material, Osram Opto has increased the intensity of the light from the SFH 4776 by 60% compared with its predecessor, yielding improved signal-to-noise ratio and simpler analysis of food and medicines.

www.osram-os.com

Osram supplying IREDs & LEDs to Joyson Safety Systems for Cadillac CT6's hands-free driver monitoring system

Osram Opto Semiconductors has partnered with mobility safety firm Joyson Safety Systems of Auburn Hills, MI, USA (a subsidiary of Ningbo Joyson Electronic Corp, which has over 50,000 staff in 25 countries) to supply key IRED and LED components for the 2018 Cadillac CT6's Super Cruise feature — the first true hands-free driving technology for the highway.

Osram IRED and LED components, which are embedded in Joyson's steering wheel for the Cadillac CT6, allow the system to monitor driver attentiveness by tracking their head position to ensure drivers are watching the road ahead while Super Cruise is engaged.

Super Cruise adaptive cruise control works only if the driver is paying attention to the road ahead. Joyson hence worked with Osram to design a steering wheel that features an embedded infrared camera that tracks the driver's head position and gaze to confirm that the driver's eyes are on the road at all times. If the driver looks away from the road for too long, the Super Cruise system will send a series of alerts for the driver to resume supervision of the road. In the rare event when a driver becomes completely unresponsive, the Cadillac CT6 uses the full capability of onboard driver assistance technologies to bring the car to a controlled stop.

"Our visible and infrared LEDs place us in a unique position to collaborate with a variety of dynamic development partners looking to innovate advanced driver assistance systems – from driver monitoring, to LiDAR, adaptive headlights and more," says Rajeev Thakur, regional marketing manager, Osram Opto Semiconductors. "Partnerships like this will continue to allow us to advance mobility and create safer transportation solutions."

The Joyson steering wheel is equipped with Osram's Olson Black SFH 4715S IREDs (which track eye movement) and its RGB Multiled (to indicate to the driver when the Super Cruise system is operating and what function it is performing: they turn green when the system is engaged, blue when it senses that the driver might not being paying attention, and red when it disengages; they also blink when the IREDs are blocked from viewing the driver's eyes).

"This Driver Monitoring System will play an important role in reducing distracted driving and enhancing road traffic safety," believes Joyson's chief strategy officer Kirk Morris.

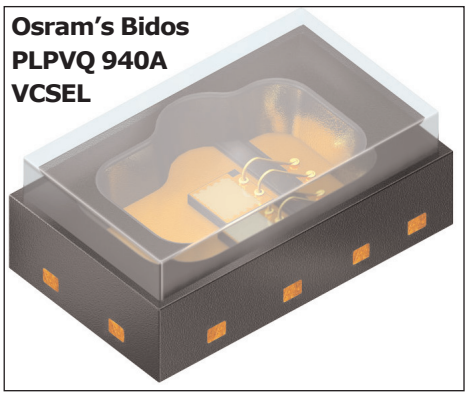
Osram launches its first VCSEL

Homogeneous 940nm IR illumination targeted at facial recognition

After its acquisition in May of Vixar Inc of Plymouth, MN, USA — a fabless company specializing in vertical-cavity surface-emitting laser (VCSEL) technology — Osram Opto Semiconductors GmbH of Regensburg, Germany is launching its first VCSEL product family with the Bidos PLPVQ 940A, paving the way for new areas of application such as 3D sensing.

The VCSEL can act as a light source for facial recognition in mobile devices, illuminating the face evenly with infrared light for a camera to capture the significant features of the user. The image is then compared with the image of the user stored in the system — if the two match, then the device will be unlocked.

VCSELs combine the outstanding properties of two lighting technologies — the high power density and simple packaging of an infrared LED (IRED) coupled with the spectral width and speed of a laser. But, unlike edge-emitting laser diodes, Bidos (as a VCSEL) emits light perpendicular to the chip's surface, and its wavelength is much less sensitive to temperature fluctuations. A VCSEL chip is also much easier to install in the end application — it can be glued into the package like an LED chip and can be used for example as an array (consisting of several hundred individual apertures per VCSEL chip).



Osram's Bidos PLPVQ 940A VCSEL

"Compared with other infrared technologies, VCSELs offer better beam quality, excellent focusing and a very small footprint," notes Bianka Schnabel, marketing manager for the Emitter Laser Sensor segment at Osram Opto. "Customers can now choose the best solution for their specific application from our extended infrared portfolio — whether it's IRED, laser or VCSEL."

With a wavelength of 940nm, the PLPVQ 940A has a maximum efficiency of 27% and an output of 300mW. Two bond wires supply the laser diode uniformly and rapidly with energy. The angle within which the VCSEL provides illumination is 65° x 78°. Its package measures just 1.90mm x 2.20mm x 0.85mm.

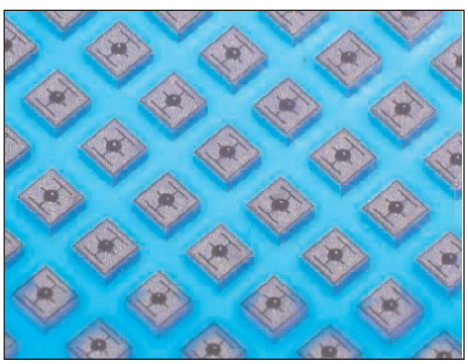
In addition to facial recognition, suitable applications of the VCSELs include robotics, drones, augmented reality and virtual reality.

www.vixarinc.com
www.osram.com

Dowa develops short-wavelength infrared LEDs with record 6.8mW output

Dowa Holdings Co Ltd subsidiary Dowa Electronic Materials Co Ltd of Tokyo, Japan has developed short-wavelength (1300nm) infrared LED chips (Figure 1) with record output power of 6.8mW for a 350μm^2 die driven by a direct current of 100mA at room temperature (3.5 times higher than existing products). The firm has started to deliver sample products.

LED-based optical sensors have advantages such as a smaller size, lower power consumption and longer life time. Also, because near-infrared and short-wavelength infrared light with a wavelength range of 800-2000nm is highly penetrative to organisms, the application of short-wavelength LEDs are proceeding in fields such as agricultural and food analysis, medicine and healthcare. In particular, in healthcare (the market for which is set to expand rapidly), LED-based sensors are expected to enable the measurement of blood glucose level without drawing blood.



Dowa says that the new short-wavelength infrared LED chips can balance higher output power and a smaller chip size (which are usually traded off), and that the optical output has been significantly improved (a requirement for sensor applications). Dowa aims to expand these technologies to peak wavelengths of 1450nm and 1650nm, broadening the range.

In the field of gallium-based compound semiconductor, Dowa offers an extensive lineup of products, ranging from materials such as high-purity gallium to wafers, LED chips and some lamp modules. Dowa also has abilities to flexibly accommodate a variety of needs, such as customizing wavelengths. Dowa will focus on enhancing the features of next-generation products and streamlining production to further expand its semiconductor business.

www.dowa-electronics.co.jp/en

EU project REDFINCH to develop PIC-based mid-IR portable sensors for chemical detection in gases & liquids

Hybrid and monolithic integration of III–V diode and interband cascade and quantum cascade materials with silicon to create high-performance, cost-effective sensors

Grenoble-based micro- & nano-technology R&D center CEA-Leti has launched the REDFINCH consortium to develop the next generation of miniaturized, portable optical sensors for chemical detection in both gases and liquids. Initial target applications are gas detection and analysis for refineries and the petrochemical industry and protein analysis for the dairy industry

Funded by the European Union's 'Horizon 2020' program, the consortium of eight European research institutes and companies will focus on developing novel, high-performance, cost-effective chemical sensors based on mid-infrared photonic integrated circuits (MIR PICs). Silicon PICs — integrating optical circuits onto millimeter-size silicon chips — create robust miniature systems in which discrete components are replaced by on-chip equivalents, making them easier to use and reducing their cost dramatically (by at least a factor of 10, it is expected).

To develop these chemical sensors, the consortium must overcome the challenge of implementing these capabilities in the important mid-infrared region (spanning wavelengths of 2–20μm), where many important chemical and biological species have strong absorption fingerprints. This allows both the detection and concentration measurement of a wide range of gases, liquids and biomolecules, which is crucial for applications such as health monitoring and diagnosis, detection of biological compounds, and monitoring of toxic gases.

Initially, REDFINCH will focus on three specific applications:

- process gas analysis in refineries;
- gas leak detection in petrochemical plants and pipelines; and
- protein analysis in liquids for the dairy industry.

Silicon photonics leverages the advantages of high-performance CMOS technology, providing low-cost mass manufacturing, high-fidelity reproduction of designs, and access to high-refractive-index contrasts that enable high-performance nanophotonics.

"Despite the mid-infrared wavelength region's importance for a wide range of applications, current state-of-the-art sensing systems in the MIR tend to be large and delicate. This significantly limits their spreading in real-world applications," says Jean-Guillaume Coutard, an instrumentation engineer at Leti, which is coordinating the project. "By harnessing the power of photonic integrated circuits, using hybrid and monolithic integration of III–V diode and interband cascade and quantum cascade materials with silicon, the consortium will create high-performance, cost-effective sensors for a number of industries."

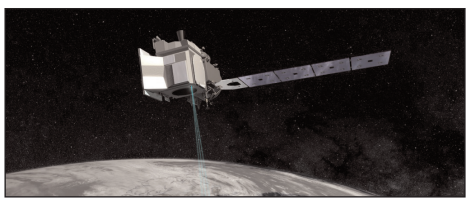
In addition to Leti, whose expertise includes the design and manufacture of PICs on a 200mm pilot line and integrated photoacoustic cells on silicon, the consortium members and contributions include:

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

www.redfinch.eu
www.leti.fr

nLIGHT lasers launch on NASA ICESat-2 satellite for measuring changing earth heights

nLIGHT Inc of Vancouver, WA, USA (which provides high-power semiconductor and fiber lasers for industrial, microfabrication, aerospace and defense applications) says its high-power semiconductors lasers are part of the transmitting laser technology that form the heart of NASA's Ice, Cloud and Land Elevation Satellite 2 (ICESat-2), launched from Vandenberg Air Force Base on 15 September.



ICESat-2 is using a laser altimeter to measure, track and report on changes to the earth's surface. This includes measuring ice-covered poles, taking stock of forests, mapping ocean surfaces and characterizing clouds.

https://icesat-2.gsfc.nasa.gov
www.nlight.net

CST Global adds InP epi overgrowth to production capability for high-volume DFB laser production

Using its commercial metal-organic chemical vapor deposition (MOCVD) reactor, III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global, a subsidiary of Sweden's Sivers IMA Holdings AB) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK has supplemented its foundry production services by adding the capability for in-house indium phosphide (InP) epitaxial overgrowth, which is critical to manufacturing high-volume distributed feedback (DFB) lasers used in passive optical network (PON) markets worldwide.

Implementation of the process is the result of a focused investment over the last year of about £0.5m (SEK6m).

"Adding InP epitaxial overgrowth to our foundry capability brings a critical production process in-house, where previously it was outsourced. It not only mitigates production bottlenecks, but also reduces DFB laser production times," says VP sales & marketing Euan Livingston. "Over the past year, we have significantly increased the capacity of our factory in Blantyre, Scotland, to meet the high demand for DFB lasers used in PON markets," he adds.

"Epitaxial overgrowth is a challenging process to master," continues Livingston. "We recognize that the combined expertise of our development and operations teams has been essential to the successful introduction of this new process."

CST Global begins developing buried heterostructure laser diodes

CST Global has begun developing a buried heterostructure (BH) laser diode production capability on its commercial MOCVD system.

Buried heterostructure lasers suit many silicon photonics applications, including passive optical network (PON) and quantum sensing markets, but there is currently a supply shortage of this type of single-frequency device and a global bottleneck in the ability to manufacture them, notes the firm.

The active layers of BH lasers are coated with an InP epitaxial overgrowth layer, applied by the MOCVD reactor. This creates a structure that simultaneously provides optical and electrical confinement while also offering high thermal performance, optimal beam shapes and low-noise, semiconductor optical amplification.

"The BH laser diode development project will enable CST Global to meet known high demand for this type of laser, which is used in silicon photonic, cloud data-center applications," says VP sales & marketing Euan Livingston. "BH lasers provide many advantages over standard lasers, such as low threshold current and high-speed modulation capability. Additionally, the epitaxial layers are uniform and can be grown simultaneously on multiple, large-area substrates, so they should be relatively quick and simple for us to make with high yield rates," he reckons.

www.CSTGlobal.uk

CST Global commissions second MOCVD reactor in collaboration with University of Glasgow

CST Global has commissioned its second MOCVD reactor. A result of an academic/industrial collaboration, it is owned by the University of Glasgow but sited, managed and operated at CST Global's production site in Blantyre, Glasgow, allowing joint research projects under the guidance of Richard Hogg, Professor of Photonics, without downtime on commercial MOCVD production. CST Global also gains extra MOCVD capacity as part of the collaboration.

The new MOCVD capability will enable development projects in bespoke III–V structures within an industrial setting, says Hogg. "We can now realise a range of advanced electronic and photonic devices."

"We can harness the benefits of siting the reactor in a professional manufacturing environment with access to excellent facilitation, safety systems, quality and exploitation routes. We can now service academic groups and industrial partners around the world developing and delivering the high-quality devices they need for advanced semiconductor research, in the timescales they require," he continues.

"Two projects are already in development. The reactor has a unique, high-temperature operation which facilitates InP laser production using overgrowth on silicon wafers. Since silicon wafers are a fraction of the price of III–V compound semiconductor wafers, a potential drop in laser cost is worth investigating," Hogg says. "We are also adding the capacity for iron (Fe) doping for heat dissipation to allow increased power and brightness in both DFB and BH lasers."

All development projects are funded by the Engineering and Physical Sciences Research Council (EPSRC) and government agency Innovate UK.

www.gla.ac.uk/schools/engineering/research/divisions/ene

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MACOM launches first single-chip TX/RX solution for 100G bidirectional optical connectivity

At the China International Opto-electronic Exposition (CIOE 2018) in Shenzhen, China (5–8 September) and at the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (24–26 September), MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications) showcased what it claims is the first integrated, single-chip transmit and receive (TX/RX) solution for short-reach 100G optical transceiver modules, active optical cables (AOCs) and on-board optical engines.

The seamless integration of four-channel transmit and receive clock data recovery (CDRs), four trans-impedance amplifiers (TIAs) and four vertical-cavity surface-emitting laser (VSCEL) drivers in the new MALD-37845 will afford customers unrivaled ease of use and reduced costs, says MACOM.

Supporting a full range of data rates from 24.3Gbps to 28.1Gbps, the MALD-37845 is designed for use in CPRI, 100G Ethernet, 32G Fibre Channel and 100G EDR InfiniBand applications, and will provide a low-power, single-chip solution suitable for small-form-factor optical subassemblies. It supports interoperability with a variety of VCSEL lasers and photodetectors, and is firmware-compatible with earlier-generation MACOM solutions.

"Optical module and AOC providers are under tremendous pressure to enable their customers with 100G connectivity at volume scale," says Marek Tlalka, senior director of marketing, High-Performance Analog. "The MALD-37845 overcomes the integration and cost challenges inherent to legacy multi-chip offerings, providing an elegant, high-performance solution for short-reach 100G applications," he adds.

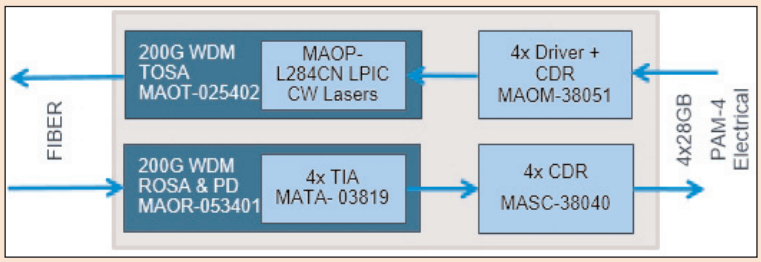
The MALD-37845 100G single-chip solutions are sampling to customers now, with production availability planned for first-half 2019.

www.macom.com/products/product-detail/MALD-37845

MACOM demos first complete chipset for 200G and 400G CWDM

At CIOE 2018 and ECOC 2018 MACOM Technology Solutions gave live demonstrations of what it claims is the first complete chipset solution for 200G and 400G CWDM optical module providers servicing cloud data-center applications. This enables 200G modules at under 4.5W and 400G modules at under 9W total power consumption, delivering what is reckoned to be industry-leading power efficiency with a fully analog architecture that ensures extremely low latency, as well as providing a lower-cost option compared to digital signal processor (DSP)-based offerings.

MACOM's full transmit and receive solution operates at up to 53Gbps PAM-4 data rates per lane and is optimized for use in 200G QSFP56 and 400G QSFP-DD and OSFP module applications. For 200G demonstration, the solution consists of the MAOM-38051 four-channel transmit CDR (clock/data recovery) and modulator driver and MAOT-025402 transmitter optical subassembly (TOSA) with embedded MAOP-L284CN CWDM L-PIC (silicon photonic integrated circuit with integrated CW lasers) transmitter, and on the receive side it features the MAOR-053401 receiver optical subassembly (ROSA) with embedded demultiplexer, BSP56B photodetectors MATA-03819 quad transimpedance amplifier (TIA) and the MASC-38040 four-channel receive CDR. The combined high-performance MACOM solution enables a low bit error rate (BER) and better than 1E–8 pre-forward error correction (pre-FEC).



The first complete chipset solution for 200G and 400G CWDM optical module providers.

"MACOM is committed to leading the evolution of data-center interconnects from 100G to 200G and 400G, as evidenced by our unique ability to deliver a complete 200G chipset and TOSA/ROSA subassembly solution with market-leading performance and power efficiency," says Gary Shah, VP, High-Performance Analog business line. "With this solution, optical module providers are expected to benefit from seamless component interoperability and a unified support team, reducing design complexity and costs while accelerating their time to market."

All of the MACOM products highlighted in the 200G live demonstrations are sampling now, with production availability targeted for early 2019. Customers can select from component-level solutions or a TOSA/ROSA subassembly-level solution.

www.cioe.cn/en
www.ecocexhibition.com

MACOM launches industrial-temperature-grade 25G lasers for high-volume deployment in 5G LTE wireless front-haul

At the China International Opto-electronic Exposition (CIOE 2018) in Shenzhen, China (5–8 September) and at the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (24–26 September), MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications) launched a portfolio of 25G distributed feedback (DFB) lasers designed for use in next-generation 5G LTE wireless front-haul infrastructure. Building on MACOM's legacy in 4G LTE connectivity solutions, the laser portfolio is expected to help wireless operators deploy 25G optical links at commercial scale and cost structures on the path to 5G.

Available in bare die chip format (1xxD-25I-LCT11-50x) and TO-packaging (1xxD-25I-LT5xC-50x) and designed for operation in the –40°C to 85°C temperature range over transmission distances of 2–10km, the new 25G DFB lasers will meet stringent operating requirements while helping to expand wireless infrastructure bandwidth for high-speed 5G connectivity.

The new industrial-temperature-grade 25G laser portfolio leverages MACOM's proprietary etched facet technology (EFT) which, at commercial-scale manufacturing levels, could enable breakthrough cost efficiencies and product uniformity, it is reckoned. MACOM believes that this high-volume production capability distinguishes it as a leading provider of 25G lasers across a host of cloud data-center and wireless infrastructure applications.

"MACOM's new 5G LTE-optimized 25G laser family builds on our comprehensive portfolio of 5G enabling technologies, and again demonstrates the value of EFT for achieving production efficiency that scales to meet industry supply and cost-structure needs," says Dr Fang Wang, VP & business line manager, Lightwave. "For customers transitioning from 10G to 25G wireless front-haul infrastructure, MACOM can provide the 25G lasers, complementary components and application expertise to help accelerate deployment time and reduce costs," he adds.

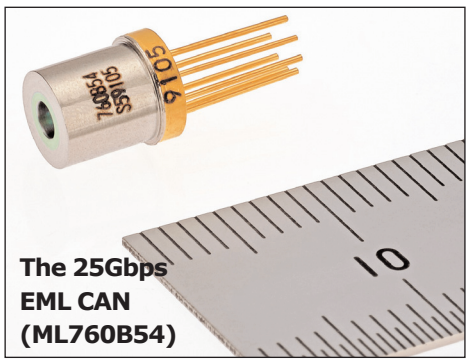
MACOM says that the industrial-temperature-grade 25G lasers are sampling to customers now. Production availability is planned for 2019.

www.cioe.cn/en
www.ecocexhibition.com
www.macom.com

Mitsubishi Electric launching 25Gbps EML CAN module for 5G mobile base stations

At the 20th China International Optoelectronic Exposition (CIOE 2018) in Shenzhen, China (5–8 September), Tokyo-based Mitsubishi Electric Corp has launched the ML760B54, a 25Gbps electroabsorption modulated laser (EML) CAN module (to be commercially available from 1 November), supporting high-speed optical data transmission in radio access networks within fifth-generation (5G) mobile base stations.

The introduction of 5G mobile networks will herald the transmission of huge volumes of data and the need for high-speed optical communication networks, notes Mitsubishi Electric. This will in turn drive customer demand for high-speed optical devices with low power consumption. The firm says that its new 25Gbps EML CAN module addresses these requirements, and can help to improve the productivity and efficiency of customer installations.



The 25Gbps EML CAN (ML760B54)

Mitsubishi Electric says that the new module supports high-speed, large-volume mobile networks by leveraging the improved bandwidth of a TO-CAN package (claimed to be a first for a 25Gbps EML). The emission wavelengths are 1270±10nm of 1310±10nm.

The module also reduces power consumption within mobile networks (by cutting the power consumption of the thermo-electric cooler by 40% compared with the existing FU-411REA model, to 0.28W typically at +95°C). The operating case temperature range is –40°C to + 95°C. Optical output power is typically more than +10dBm. The extinction ratio is typically more than 6dB.

Finally, the ML760B54 is expected to improve the productivity and efficiency of customer installations. Specifically, being compatible with the standard 5.6mm TO-56 CAN package, a simplified fabrication process should improve the productivity of bi-directional optical modules and transceivers.

www.mitsubishielectric.com/semiconductors/products/opt

Lumentum participating in nine tradeshows in four months

Over the course of four months, optical and photonic optical component and subsystem maker Lumentum Holdings Inc of Milpitas, CA, USA is participating in nine tradeshows worldwide, displaying its portfolio of products for the telecom, enterprise, data-center, 3D sensing and commercial laser markets:

- AutoSens Brussels 2018 (18–20 September) in Brussels, Belgium at the Auto World Museum, exhibiting high-volume laser illumination for automotive applications.
- ECOC 2018 (24–26 September) in Rome, Italy, displaying products including Lumentum's next-generation TrueFlex ROADM portfolio and a wide-ranging display of optical transceivers.

Presentations:

— 'Achieving Cost Effective 400G Interconnects' by Justin Abbott, senior product line manager, Datacom;

— 'Photonic Devices for Consumer and Automotive 3D Sensing Applications' by Brandon Collings, chief technology officer.

- Automotive LIDAR 2018 (26–28 September) in Detroit, Michigan at the Dearborn DoubleTree, showcasing 3D sensing solutions for LIDAR applications.

Presentation: 'Sponsor Showcase' by Dr Tomoko Ohtsuki, product line manager.

- Image Sensors Auto Americas 2018 (8–10 October) in San Francisco, Hyatt Centric Fisherman's Wharf Hotel, exhibiting high-volume laser illumination for automotive applications.

Presentation: 'Laser Diode Solutions for Automotive LiDAR Systems' (10 October, 1:30-2pm) by Dr Tomoko Ohtsuki, product line manager.

- ICALEO 2018 (14–18 October) in Orlando, Florida at the Rosen Centre Hotel (booth #9), presenting high-performing laser solutions used in cutting, welding, brazing, and micromachining.
- EuroBLECH 2018 (23–26 October) at the Hanover Exhibition Grounds, Germany (booth #E117 – Hall 16), highlighting its product line of laser solutions.
- Medical Design & Manufacturing (MD&M) Minneapolis 2018 (31 October – 1 November) at the Minneapolis Convention Center, Minnesota (booth #1541), exhibiting commercial lasers that are often used in medical manufacturing to achieve high degrees of precision and quality.
- FABTECH Expo 2018 (6–8 November) in Atlanta at the Georgia World Congress Center (booth #B8967 – Hall B), displaying a broad spectrum of industrial laser systems, from PicoBlade 2 to a 9kW fiber-laser engine.
- Photonix Japan 2018 (5–7 December) in Chiba City at the Makuhari Messe Expo Center, exhibiting solutions for applications from optical communications to 3D sensing.

www.lumentum.com

Lumerical and Mentor co-develop PDK for TowerJazz's silicon photonics foundry process

Photonic simulation software provider Lumerical Inc of Vancouver, British Columbia, Canada has made available a process design kit (PDK) developed in collaboration with electronic design automation (EDA) software provider Mentor (a Siemens business). The PDK gives designer access to the first open silicon photonics (SiPho) manufacturing process offered by a commercial foundry through an integrated flow that enables significantly higher productivity.

Targeting optical networking and data-center interconnect applications, the SiPho PH18MA process is an 'open' platform offered by specialty foundry TowerJazz to all SiPho customers, unlike other 'closed' processes only offered to certain customers or restricted to low-volume prototyping. TowerJazz's SiPho process complements its silicon germanium (SiGe) BiCMOS processes, which are used to build the electronic components of 100–400Gb optical fiber communication systems.

The SiPho market is expected to rise at a compound annual growth rate (CAGR) of over 20% to 2023, according to a MarketsandMarkets report. SiPho has the potential to become a cost-effective, scalable technology for the production of electro-optical integrated circuits and transceivers for data centers and high-performance computing, telecoms, military, defense and aerospace applications. TowerJazz's SiPho process addresses the high-performance requirements of these applications, such as a reduction in power consumption, high bandwidth and high data transfer capabilities.

The collaboration between foundry, EDA and photonic simulation firms provides photonic designers with a high-productivity path to silicon at a proven commercial specialty foundry, say the firms. The integrated flow developed by Lumerical and Mentor enables photonic designers to combine photonic simulation and EDA tools. The flow improves photonic circuit and system designers' productivity by providing a layout-driven flow featuring Python-driven layout generation with Mentor's recently announced LightSuite Photonic Compiler, integrated with Lumerical's photonic integrated circuit simulator INTERCONNECT, and DRC checking with Mentor's Calibre RealTime Custom verification tool. This integration introduces a path towards efficient photonic-electronic co-simulation. Mentor's LightSuite Photonic Compiler enables designers to generate as well as update large photonic layouts rapidly, in some cases in minutes versus weeks.

Targeting optical networking and data-center interconnect applications, the SiPho PH18MA process is an 'open' platform offered by specialty foundry TowerJazz to all SiPho customers, unlike other 'closed' processes only offered to certain customers or restricted to low-volume prototyping

The Compact Model Library (CML) contains passive components such as waveguides, directional couplers, grating couplers and multi-mode interference (MMI) couplers as well as active components such as Mach–Zehnder modulators, a photodiode and PN junction phase shifters.

"We have worked closely with TowerJazz's industry-leading PH18MA process and device experts to provide a reliable compact model library (CML) for accurate time- and frequency-domain simulation using Lumerical's photonic integrated circuit (PIC) simulator, INTERCONNECT," says Lumerical's chief technology officer Dr James Pond. "We have integrated this CML seamlessly into the TowerJazz/Mentor PDK to enable high-quality photonic simulation within the Mentor design flow, in addition to standalone simulation with INTERCONNECT," he adds.

Enabling a comprehensive photonic IC design flow "will allow our mutual customers to efficiently design, verify and synthesize their photonic integrated circuits," says Dr Marco Racanelli, senior VP & general manager of TowerJazz's RF & High Performance Analog business unit.

"With our new LightSuite Photonic Compiler and Calibre RealTime Custom teamed with Lumerical's photonic simulation solutions, we are providing TowerJazz customers with a progressive tool flow that will enable them to move silicon photonics from the lab to mainstream design," says Greg Lebsack, general manager of the IC Design Solutions Division at Mentor. "We anticipate photonic designers will increasingly use this path to accelerate the impact of photonics on technology."

The PH18MA PDK is available immediately from TowerJazz. LightSuite Compiler will be available from Mentor from 1 October. INTERCONNECT and interoperability & reader licenses enabling the flow are available immediately from Lumerical.

A demonstration of the TowerJazz SiPho design enablement platform featuring TowerJazz's PH18MA PDK, Lumerical's INTERCONNECT and Mentor's LightSuite Photonic Compiler took place in both the Mentor and TowerJazz booths at the 44th European Conference on Optical Communications (ECOC 2018) in Rome, Italy (24–26 September).

www.towerjazz.com
www.lumerical.com
www.mentor.com

Mellanox ships 200G LinkX copper and optical cables and transceiver for Ethernet and HDR InfiniBand

First to market with product line of 200Gb/s DAC, AOCs and transceivers

Mellanox Technologies Ltd of Sunnyvale, CA, USA and Yokneam, Israel (a supplier of end-to-end Ethernet and InfiniBand interconnect solutions for servers, storage systems and hyper-converged infrastructure) has begun shipping 200GbE Ethernet and InfiniBand HDR LinkX optical transceivers, active optical cables (AOCs) and direct attach copper cables (DACs) for use in upcoming 200Gb/s systems. Additionally, Mellanox has begun shipping 400G QSFP-DD DAC cables for next-generation systems.

LinkX is part of the Mellanox 'end-to-end' ecosystem including Spectrum2 200GbE and Quantum HDR systems and ConnectX-6 network adapters. The new LinkX 200Gb/s product line provides comprehensive options for switch, server and storage network connectivity for HDR InfiniBand and 200/400GbE infrastructures.

Mellanox showcased its complete LinkX product line of 100G, 200G and 400G products at the China International Optoelectronic Exposition (CIOE 2018) in Shenzhen, China (5–8 September) and at the European Conference on Optical Communications (ECOC 2018) in Rome, Italy (24–26 September):

- 200G SR4/HDR transceiver: Designed and manufactured by Mellanox, the 4x50G PAM4 transceiver uses the QSFP56 form factor and forms the basis for transceivers and AOC products for Mellanox's upcoming 200G systems.
- 200GbE and HDR DAC and AOC cables: Designed and manufactured by Mellanox, both straight and y-splitter 100GbE and HDR100 form factors are being exhibited.
- 400GbE DAC Cables: Mellanox kicks off its LinkX 400GbE line by shipping its 400G 8x50G PAM4 DAC cables in the QSFP-DD form factor.
- Live demos: At ECOC, Mellanox is hosting a live demonstration with Keysight/Ixia showing 200Gb/s SR4 transceivers and 400Gb/s QSFP-DD DAC cables.
- 400G SR8 transceiver: Mellanox-designed, 8-channel parallel transceiver are on display.
- Low-loss DAC cables: The firm is extending what is claimed to be one of the industry's largest offerings of interconnect products, with new low-loss DAC cables that enable simplified or even FEC-less links for Mellanox's SN2000 series of 25/50/100G network switches and ConnectX network adapters. The new cables offer lengths up to 5m and support the IEEE CA-N and CA-L specifications, enabling considerable interconnect latency savings.

Mellanox also displayed its full line of 25/50/100Gb/s cables and transceivers for hyperscale and data-center applications:

- LinkX 25G/50G/100Gb/s DAC & AOC cables and SR, SR4, PSM4, CWDM4 and LR4 transceivers;
- DAC and AOC breakout cables for 100Gb/s to 4x25Gb/s and 2x50Gb/s;
- DynamiX QSA Adapter, to convert any QSFP port to support an SFP-based DAC, AOC or transceiver available in 10G and 25G versions

www.cioe.cn/en
www.ecocexhibition.com
www.mellanox.com

Source Photonics and Ixia demo maturity of 400G-LR8 platform at ECOC, enabling migration to higher data rates

At the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (24–26 September), Source Photonics Inc of West Hills, CA, USA (which provides optical connectivity products for data centers, metro and access networks) and Keysight business Ixia of Calabasas, CA, USA (a provider of network test solutions) demonstrated optical links with full-line-rate 400G Ethernet (400GE) live test traffic with pre-FEC (forward error correction) results utilizing Source Photonics' 400G QSFP-DD LR8 transceivers and Ixia's field-proven K400 QSFP-DD test system.

Source Photonics' 400G QSFP-DD LR8 transceiver.

Demand for higher bandwidth continues to drive the need for faster transmission speeds in the data center, optical transport networks and metro networks. Source Photonics says that its several demonstrations in traffic test beds with small-form-factor 400G-LR8 QSFP-DD transceivers have shown that the 400G ecosystem is advancing and deployment of this higher data rate is imminent.

Source Photonics is now taking sample orders of the 400GBASE-LR8 QSFP-DD modules and is going into production in January 2019. The 400G portfolio will be complemented by QSFP-DD 400G-DR4 and 400G-FR4 transceivers, which will be available for sampling in fourth-quarter 2018 and first-quarter 2019, respectively.

www.sourcephotonics.com
www.ixiacom.com
www.ecocexhibition.com

II-VI completes acquisition of WSS firm CoAdna

Engineered materials and optoelectronic component maker II–VI Inc of Saxonburg, PA, USA has completed its acquisition of CoAdna Holdings Inc of Sunnyvale, CA, USA (announced its on 26 March).

Founded in 2000, CoAdna designs and manufactures highly integrated, intelligent optical components, modules and sub-systems, such as LC (liquid crystal) devices, wavelength-selective switches (WSS) and reconfigurable optical add-drop multiplexers (ROADMs) based on its patented LightFlow liquid-crystal platform.

Specifically, CoAdna produces wavelength-selective switches based on LightFlow and II–VI's micro-optics. Its WSS modules have a long history of field deployments and, over the years, have been integrated alongside II–VI's optical amplifiers, optical channel monitors and other components on reconfigurable optical add-drop multiplexer (ROADM) line-cards designed by II–VI, CoAdna and their customers.

CoAdna will be integrated into the II–VI Photonics Segment. Post-closing, II–VI maintains its fiscal first-quarter 2019 financial guidance, as stated in its most recent earnings release on 7 August.

"Together, we will be able to leverage our vertical integration and our combined capabilities to offer differentiated modules, ROADM line-cards and subsystem products in a rapidly evolving market," says II–VI Inc's president & CEO Dr Chuck Mattera.

CoAdna's LightFlow WSS product series complements II–VI's portfolio of products for optical amplification and monitoring that enables ROADM line cards. CoAdna's headquarters in Sunnyvale, CA now becomes the II–VI Technology Center Silicon Valley.

II–VI showcased its portfolio of optical communications products at 20th China International Optoelectronic Exposition (CIOE 2018) in Shenzhen, China (5–8 September) and at the 44th European Conference on Optical Communications (ECOC 2018) in Rome, Italy (24–26 September).

www.cioe.cn/en
www.ecocexhibition.com
www.CoAdna.com
www.ii-vi-photonics.com

POET appoints senior vice president of strategic marketing & product management

POET Technologies Inc of Toronto, Canada and San Jose, CA, USA — a designer and manufacturer of optoelectronic devices, including light sources, passive waveguides and photonic integrated circuits (PIC) for the sensing and datacom markets — has appointed Rich Zoccolillo as senior VP of strategic marketing & product management.

"Rich brings a vast network of executive, technical and operational relationships to POET that he's developed over a 30-plus year career in the photonics industry [including senior management roles at Infinera, Opnext and Lucent Technology's optical networking business], dating back to Bell Labs in the late 1980s," comments CEO Dr Suresh Venkatesan. "Rich will be a tremendous asset to the company's marketing and growth initiatives by leveraging POET's highly differentiated Optical Interposer Platform across expanded opportunities in both the datacom and telecom markets," he believes.

Zoccolillo will report to Venkatesan, with responsibilities including strategic marketing to customers, management of product sales activities as well as driving a growing pipeline of new business opportunities and prospective partnership engagements.

"I am excited to join POET during this period of dynamic growth in the photonics industry, which is largely being driven by demand from cloud data centers and next-generation 5G communications," says Zoccolillo. "By leveraging its disruptive technology platform for the integration of electronics and optics, POET is redefining the fundamental economics of high-performance optical communications. This has the potential to represent a significant value proposition to both strategic partners and leading suppliers seeking differentiation," he comments. "I look forward to leading the company's marketing efforts to identify and capitalize on these transformational opportunities."

Zoccolillo most recently served as the VP of systems manufacturing at Infinera, responsible for overseeing both internal and contract manufacturing. Previously, he held multiple roles at Opnext (acquired by Oclaro), including president of the Pluggables business unit and general manager of Optical Subsystems. Prior to Opnext, Zoccolillo held a number of management positions during his almost 16-year tenure at Lucent Technologies, AT&T Bell Laboratories. These included general manager of the Lucent Metro WDM business, director of product management for both Lucent's SONET and SDH systems, and roles in Lucent's consumer product organization. Previously, he had roles in planning and product development at AT&T Bell Labs.

Zoccolillo served on the advisory council for Monmouth University's School of Science and Technology. He holds both Bachelor and Master of Science degrees in Computer Science from Polytechnic University of New York.

www.poet-technologies.com

NeoPhotonics showcases lasers and components for 400G EML and silicon photonics-based data-center links

At the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (24–26 September), NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated optoelectronic modules and subsystems for high-speed communications networks) showcased its suite of lasers and analog ICs for uncooled, non-hermetic single-laser 100G and 4-laser 400G links within data centers. The product suite includes electro-absorptively modulated lasers (EMLs) for 2km PAM4-based links and high-power continuous-wave (CW) laser sources for 0.5km and 2km silicon photonics-based links, along with the photodetectors, drivers and transimpedance amplifiers (TIAs) required.

The demand for higher port density and lower cost per bit for optical connections inside the data center is driving a technology shift to single-laser (lambda) 100Gbps and 4-laser (lambda) 400Gbps using 4-level pulse amplitude modulation (PAM4), notes NeoPhotonics. EML-based solutions are preferred for longer-reach, higher-performance applications, and the firm says that its 53Gbaud family offers module designers a complete set of optical components with accompanying analog electronic chips designed to achieve high performance with low power consumption in small-form-factor applications. The 100G/400G component suite includes:

- *53GBaud uncooled CWDM4 EML, which includes the option for integration with NeoPhotonics' open drain driver*. With an uncooled operating temperature range of 20–70°C and the capability to operate reliably in 'open-air' transceiver designs (eliminating hermetic enclosures), this EML is a preferred transmitter solution for PAM4-based FR4 2km data-center applications. Versions are also available at 1310nm for DR1 and DR4 500m applications.
- *53GBaud open drain driver (ODD) for linear operation of EML lasers*. With a typical 90mW of power consumption per channel and small size, this high-speed driver can be co-packaged with the EML (reducing power and increasing linearity) and is suited to use in small-form-factor pluggable modules.

The suite includes EMLs for 2km PAM4-based links and high-power CW laser sources for 0.5km and 2km silicon photonics-based links, along with the photodetectors, drivers and TIAs required

- *53GBaud PIN photodetectors*. The side-illumination structure of the PIN PD enables a simple coplanar assembly with a mux/demux chip and TIA and is well suited for compact modules.
- *53GBaud transimpedance amplifier (TIA)*. With low noise and a typical power consumption of 60mA over a 3.3V rail, this TIA is suited to receiver signal amplification for up to 10km transmission.

In addition, transceiver developers have begun deployment of silicon photonics-based transceivers for industry-standard multi-source agreements (MSAs) such as CWDM4, CLR4 and PSM-4, which has led to the need for custom, high-power and non-hermetic laser sources to drive these transceivers. To support this emerging silicon photonics eco-system, NeoPhotonics has developed and qualified a line of high-power, uncooled lasers and laser arrays for several industry-leading silicon photonics transceiver manufacturers, as well as offering single and quad drivers for silicon photonics modulators:

- *High-power 40mW and 70mW non-hermetic CW laser sources for silicon photonics-based CWDM4 FR4 and 1310nm DR1 and DR4 applications*. These efficient, high-power distributed feedback (DFB) lasers can operate up to 75°C and have completed the non-hermetic testing compliant with the Telcordia GR-468-CORE, making them suited to use in non-hermetic silicon photonics-based small-form-factor pluggable modules.
- *53GBaud quad MZM drivers for silicon photonics modulators*. This quad driver has a high $3.5V_{ppd}$ output per channel and a typical 2.2W low power consumption for all four channels designed for small-form-factor pluggable modules. This component is also available in single-driver configurations for DR1 applications.

Our complete suite of 53GBaud linear optical components provides all needed optical components for single-laser 100Gbps transmitters and receivers, scalable to 400Gbps transceivers with CWDM4 wavelengths. Our uncooled, high-power CW DFB lasers and laser arrays are critical elements

"Our complete suite of 53GBaud linear optical components provides all needed optical components for single-laser 100Gbps transmitters and receivers, scalable to 400Gbps transceivers with CWDM4 wavelengths," says chairman & CEO Tim Jenks. "Furthermore, our uncooled, high-power CW DFB lasers and laser arrays are critical elements for any 100G, 200G or 400G silicon photonics-based transceiver," he adds. "We are pleased to offer the lasers and critical analog electrical components for both next-generation data-center transceiver approaches."

www.ecoc2018.org
www.neophotonics.com

NeoPhotonics' 64GBaud coherent optical components selected by tier-1 customers for 600G system development

NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated opto-electronic modules and subsystems for high-speed communications networks) says that its suite of 64GBaud optical components for coherent systems are being used by multiple major customers to develop systems with 600G-per-wavelength transport capacity.

The suite consists of three critical optical components: a 64GBaud CDM (coherent driver modulator) plus a 64GBaud ICR (coherent intradyne receiver) and finally an ultra-narrow-linewidth tunable laser. These work together to enable the implementation of single-wavelength 600G or dual-wavelength 1.2T data transmission over data-center interconnect (DCI) distances of 80km.

Three leading OEM customers have elected to use all three components in their development, while additional customers have elected to use a subset of the 64GBaud coherent component suite. The components also support 400G over metro distances of 400–600km using 64GBaud and 16 QAM or 200G over long-haul distances of greater than 1000km using 64GBaud and QPSK.

64GBaud components double the symbol rate over standard 100G (32GBaud) coherent systems. Higher symbol rates increase data capacity while maintaining superior optical signal-to-noise ratio (OSNR), spectral density and reach performance. All of these components are available in compact-form-factor packages suitable for pluggable modules and compact daughter cards.

- **64GBaud CDM**: NeoPhotonics' 64GBaud polarization-multiplexed, quadrature coherent driver modulator (CDM) is shipping in limited availability and features a co-packaged indium phosphide (InP) modulator with a linear, high-bandwidth, differential driver in a compact package designed to be compliant with the anticipated OIF Implementation Agreement.
- **64GBaud micro-ICR**: NeoPhotonics' Class 40 high-bandwidth micro-intradyne coherent receiver (micro-ICR) is in volume production and is designed for 64GBaud symbol rates, doubling the bandwidth of standard 100G ICRs. The compact package is designed to be compliant with the OIF Implementation Agreement OIF-DPC-MRX-02.0.
- **Low-profile Micro-TL**: NeoPhotonics' ultra-narrow-linewidth external cavity tunable laser features very low phase noise and power consumption and has been proven in volume production. It is now configured in a smaller, lower-profile package that is compliant with the OIF Implementation Agreement OIF-MicroITLA-01.

The suite consists of three critical optical components: a 64GBaud coherent driver modulator plus a 64GBaud coherent intradyne receiver and an ultra-narrow-linewidth tunable laser

NeoPhotonics has introduced its next generation of coherent products, which approximately halve the size of coherent optics while featuring the same high performance required for 400G and 600G per wavelength

In addition to these shipping products, NeoPhotonics has introduced its next generation of coherent products, which approximately halve the size of coherent optics while featuring the same high performance required for 400G and 600G per wavelength. The coherent optical subassembly (COSA) integrates NeoPhotonics' 64GBaud coherent driver modulator with its 64Gbaud coherent receiver in a very compact form factor. Alongside this, NeoPhotonics introduced a 'Nano' ultra-narrow-linewidth external cavity tunable laser, which again approximately halves the size while featuring industry-leading linewidth and phase noise and with low electrical power consumption.

These next-generation products were demonstrated in operation at the Optical Fiber Conference (OFC 2018) exhibition in March, both individually and incorporated into a compact 400G pluggable module.

"We are working closely with customers to provide a matched suite of high-speed optical components for 600G per wavelength to enhance system performance and reduce time to market," says chairman & CEO Tim Jenks. "With our next-generation highly integrated COSA, operating at 64 Gbaud and beyond, and our Nano-Tunable Laser, we are working to enable highly compact pluggable 400G modules," he adds.

NeoPhotonics exhibited its suite of coherent components for 600G and 1.2T at the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (24–26 September) along with its broad family of products for high-speed applications.

In addition, in the Exhibition Market Focus session 'Optical Network Agility/Software Defined Networks', NeoPhotonics' CTO systems Dr Winston Way presented a paper 'Next-Generation Coherent Pluggable Transceivers in a CDC ROADM Based Optical Network'.

www.ecoc2018.org
www.neophotonics.com

Oclaro showcases portfolio of high-speed lasers for access and wireless networks

Production capacity expanded in Japan & UK to meet demand for new generation of 5G-ready wide-temperature and high-performance lasers

Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has announced availability of its full suite of high-speed lasers for access and wireless networks.

Designed to meet the high-performance and rigorous environmental conditions of access deployments, the lasers include a 25Gbps uncooled industrial-temperature (I-temp)-rated direct-modulated distributed feedback (DFB) laser (DML) chip, 10Gbps high-power I-temp DML chip and new electro-absorption modulated (EML) lasers that also service data-center applications:

- The 25Gbps uncooled DML chip is capable of operating at high temperature up to 95°C, so transceiver suppliers do not need to mount an expensive, power-hungry thermoelectric cooler inside the SFP28 I-temp. Also, the DML chip's high bandwidth enables 50Gbps PAM4 waveforms to be obtained with 5dB extinction ratio and TDECQ (transmitter and dispersion eye closure quaternary) values of less than 2.0dB. These features enable the laser to operate in 50GbE transceivers such as SFP56 or QSFP28.
- The 10Gbps high-power I-temp DML laser chip is designed for carriers currently upgrading the data rate to 10Gbps, as per the new XGS-PON/10GE-PON (passive optical network) standards. By enhancing its DML waveguide design, Oclaro has delivered a 10Gbps high-power 1270nm DML chip for optical networking unit (ONU) equipment for XGS-PON/10GE-PON. Key differentiators are the laser chip's high optical output power (15mW at 95°C) and high bandwidth (more than 15GHz).
- Oclaro's EML designs are capable of high-speed operation for 100Gbps PAM4 using an extremely high-bandwidth modulator. The EMLs have passed the rigorous damp heat operating and storage requirements of GR-468, making them an option for coolerless operation over typical data-center temperature ranges. The lasers do not require hermetic packaging, saving cost over other lasers requiring hermetic transmitter optical subassembly (TOSA) designs. Oclaro is also developing new 10Gbps EMLs for downstream PON applications and will be working with access market architects and transceiver manufacturers to bring these products to market.

Oclaro's 25Gbps uncooled and 10Gbps high-power I-temp DML laser chips and EML lasers are all currently in mass production.

To meet growing customer demand for these lasers and in anticipation of the future ramp of 5G optical links, Oclaro has recently expanded its production capacity by investing in new wafer fab equipment in its Japan and UK production facilities.

"Network upgrades to the current access infrastructure will require a new generation of low-cost, robust and high-speed lasers that can withstand the rigorous requirements demanded by deployments in outdoor enclosures and uncontrolled temperature nodes," says Walter Jankovic, president of Oclaro's Optical Connectivity business unit. "Oclaro has designed its lasers specifically to deliver a higher level of performance over wide operating temperature ranges and support critical features such as PAM4 modulation," he adds. "These lasers are expected to be critical components to support the introduction of 5G wireless networks by enabling customers to upgrade their wireless front-haul links from 10Gbps to 25Gbps to 50Gbps."

www.oclaro.com

Applied Optoelectronics showcases 400G transceivers

At the European Conference on Optical Communication (ECOC) in Rome, Italy (24–26 September), Applied Optoelectronics Inc (AOI) of Sugar Land, TX, USA — a manufacturer of optical components, modules and equipment for fiber access networks in the Internet data-center, cable TV broadband, fiber-to-the-home (FTTH) and telecom markets — showcased its latest transceiver products for telecom and data-center applications, including:

Datacenter: 400G QSFP-DD/OSFP DR4, 400G QSFP-DD/OSFP FR4, 400G QSFP-DD FR8/LR8, 4x100G OBO x16, 2x100G QSFP-DD CWDM4, 2x100G QSFP-DD PSM4, 2x100G QSFP-DD SR4, 2x100G QSFP-DD AOC, 200G QSFP-DD FR4, 100G QSFP28 LR4, and 100G QSFP28 DR/FR;
Telecom: 50G QSFP28 LR, 25G SFP28 BIDI and 25G SFP28 LR C-temp/I-temp.

"We have worked closely with our partners to demonstrate a 400G DR4 breakout to 4x 100G FR transceivers," says David Chen, AVP & senior director of product management. "As customers shift from their current 100G architecture to a native 400G network, this application allows for the two speed generations to run in parallel. As the industry moves to 400G connections, this breakout brings us one step closer to transitioning to a native 400G ecosystem."

www.ao-inc.com

Oclaro demos 100–200G coherent CFP2-DCO

Complements CFP2-ACO with DCO solution for DSP-less customers; delivers interoperable modules for coherent 100G and 200G networks

At the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (23–27 September), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) demonstrated its CFP2-DCO module (due for production in early 2019), which is based on the firm's proven indium phosphide (InP) photonic integrated circuit (PIC) technology for tunable lasers, modulators and receivers and builds on its claim as the market leader in CFP2-ACO modules. Interoperability between Oclaro's CFP2-DCO and Acacia's AC200 CFP2-DCO has been demonstrated at both 100Gbps and 200Gbps data rates through joint testing in Oclaro's labs.

"Customers are looking for a plug-and-play digital solution leveraging the recognized performance of Oclaro's indium phosphide PICs," says Beck Mason, president of the firm's Integrated Photonics Business. "By delivering its first CFP2-DCO, based on Acacia's Meru DSP, Oclaro expands its addressable market while leveraging the proven value-add of its ACO platform," he adds. "This live demonstration represents a significant milestone in the industry because it highlights the availability of two fully interoperable supply sources for these critical components, which will help encourage broader adoption by network operators."

The CFP2-DCO is a complementary product offering to the CFP2-ACO product family where customers are able to utilize their DSP of choice in order to achieve optimum performance and cost. Oclaro says that its CFP2-ACO remains a critical, flagship product with proven high-volume production capability that leverages the firm's InP PIC development and production expertise.

The CFP2-DCO integrates the coherent DSP into the pluggable module and, by operating at data rates up to 200Gbps, can deliver double the capacity of current-generation CFP-DCO solutions in a much smaller, lower-power, pluggable module. This improved density, coupled with the digital host interface, enables quick and cost effective roll-out of 200Gbps networks, the firm claims.

At the heart of the CFP2-DCO is Oclaro's 43Gbaud coherent transmitter receiver optical sub-assembly (TROSA), which leverages proven InP PIC technology from Oclaro's CFP2-ACO to achieve what is claimed to be industry-leading optical performance in a small form factor.

The CFP2-DCO's digital host interface enables simpler integration between module and system, which results in faster service activation and facilitates a pay-as-you-grow deployment model for telecom providers, says Oclaro. The cost of additional ports can hence be deferred until additional services are needed.

www.ecocexhibition.com

Applied Optoelectronics cuts Q3 revenue guidance from $82–92m to $55–58m

Transceiver shipments resumed after solving issue with 25G lasers for one customer

Applied Optoelectronics Inc (AOI) of Sugar Land, TX, USA — a designer and manufacturer of optical components, modules and equipment for fiber access networks in the Internet data-center, cable TV broadband, fiber-to-the-home (FTTH) and telecom markets — has lowered its third-quarter 2018 revenue guidance from $82–92m (given on 7 August) to $55–58m.

"During the third quarter, we identified an issue with a small percentage of 25G lasers within a specific customer environment," says founder, president & CEO Dr Thompson Lin. "Consistent with AOI's commitment to supreme product quality and customer support, we mutually agreed with the customer to temporarily suspend shipments of certain transceivers utilizing these lasers while we worked to gain a deeper understanding of the scope of the issue and implement a solution. We have since determined that less than one percent of these lasers were subject to this issue; we have enacted a solution and with the agreement of the customer, resumed shipments," he adds.

"Our customers appreciate our willingness to thoroughly resolve any issues, even at the expense of a delay in our revenue, and we believe that we continue to have strong relationships with our customers," Lin believes. "Outside of the temporary delay in shipments that impacted our third quarter revenue, sales and shipments as well as the pricing environment were consistent with our prior expectations."

AOI will report detailed third-quarter financial results on 7 November.

www.ao-inc.com

100G Lambda MSA announces progress towards 100Gb/s optical technology product maturity

Consortium members release updated specs and collaborate to validate optical interoperability at 100GbE and 400GbE

The 100G Lambda Multi-Source Agreement (MSA) Group, which has grown to include 39 member companies, has announced the release D2.0 of three specifications based on 100Gb/s per wavelength PAM4 (4-level pulse amplitude modulation) optical technology.

These specifications are targeting applications for data centers and service provider networks, enabling multi-vendor interoperability for optical transceivers produced by different manufacturers and in various form factors. These updated 100GbE interface specifications are designated as 100G-FR and 100G-LR for duplex single-mode links over 2km and 10km, respectively.

The MSA has also updated the 400G-FR4 specification for 400GbE duplex single-mode fiber links relying on multiplexing four wavelengths of 100Gb/s PAM4 modulated optical signals. In addition, the MSA is also working on a 400G-LR4 specification for a 10km reach at 400GbE.

Members of the 100G Lambda MSA Group have also announced the success of their optical interoperability private plugfest. In total, 12 member companies came together for two and a half days of testing to validate the compatibility, testability and optical interoperability between members' module or test equipment designs for the newly released specifications. The activity was hosted by MSA member company MultiLane. The areas of focus included testing optical interoperability for 100GbE and 400GbE modules and modules that support 4x 100GbE breakout. The importance of the private plugfest is to ensure that member companies' products meet the 100G Lambda MSA specification and interoperate before they are released for production.

"The rapid convergence of stakeholders and technical agreement highlights the strong industry effort and the demand to bring this technology to market as soon as possible," says MSA co-chair Mark Nowell.

"The successful testing between so many members involved in the plugfest shows the rapid maturity of the various product and technology developments across the ecosystem," comments co-chair Jeffery Maki.

The 100G Lambda MSA Group hosted module interoperation demonstrations at the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (24–26 September).

www.100GLambda.com

QSFP-DD MSA Group releases updated 4.0 Hardware Spec and Common Management Interface Spec

The Quad Small Form Factor Pluggable Double Density (QSFP-DD) Multi Source Agreement (MSA) group (supported by 66 companies to address the need for an improved high-density, high-speed networking solution) has released an updated 4.0 Hardware Specification for the QSFP-DD form factor. Notable features include additions to the thermal section, synchronous clocking and improved keying.

In addition to the updated 4.0 specification that addresses broad market support and overcomes the technical challenges of specifying a QSFP28-compatible double-density interface, the group has also released the 3.0 Common Management Interface Specification (CMIS), which provides a set of management interactions and a register map for 8- and 16-lane modules.

Initial work on the CMIS was by the QSFP-DD MSA and later expanded to include other industry standards groups. The CMIS is similar to the QSFP module management interface specification with expansion to the management of 8 and 16 lanes using a 'banking' feature. The CMIS is the first management specification designed to cover a wide range of module form factors, functionalities and applications, ranging from passive copper cable assemblies to coherent DWDM modules.

The CMIS defines host-to-module interactions needed to ensure that modules will initialize and operate consistently through the management interface. The defined state machines simplify operation by allowing the host to identify and control the power-up sequencing of new high-power class modules.

"Through strategic collaborations we are able to provide specifications that address the challenges of common management requirements for the mechanical, thermal and electrical parameters," says Tom Palkert, editor of the QSFP-DD MSA specifications. "The CMIS breaks the barriers to multi-vendor interoperability by addressing the ability of next-generation modules to meet user needs."

The MSA QSFP-DD HW Specification supports up to 400Gbps in aggregate over an 8 x 50Gbps electrical interface. The CMIS supports multiple interface settings and speed negotiation controls and allows support for multiple 'Data Paths' where each 'Data Path' consists of a sub-group of lanes to be controlled together within the multi-lane module.

www.qsfp-dd.com

Molex demos next-generation 100Gbps-per-wavelength PAM-4 100GbE and 400GbE optical technology

At the European Conference on Optical Communications (ECOC 2018) in Rome, Italy (25–26 September), high-speed fiber-optic interconnect firm Molex Inc of Lisle, IL, USA demonstrated next-generation 100Gbps-per-wavelength PAM-4 optical technology, including the 100G FR QSFP28 and 400G DR4 and FR4 QSFP-DD products in compliance with the 100G Lambda Multi-Source Agreement (MSA).

As an MSA promoter company, Molex joined forces with other industry leaders to enable a technology ecosystem for next-generation networking equipment, as well as promoting 100G PAM-4 as a foundation to support 4x100G and 400G FR4 solutions for high-volume deployment for data centers. The new 100G Lambda MSA specifications address the technical design challenges of achieving optical interfaces utilizing 100Gbps-per-wavelength PAM-4 (4-level pulse amplitude modulation) technology, and multi-vendor interoperability. The 100G Lambda MSA enables 100GbE with reaches of 2km and 10km and 400GbE with a reach of 2km over duplex single-mode fiber (SMF), tested for optical interoperability during the private 100G Lambda MSA Group plugfest.

100G FR 400G DR4 and 400G FR4 are products in Molex's 100Gbps-per-wavelength PAM-4 product family, which share the same opto-electronics technology platform. Live demonstrations in Molex's booth highlight the platform's technical readiness. 100G FR QSFP28 supports a 4x25G NRZ host electrical interface. The module transmits and receives 100G PAM-4 modulated optical signals over 2km of single-mode fiber. The technology variations can support different reaches such as 100G DR (500m) and 100G LR (10km). Aggregating four 100Gbps-per-wavelength lanes, the technology platform will also offer 400G versions such as 400G DR4, 400G FR4 and 4x100G for breakout applications.

www.molex.com/opticalsolutions

Synopsys and SMART Photonics expand InP-based PIC design automation

Synopsys Inc of Mountain View, CA, USA — which provides electronic design automation (EDA) software, semiconductor IP and services for chip and electronic system design — says that a new, production-ready process design kit (PDK) based on the indium phosphide (InP) process of independent pure-play InP foundry SMART Photonics of Eindhoven, The Netherlands is now available in its OptSim Circuit tool to support InP-based photonic integrated circuit (PIC) design and simulation.

Synopsys' PIC Design Suite, which consists of OptSim Circuit and OptoDesigner tools, provides a seamless PIC design flow from idea to manufacturing from a single solutions provider. The addition of the SMART PDK to OptSim Circuit, combined with the PDK's availability in OptoDesigner, enables users to use the PIC Design Suite to schematically capture and simulate InP-based PIC designs with the SMART PDK building blocks, and then synthesize and verify a SMART-foundry-compatible layout.

As PIC technologies advance, photonic design automation (PDA) software has become critical for improving PIC design productivity, driving time to market, and reducing costs, says Synopsys. PDKs provide a crucial link between PDA circuit simulation and layout tools by supporting efficient design concept verification, signoff checks and mask generation. The PIC Design Suite, together with the RSoft photonic device modeling tools, give PIC designers and PDK developers an infrastructure for creating and using custom PDKs, which is vital for generating foundry-specific intellectual property (IP), as well as augmenting existing PDKs with custom components such as the SMART PDK.

"PhoeniX Software was the first commercial software partner with a proven track record for designing photonic circuits. The acquisition of PhoeniX and the OptoDesigner tool by Synopsys strengthens collaboration further and enables customers to move forward to use a single partner for the full simulation and design flow," comments SMART Photonics' business developer Jeroen Duis. "We have been working closely with the Synopsys team to complete our PDK for use with the OptSim Circuit and OptoDesigner tools. This will help our mutual customers create more complex designs with a higher quality and shortened time to market," he adds.

"This is another example of a world-class PIC foundry taking advantage of the new opportunities offered by rapid advances in photonic integration," comments Tom Walker, group director of R&D for Synopsys' Photonic Solutions. "We are excited to be working with SMART Photonics and to be able to give our mutual customers the ability to design advanced custom photonic applications using the SMART Photonics InP semiconductor process."

Synopsys highlighted the PIC Design Suite at ECOC 2018.

www.smartphotonics.nl

http://optics.synopsys.com/rsoft

Finisar launches QSFP-DD DR4 transceiver for data centers and first 64Gbaud coherent integrated assembly

At the European Conference on Optical Communication (ECOC 2018) in Rome, Italy (24–26 September), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA launched several new products and gave technology demonstrations of several 200G and 400G transceivers including 400G QSFP-DD DR4, 400G QSFP-DD eLR8 (extended-reach), 200G QSFP56 FR4 and 200G QSFP56 eFR4. It also demonstrated what it claims is the first 64Gbaud integrated tunable transmitter and receiver assembly (ITTRA) and a new Flextune self-tuning feature for tunable DWDM modules.

The QSFP-DD (Quad Small Form Factor Pluggable Interface Double Density) is the latest module form factor targeting 400G data rates. The design provides an eight-lane electrical interface, compared with traditional single- or four-lane interfaces, increasing bandwidth, channel capacity and port density. Defined by the QSFP-DD MSA Group, this form factor addresses the need for high-density, high-speed networking solutions in a module host that's backwards compatible with QSFP28 and QSFP56.

QSFP56 is a form factor supporting 200G data rates. This module has the same mechanical design and electrical connector as a QSFP28 but provides a four-lane electrical interface running at 50G PAM4 (4-level pulse amplitude modulation) per channel, instead of 25G NRZ.

● *400G QSFP-DD DR4 transceivers*

Finisar has unveiled a 400G QSFP-DD DR4 transceiver targeting parallel single-mode fiber (SMF) links in hyperscale cloud data-center applications. The demonstration showed an optical module transmitting data point-to-point over parallel SMF using four 100G PAM4 optical lanes, per the IEEE 802.3bs 400GBASE-DR4 standard. These DR4 modules can also be used in break-out applications to four 100G QSFP28 DR transceivers.

● *400G QSFP-DD eLR8 transceivers*

Finisar gave what it claims is the first public demonstration of a 400G QSFP-DD eLR8 extended-reach transceiver, transmitting data over 30km of duplex SMF. These modules provide a cost-effective option for router-to-router or router-to-transport interconnections and use a directly modulated laser (DML)-based 8x50G PAM4 optical architecture. The demonstration showed an extension of the technology which is already in production in Finisar's 400G CFP8 LR8 modules and which has been demonstrated in Finisar's 400G QSFP-DD LR8 modules over 10km at March's Optical Fiber Communication (OFC 2018) event in San Diego, CA, USA.

● *200G QSFP56 FR4 and eFR4 transceivers*

For applications in hyperscale cloud data centers that require 200G optical connectivity, Finisar demonstrated both an IEEE Standard-based 200G QSFP56 FR4 module operating over 2km of duplex SMF and an extended-reach eFR4 version operating over 10km of duplex SMF. Both types of modules employ low-cost DML transmitters, providing cost-effective options for both standard and longer reaches.

All QSFP-DD and QSFP56 demonstrations showing error-free post-FEC transmission over fiber at the Finisar booth used Ixia's second-generation 400GE AresONE test system, which is capable of generating 3.2Tbps of Ethernet test traffic and is based on the field-proven K400 test system.

● *64Gbaud ITTRA demo*

Deployment of coherent optical technology is taking an increasingly important role in data-center interconnect applications. To support the market trend toward higher port densities, Finisar demonstrated a 64Gigabaud integrated tunable transmitter and receiver assembly (ITTRA), transmitting and receiving data error-free at 400Gbps using DP-16QAM modulation. The ITTRA is a complete coherent optics assembly that integrates a transmitter and a receiver into what is reckoned to be the smallest 64Gbaud footprint on the market. It can be easily integrated into coherent line cards or 400G digital coherent optics (DCO) transceivers, accelerating time to market and decreasing development and manufacturing labor costs due to fewer assembly steps and lower test times. The 64Gbaud ITTRA product complements the 32Gbaud ITTRA introduced by Finisar at OFC.

● *Flextune automatic wavelength tuning feature demo*

Flextune is an automatic transceiver wavelength tuning feature that can significantly reduce provisioning time and operating expenses when deploying tunable DWDM transceivers. Using Finisar-patented technology, each transceiver on a DWDM optical link can self-tune to the correct wavelength determined by its physical connection to the passive mux/demux infrastructure, and without intervention by the host system or technicians. Finisar gave a functional demonstration of Flextune on duplex Tunable SFP+ transceivers, and the feature is also being implemented on bidirectional tunable SFP+ as well as on coherent transceivers.

● *Measurement capabilities added to optical instrumentation portfolio*

Finisar also demonstrated new capabilities of the WaveShaper and WaveAnalyzer optical instrumentation portfolio. The new WaveAnalyzer GUI release 1.8 supports measurements of the side-mode suppression ratio (SMSR) of lasers, a key performance characteristic for such devices operating in optical communication systems. Also, release 1.8 provides an in-channel optical signal-to-noise ratio (OSNR) measurement technique, which is important in networks with filter elements like reconfigurable optical add/drop multiplexers (ROADMs).

www.finisar.com

DSFP transceiver MSA Group releases Hardware Specification Rev. 1.0

Eight industry leaders join forces to double data rate and port density of SFP transceivers

The DSFP (dual small-form-factor pluggable) MSA (multi-source agreement) Group has released the Rev. 1.0 Hardware Specification for the DSFP form-factor module (posted on its website on 12 September).

The DSFP MSA's founding member companies (Amphenol, Finisar, Huawei, Lumentum, Molex, NEC, TE Connectivity and Yamaichi) say they have addressed the technical challenges of doubling the SFP module density in the same footprint, while ensuring mechanical and electrical interoperability for optical transceivers produced by different manufacturers. DSFP networking equipment will also interoperate with existing SFP modules and cables.

DSFP Hardware Specification Rev. 1.0 includes complete electrical, mechanical and thermal specifications for the module and host card, including connector, cage, power and hardware I/O. Also included are operating parameters, data rates, protocols and supported applications.

The DSFP MSA Group is now developing the DSFP MIS (Management Interface Specification), as an abridged version of the Common MIS being developed by the QSFP-DD, OSFP and COBO Advisors Group.

To address the growing port density and scalability requirements of wireless and 5G mobile infrastructure, the DSFP specification doubles the data rate and port density of SFP modules. SFP has a single electrical lane pair operating at bit and data rates up to 28Gbps using NRZ (non-return to zero) modulation and 56Gbps using PAM4 (four-level pulse amplitude modulation). DSFP has two electrical lane pairs, each operating at bit rates up to 28Gbps using NRZ and 56Gbps using PAM4, supporting aggregate date rates up to 56Gbps and 112Gbps, respectively. DSFP will potentially scale to a per lane bit rate of 112Gbps using PAM4, supporting aggregate data rate up to 224Gbps. SFP modules can be plugged into DSFP ports for backwards compatibility.

The new DSFP MSA form factor will "double interface bandwidth and port density while maintaining compatibility with the existing SFP family of optics," says Zhoujian Li, president of R&D, Wireless Networks, at Huawei. "The DSFP form factor is low cost, has excellent high-speed signal integrity, reduces PCB area and is easy to design and manufacture. It is a great platform that enables 5G deployment and evolution, while fully protecting our customers' investment," he adds.

"Publication of the DSFP Hardware Specification is part of an industry trend of quickly developing solutions optimized for specific applications. Stringent cost, power and size constraints in demanding market segments, like mobile infrastructure, leads to solutions focused strictly on required functionality," says DSFP MSA Group chair Chris Cole, Finisar's VP of advanced development.

"TE works closely with our customers and end-equipment operators to understand their requirements and meet the market needs," says Nathan Tracy, technologist at TE Connectivity and manager of industry standards. "The new DSFP form factor provides a method to double data rate and channel density using the well-established SFP mechanical geometry as a starting point," he adds.

"There is tremendous industry pull for higher speeds and densities on switches and servers, while maintaining backwards compatibility. The DSFP form factor achieves this by doubling the number of high-speed lanes in the same size package as SFP," says Amphenol's technical business development manager Greg McSorley.

www.dsfpmsa.org

Finisar's quarterly revenue grows more than expected due to ROADM deployment in China and India

Growth to be driven by demand for VCSEL arrays for 3D sensing when Sherman fab ramps up

For its fiscal first-quarter 2019 (ended 29 July 2018), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA has reported revenue of $317.3m, down 7.2% on $341.8m a year ago but up 2.3% on $310.1m last quarter (and above the mid-point of the $305–325m guidance range).

Datacom & Sensing product sales — including vertical-cavity surface-emitting laser (VCSEL) arrays for 3D sensing applications — were $238.1m, down 7.8% on $258.3m a year ago and 4% on $248m last quarter, due mainly to lower demand for 40G transceivers. Half of datacom revenue still came from 100G products, with growth for CFP and CFP2 modules offsetting a drop for QSFP28 modules due to pressure on average selling prices.

Telecom product sales were $79.2m, down 5.1% on $83.5m a year ago but up 27.5% on $62.1m last quarter, due mainly to increased demand for wavelength-selective switches (WSS) driven by carrier deployments in India and China. "In our core business, we are continuing to see a very strong demand for our ROADMs [reconfigurable optical add/drop multiplexers] on a global basis, with India and China beginning to deploy ROADMs in large volumes," notes CEO Michael Hurlston.

Like last quarter, Finisar had two 10%-or-greater customers. The top 10 customers represented 62% of total revenue.

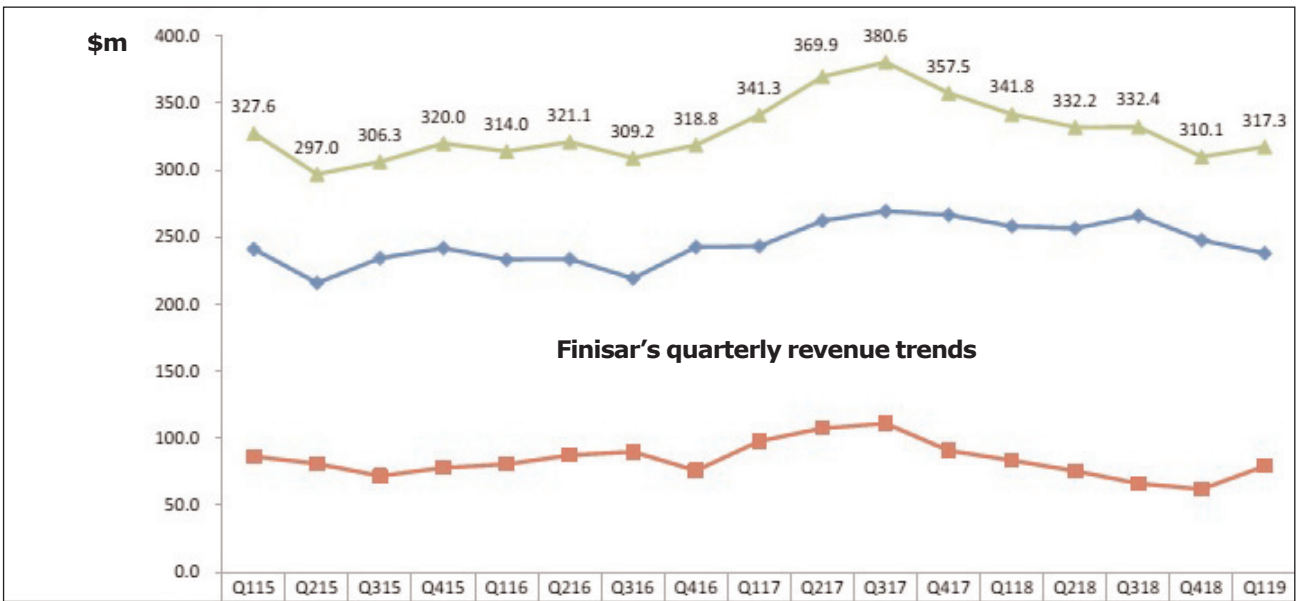
On a non-GAAP basis, gross margin was 27.5%, down from 34.9% a year ago but up from 24.7% last quarter (and above the expected 26–27%) due mainly to lower levels of additions to non-cash inventory reserves and a favorable product mix.

Operating expenses have been cut further, from $73.2m a year ago and $72m last quarter to $68.3m (21.5% of revenue). "We were able to accelerate the process of bringing more focus to our product development efforts, which allowed the company to reduce relative expense levels faster than expected," says Hurlston.

Despite being down from $46m (13.5% margin) a year ago, operating income was $18.8m (operating margin of 5.9% of revenue, above the expected 4–5%), up from $4.6m (1.5% margin) last quarter, due mainly to the higher revenue, higher gross margin and lower operating expenses. "We made better-than-expected process in our efforts to focus the product portfolio and be more strategic as to how do we invest our R&D dollars," notes Hurlston. "This in turn allowed us to make great strides toward our goal of a sustainable operating margin of 12–15%."

Net income was $21.3m ($0.18 per diluted share, exceeding the expected $0.10–0.16), down from $45.3m ($0.40 per diluted share) a year ago but up from $5.8m ($0.05 per diluted share) last quarter.

During the quarter, cash and short-term investments fell slightly from $1.197bn to $1.159bn. This was after capital expenditure (CapEx) of $112.7m, of which $4m related to construction and fit out of the third building of Finisar's manufacturing site in Wuxi, China and $97m related to uplift of the new 700,000ft^2 facility in Sherman, TX (purchased in late 2017) and the



	Q115	Q215	Q315	Q415	Q116	Q216	Q316	Q416	Q117	Q217	Q317	Q417	Q118	Q218	Q318	Q418	Q119
Datacom	241.2	215.9	234.4	242.0	233.3	233.8	219.3	242.9	243.4	262.3	269.5	266.7	258.3	256.6	266.1	248.0	238.1
Telecom	86.4	81.1	71.9	78.1	80.7	87.4	89.9	75.9	97.9	107.6	111.1	90.9	83.5	75.6	66.3	62.1	79.2
Total Optics Revenue	327.6	297.0	306.3	320.0	314.0	321.1	309.2	318.8	341.3	369.9	380.6	357.5	341.8	332.2	332.4	310.1	317.3

delivery of capital equipment for it (to expand manufacturing capacity for VCSELs using 6-inch wafers, compared with 4-inch wafers at Finisar's existing VCSEL fab in Allen, TX).

In fiscal second-quarter 2019 (to end-October 2018), Finisar expects CapEx of $35m for additional equipment for the Sherman fab, plus $28m in other CapEx, including $3m for the third building in Wuxi (due for completion largely by the end of the quarter).

For fiscal Q2, Finisar expects revenue to grow to $315–335m, due to an increase in demand for VCSEL arrays for 3D sensing applications in connection with the expected timing of new product introductions, partially offset by lower revenue from 10G-and-below Ethernet transceivers. Telecom revenue should be relatively flat due to capacity constraints. Gross margin should improve further to 28%. Due to a combination of higher revenue, better gross margin and lower operating expenses, operating margin is expected to continue to improve, to 7–8%. Earnings per fully diluted share should rise to $0.19–0.25.

"Our Allen fab is a gate for us, and is capacity limited in the near term [to $20–25m revenue per quarter]," says Hurlston. "As we start ramping Sherman, that capacity gate comes off, but in the very near term it is still dominated by one customer. Our ability to show revenue growth is going to be in terms of increasing market share at that customer," he adds.

"But, in addition, we are either in process or have completed qualifications with many new VCSEL array customers for both consumer and automotive applications that would drive future growth in this important market segment," says Hurlston. "In our new VCSEL laser fab in Sherman, Texas, we have completed the uplift of the building and installed a significant amount of the capital equipment for our first phase of capacity. We have begun the internal qualification for process of all the equipment and still expect to be qualified and in production using our 6" wafers by the end of this calendar year," he adds.

"For the upcoming 5G transition for wireless, we are a leading supplier of the major OEMs of 25G and 100G data rates for both short- and long-reach applications. We also believe we are well positioned for the 100G-to-400G transition in the enterprise and data-center markets starting in calendar 2019," continues Hurlston.

"We expect to further reduce operating expenses. Last quarter I said that, to achieve our operating margin model, we needed to manage our operating expenses to 18–20% of revenue, and we now expect operating expenses to be 20–21% in the second fiscal quarter. Over the coming quarters, we will continue to take additional steps to execute a plan consistent with these financial objectives."

www.finisar.com

Emcore launches 6GHz-bandwidth cooled coaxial laser module for 5G wireless

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 — has launched the Model 1998 cooled, coaxial distributed feedback (DFB) laser module for next-generation wireless fiber-optic link applications.

The 1998 laser module features wide bandwidth above 6GHz and is designed for 5G wireless, distributed antenna systems (DAS), L-band and S-band signal distribution. The model 1998 and Emcore's line of lasers and optical receivers for wireless were on display at the Mobile World Congress Americas (MWCA) in Los Angeles (12–14 September).

Migration to 5G wireless networks is fast approaching with Verizon's planned deployment of its fixed-wireless 5G in up to five markets by the end of 2018, and 5G hotspots from AT&T expected by late 2018. Full-blown 5G smartphones are expected to be launched in first-half 2019. Emcore's new 1998 is an ultra-linear, coaxial 1550nm DFB laser module optimized for 5G wireless remoting fiber-optic links. It is designed to enhance bandwidth and signal integrity for delivery of consistent, reliable wireless signals. The laser is packaged in a compact, hermetic, cooled tunable optical sub-assembly (TOSA) with monitor photodiode, thermistor, thermoelectric cooler (TEC), optical isolator and flex circuit for integration into various transmitter configurations. It delivers what is claimed to be superior optical performance over an enhanced temperature range of –40°C to +85°C.

"Our new 1998 laser builds upon Emcore's long history of high-performance designs for CATV, wireless and high-speed digital applications," says Gyo Shinozaki, VP of marketing. "With bandwidth above 6GHz, the 1998 will deliver maximum high-speed signal integrity for 5G, DAS and long-distance fiber-optic link networks," he adds.

At MWCA, Emcore also showcased its 1618A and 1718A 6.5GHz DFB laser modules and its 5200 Series 3GHz and 6.5GHz fiber-optic links. The 1618A and 1718A lasers are packaged in Emcore's classic 14-pin butterfly cooled laser form-factor and deliver highly linear optical performance at 1310nm and 1550nm wavelengths. The 5200 Series comprises a compact, weatherproof fiber-optic transmitter and receiver pair for inter-facility link (IFL) applications where high performance under demanding conditions is critical.

www.emcore.com

Ascent Solar selected by US DOE for Technology Commercialization Fund projects

Collaboration with NREL to commercialize sputtered Zn(O,S) buffers in flexible CIGS solar cells and develop high-efficiency perovskite/CIGS tandem cells

Ascent Solar Technologies Inc of Thornton, CO, USA – which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules that can be integrated into consumer products, off-grid applications and aerospace applications – has been selected by the US Department of Energy (DOE), supported by the Office of Technology Transitions (OTT) Technology Commercialization Fund (TCF), for two exclusive development projects.

The TCF was created by the Energy Policy Act of 2005 to promote promising energy technologies. The selections announced on 23 August aim to expand the DOE's efforts to catalyze the commercial impact of its portfolio of research, development, demonstration, and deployment activities. TCF funds require a 50% match of non-federal funds from private partners.

"The Department of Energy is one of the largest supporters of technology transfer within the federal government. By connecting innovators at our national labs with entrepreneurs in the private sector, DOE is breaking down barriers and finding the nexus between ingenuity and opportunity," says US Secretary of Energy Rick Perry. "The projects announced today will further strengthen those efforts across a broad spectrum of energy technologies and advance DOE's important mission of technology transfer," he adds.

As part of the awards (worth up to $100,000 each), Ascent Solar will work towards commercialization of sputtered Zn(O,S) buffers in flexible CIGS solar cells and also the development of next-generation, high-efficiency perovskite/CIGS tandem cells. These projects are part of Ascent's plans for next-generation lightweight and flexible solar cells. The first project will utilize sputtered Zn(O,S) buffers, which should help to reduce costs and further improve the environmental friendliness of Ascent's CIGS manufacturing process. The perovskite/CIGS tandem junction project is designed to significantly improve efficiencies and drive further cost reduction by enabling a more complete conversion of the solar spectral energy into electricity.

"While there are challenges to be overcome with the use of perovskite-based devices, with already proven high-efficiencies, we believe that Ascent Solar is well positioned to incorporate these materials into our large-scale roll-to-roll processing," says Dr Lawrence Woods, director and head of R&D for Ascent Solar.

"We are honored to be the only PV developer and manufacturer to have been selected for the TCF projects, let alone two projects selected at the same time," comments Dr Joseph Armstrong, chief technology officer and founding member of Ascent Solar. "This is a strong testament to the DOE's faith in our ability to once again demonstrate our 'lab-to-fab' expertise," he adds. "In both cases, we are leveraging our significant intellectual property with flexible monolithically integrated CIGS and teaming with the National Renewable Energy Laboratory (NREL) to inject their substantial knowledge in novel advanced materials to create a potentially substantial leap in the advancement of our product."

www.nrel.gov
www.AscentSolar.com

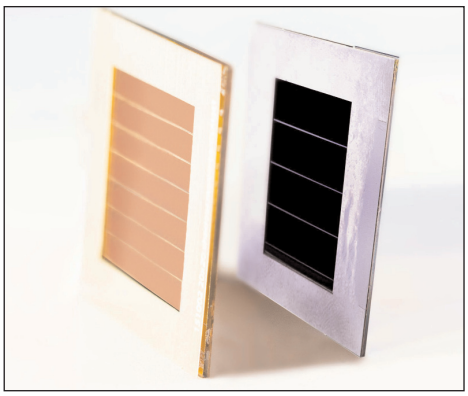
Imec/ZSW perovskite/CIGS tandem cell achieves record 24.6% efficiency

Combination paves way to flexible solar cells and high-efficiency building-integrated PV

At the 35th European Photovoltaic Solar Energy Conference (EU PVSEC 2018) in Brussels, Belgium (24–28 September), nanoelectronics research centre imec of Leuven, Belgium has presented a thin-film tandem solar cell consisting of a top perovskite cell developed by imec within the partnerships of EnergyVille and Solliance, and a bottom copper indium gallium diselenide (CIGS) cell from ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung — or Center for Solar Energy and Hydrogen Research — Baden-Württemberg) in Stuttgart, Germany. The tandem cell resulting from this collaboration (involving an international collaboration between imec, ZSW and Karlsruhe Institute of Technology) achieves a record efficiency of 24.6%.

The perovskite top cell uses light in the visible part of the solar spectrum, while the light in the near-IR spectrum that passes through the perovskite cell is harvested by the underlying CIGS cell. The tandem cell hence significantly outperforms the standalone perovskite and CIGS cells. Moreover, both perovskite and CIGS cells are thin-film solar cells, paving the way to high-efficiency flexible solar cells and building-integrated photovoltaic (BIPV) solutions.

The four-terminal tandem consists of a perovskite solar cell stacked on



top of a CIGS cell, based on a fully scalable device concept to enable industrial adoption of the process. The record efficiency of 24.6% was achieved due to several innovations. First, the transmittance of the perovskite cell for near-IR light was improved by adding optical coupling layers to the tandem stack and by optimizing the transparent electrodes. Second, the perovskite itself was optimized in terms of a wide bandgap of 1.72eV for higher tandem efficiency.

The CIGS cell of 0.5cm^2 size has been made on the high-efficiency line at ZSW, employing all optimized processes necessary for the preparation of record devices. Further improvements of the technology should ultimately pave the way to thin-film tandem solar cells with efficiencies of more than 30%, it is reckoned.

"We work on two types of tandem cells," explains Tom Aernouts, group leader for thin-film photovoltaics at imec/EnergyVille. "We combine our state-of-the-art perovskite technology with silicon or CIGS bottom cells. The advantage of CIGS is that it is a thin-film technology, just like perovskite, and that the tandem cells therefore can be fabricated in a wide variety of shapes and sizes. This makes it possible to use this technology in building-integrated PV applications. Future work will focus on upscaling the technology towards larger modules. Moreover, we will also look into developing solutions for two-terminal cells because of their importance to the PV industry," he adds.

"We owe the record efficiency to two factors," says professor Michael Powalla, member of the board and head of the Photovoltaics Division at ZSW. "On the one hand to the improved perovskite cell, on the other hand to one of the world's best efficiencies for CIGS cells," he adds. "There are several parameters of the CIGS cell which we can optimize with regard to its combination with the perovskite top cell. Thus, we expect even better efficiency values in the future, paving the way to further cost reductions."

www.photovoltaic-conference.com
www.zsw-bw.de
www.imec.be
www.solliance.eu
www.energyville.be

III-nitride solar cells on h-BN separation layer

Transferring indium gallium nitride solar cells to glass with an aluminium or frequency-selective dielectric mirror can increase short-circuit current.

Georgia Institute of Technology's collaboration with France-based researchers in Metz has used hexagonal boron nitride (h-BN) as a separation layer for indium gallium nitride (InGaN) solar cells grown on sapphire [Taha Ayari et al, ACS Photonics, 2018, 5 (8), p3003].

After separation, the devices were transferred to glass with an aluminium (Al) back-reflector or a frequency-selective dielectric mirror. The hope is to hybridize the InGaN cell with other group IV and III–V cells, extracting power optimally from the solar spectrum in a lightweight, low-cost format.

The research collaboration includes GT–Lorraine (http://lorraine.gatech.edu), GT–CNRS (https://umi2958.gatech.edu) and Institut Lafayette (http://kippelengroup.gatech.edu/institut-lafayette).

Many techniques have been developed for separating III-nitride materials from sapphire growth substrates. Recently h-BN, a van der Waals bonded material, has been tried for light-emitting diodes and transistors. The GT–France researchers claim that theirs is the first attempt at using the technique for solar cells.

The active structure consisted of 5x2.5nm $In_{0.18}Ga_{0.82}N$ quantum wells (QWs) with 12nm GaN barriers grown on 3nm h-BN on 2"-diameter sapphire using 'van der Waals' metal-organic vapor phase epitaxy (MOVPE).

Ammonia (NH_3) was used as the nitrogen precursor, while triethylboron (TEB), trimethylgallium/triethylgallium (TMGa/TEG), trimethylindium (TMIn) and trimethylaluminum (TMAl) provided the metal sourcing. Silicon and magnesium doping for n-type and p-type GaN layers, respectively, came from silane (SiH_4) and bis(cyclopentadiene)magnesium (Cp_2Mg).

The h-BN was grown at 1300°C. The nucleation layer was 300nm silicon-doped 1100°C $Al_{0.14}Ga_{0.86}N$. The n-side of the device consisted of 0.5μm n-GaN; the p-side was 0.3μm p-GaN. The photoluminescence from the InGaN wells had a peak at 475nm.

The 'van der Waals epitaxy' refers to the base material h-BN, which has strong in-plane bonds but weaker 'van der Waals' forces keeping the hexagonal layers of BN sheets together. The weaker van der Waals bonds allow for easier damage-free separation from the sapphire substrate.

Fabrication involved plasma etching mesas and the deposition of titanium/aluminium/nickel/gold n- and nickel/gold p-contacts. Titanium/aluminium/nickel/gold was also used for bus bars.

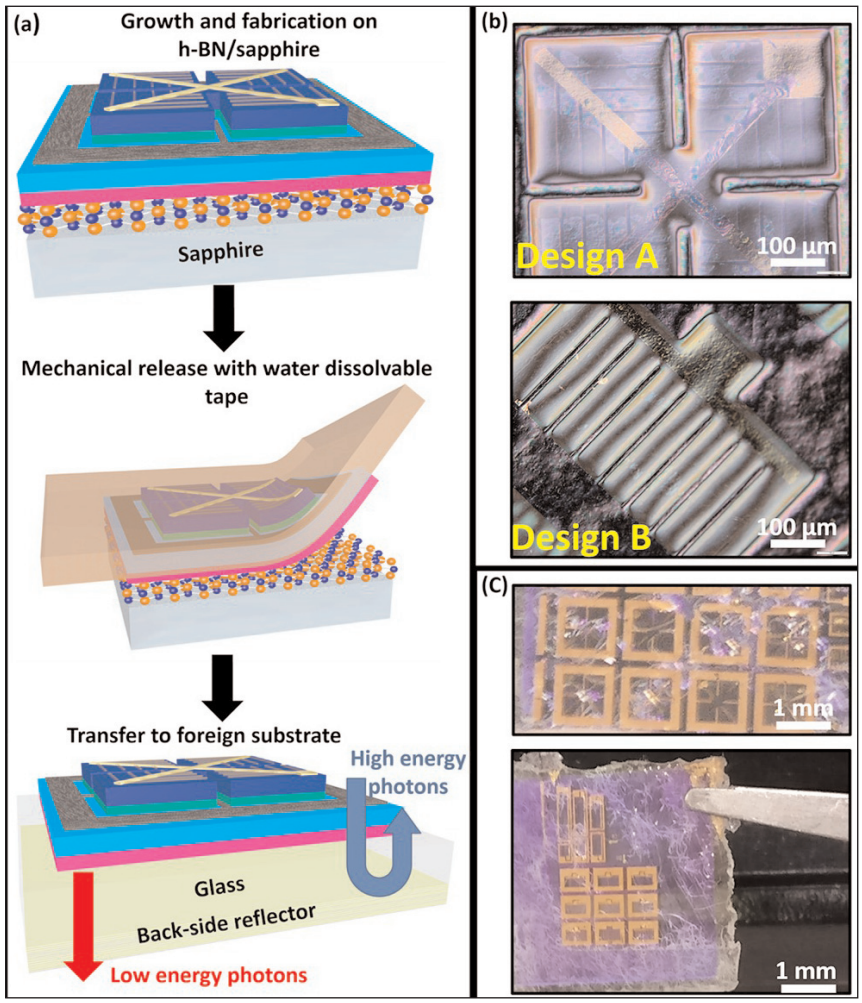


Figure 1. (a) Schematics of fabrication steps for releasing InGaN-based solar cells from sapphire and transfer onto foreign substrates. (b) Optical microscopy images from back side of ~1mm² solar cells with two different designs on water-dissolvable tape after release. (c) Photographs of devices with different sizes and designs transferred to glass with dielectric mirror (purple background is due to reflected wavelengths between 375nm and 465nm).

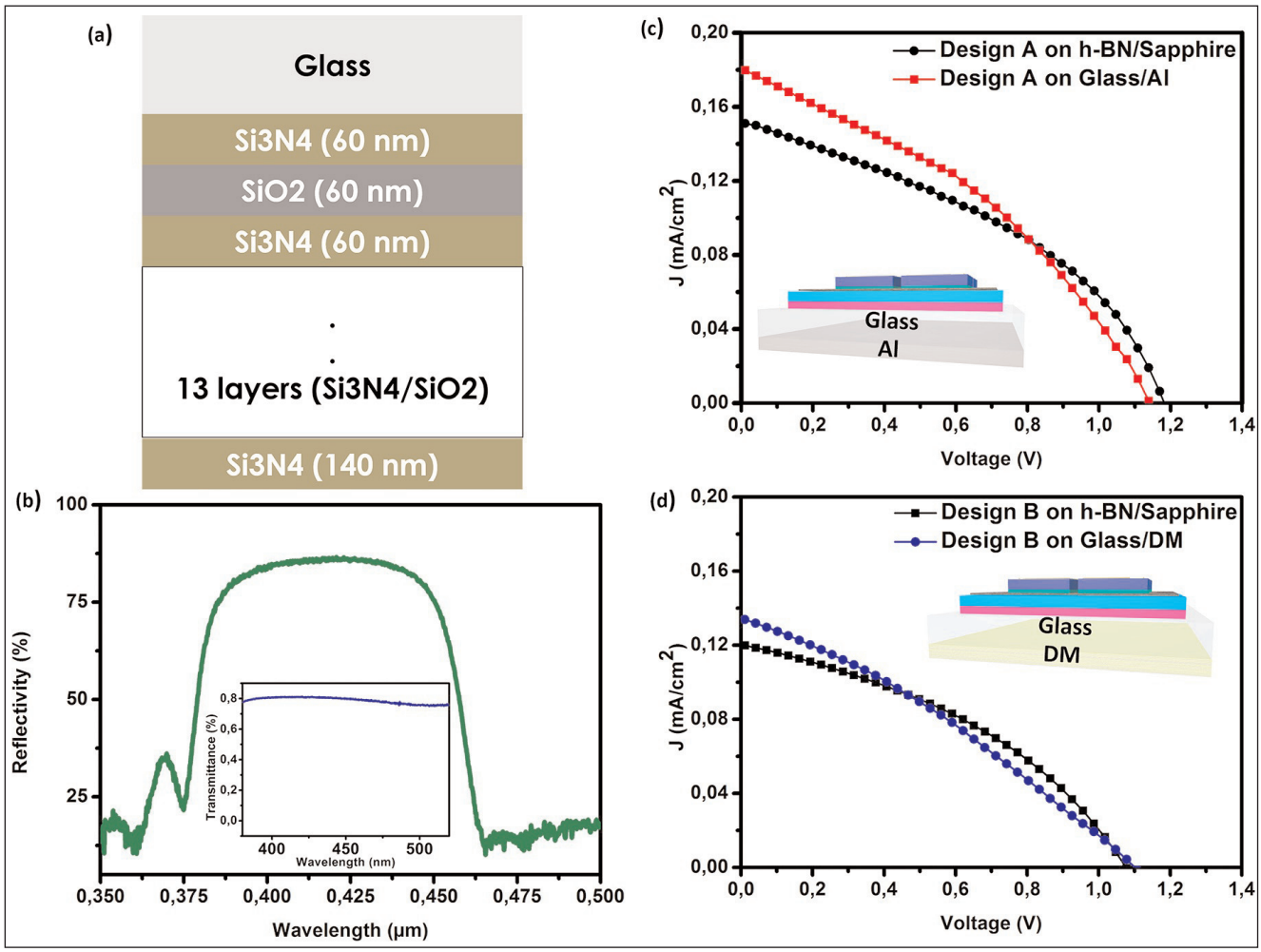


Figure 2. (a) Schematic and (b) reflectivity measurements of dielectric mirror. (c, d) Respective current density–voltage (J–V) curves under AM1.5 illumination of before and after transfer to glass with Al back-reflector and dielectric mirror. Inset: (b) transmittance of polyurethane-based resin.

The devices on sapphire under AM1.5 solar illumination conditions achieved 0.08% extracted efficiency, 39.5% fill factor, 1.17V open-circuit voltage and 0.17mA/cm^2 short-circuit current density, comparable with the performance of conventional sapphire-substrate devices according to the team. The open-circuit voltage was lower than expected from simulations (2.28V) — the researchers suggest that this was mainly due to the difficulties in obtaining good ohmic contacts on p-GaN. The simulated efficiency was also higher at 0.14%.

The low sub-1% efficiency is due to the short-wavelength response, which does not cover much of the solar AM1.5 spectrum (roughly the spectrum viewed from the ground at 48.2° solar zenith angle suitable for mid-latitudes in summer).

Illumination with 440nm-wavelength light at 140mW/cm^2 power density gave an open-circuit voltage of 1.6V and short-circuit current density of 40mA/cm^2. The team comments: "These increased performances under high irradiance confirm the suitability of the InGaN solar cells for high concentrated photovoltaic (HCPV) applications."

The devices were transferred to glass with a back-reflector. The transfer involved water-dissolvable tape and polyurethane resin as bonding. The technique enabled transfer intact without damage. The absence of harsh chemicals in the process is seen as enabling reuse of the growth substrate, reducing manufacturing costs.

The transfer process resulted in an increase in short-circuit current density of the order of 20% (Figure 2), attributed to increased conversion from reflected photons from the 100nm Al mirror with 90% reflectivity.

The researchers were keen to design a structure that could be used in a tandem device that would extract energy from photons of the most suitable energy and transmit lower-energy photons into lower layers. For this they designed a dielectric mirror with ~85% reflectivity in the InGaN QW range, but falling to 20% for longer wavelengths. The dielectrics were applied using plasma-enhanced chemical vapor deposition (PECVD) — 13 bilayers of 60nm silicon nitride (Si_3N_4) and 60nm silicon dioxide (SiO_2), topped off with 140nm silicon nitride.

With the dielectric mirror deposited on glass, followed by transfer, the short-circuit current increased by 12% relative to non-transferred performance. Simulations predicted a 30% increase in current for 85% reflectivity.

The open-circuit voltage was practically unchanged for both transferred set ups. ■

https://pubs.acs.org/doi/10.1021/acsphotonics.8b00663

Author: Mike Cooke

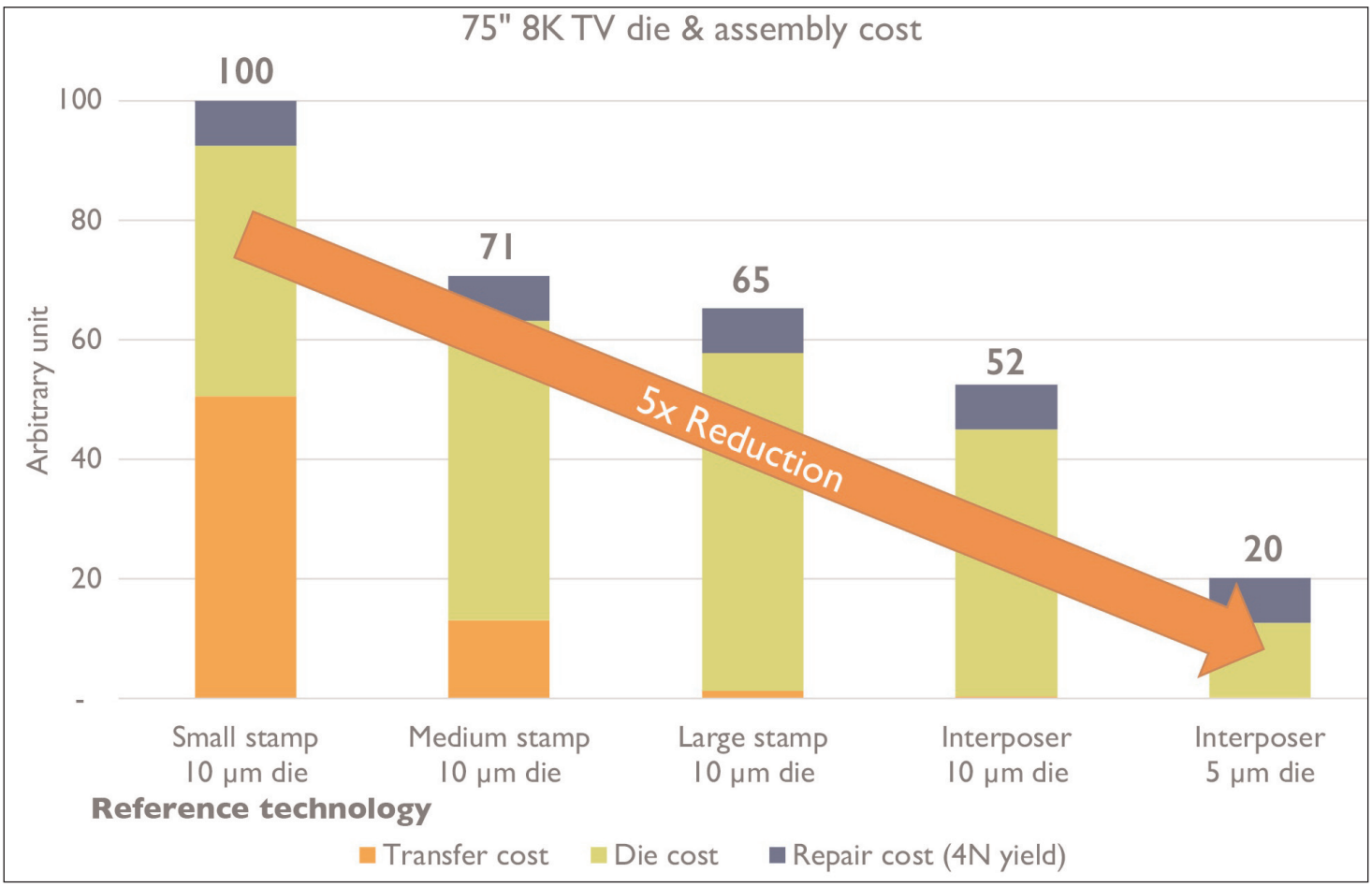
Technology advances paving way for micro-LED cost reduction in high-volume applications

Technology solutions should start converging by the end of 2019, reckons Yole Développement.

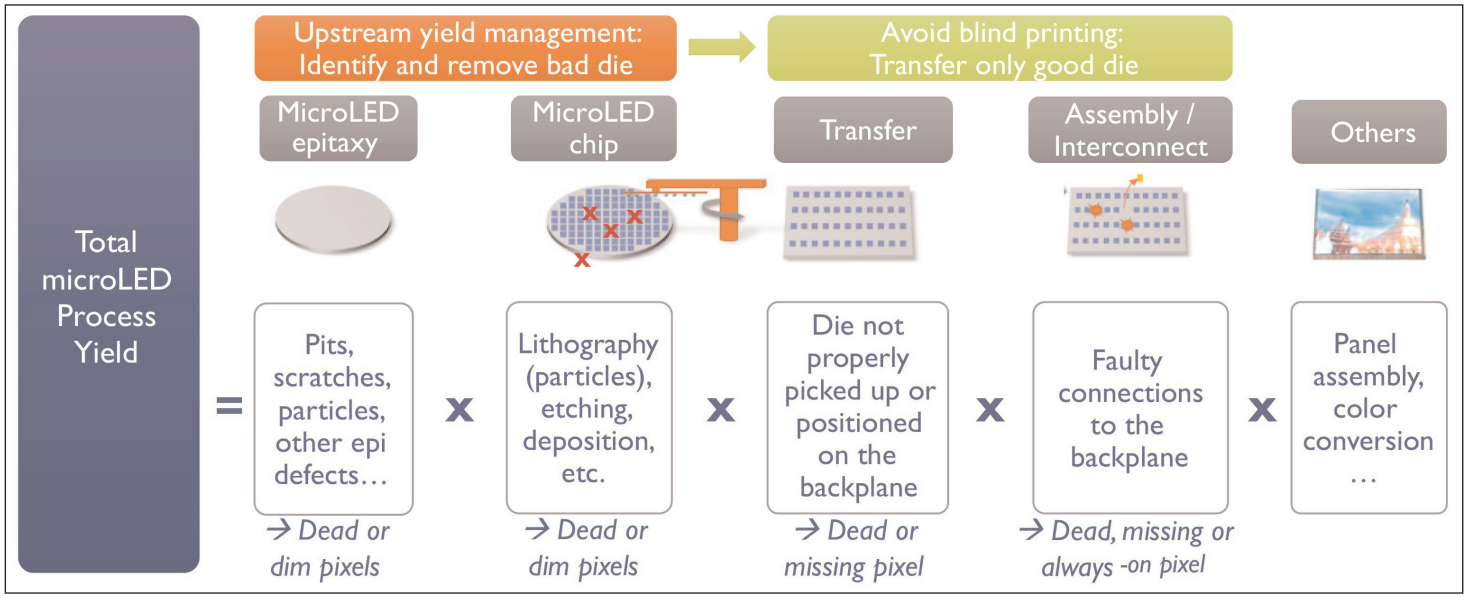
Micro-LED technologies are improving rapidly and new technology paths are emerging at a rapid pace, notes market research and strategy consulting firm Yole Développement in its report 'MicroLED Displays 2018'. The challenge is now focused on cost reduction. What is the feasibility of each solution? Can micro-LED TV or smartphone display manufacturing costs be compatible with these applications? Which cost reduction paths are the most realistic?

"Technology advancements pave the way for various cost-reduction paths toward volume manufacturing, but none are straightforward," comments senior market & technology analyst Dr Eric Virey.

Dozens of technologies are being developed for micro-LED assembly and pixel structures. The cost and complexity range can be staggering. However, there are some fundamentals that anchor all those processes. Alignment dominates assembly cycle times, die size cannot get infinitely small, epitaxy cost has already been through more than 20 years on the cost reduction curve. Cost analysis therefore allows companies to narrow the process parameters down to



Micro-LED display technology: cost-reduction path for 75-inch 8K TV with 99.99% (4N) yield.



Major micro-LED display yield contributors.

economically realistic windows and identify efficient cost-reduction strategies.

"Micro-LED companies must understand the cost targets for each application and work backward, making process choices and developing each step so it fits the cost envelope," asserts Virey. "Processes that cannot deliver the right economics will disappear. If none can deliver the right economics, the opportunity will never materialize," he adds. "MicroLED is entering the valley of death between technology development and industrialization and commercialization." Technology solutions should start converging by the end of 2019, it is reckoned.

As the technology improves, there are credible cost-reduction paths for micro-LEDs to compete in the high-end segment of various applications such as TV, augmented reality and virtual reality (AR/VR) and wearables, says Yole. With the right approaches, assembly cost could become a minor contributor. For smartphones, however, approaching the cost of organic light-emitting diodes (OLEDs) implies pushing micro-LEDs toward what is likely to be the limits of the technology in term of die size.

To succeed, micro-LEDs must count on some level of price elasticity, says Yole. They must deliver performance and features that no other display technology can offer and that are perceived by the consumer to be highly differentiating. Micro-displays for AR and head-up displays (HUD) will be the first commercial applications, followed by smartwatches. TVs and smartphones could follow 3–5 years from now, forecasts Yole. ■

www.i-micronews.com/report/product/microled-displays-2018.html

Atomic-layer sidewall passivation of InGaN μLEDs

Square 20μm x 20μm devices achieve peak external quantum efficiency of 33% with passivation, compared with 24% for no passivation.

University of California Santa Barbara (UCSB) in the USA has improved the performance of indium gallium nitride (InGaN) micro-sized light-emitting diodes (μLEDs) through atomic layer deposition (ALD) of sidewall passivation [Matthew S. Wong et al, Optics Express, vol26, p21324, 2018].

Unpassivated sidewalls can be a source of LED inefficiencies through electron–hole recombination into photons being diverted into non-radiative surface recombination at dangling bonds and surface-roughness defects arising from dry plasma etching. Sidewall recombination becomes more influential as devices become smaller, impacting efficiency. Conventionally, plasma-enhanced chemical vapor deposition (PECVD) is used to apply passivation. The UCSB team has found that ALD-passivated μLEDs had better performance than PECVD-passivated devices.

μLEDs demonstrate long operating lifetime, high luminous efficiency, and chemical robustness. Applications include their use as pixels in displays — both in large-area and in near-eye head-mounted varieties. Monochrome μLED displays have demonstrated high resolution, efficiency and contrast ratio. The small size of μLEDs can also enable higher-speed operation for high-speed gigahertz-modulation-bandwidth visible-light communication.

Epitaxial structures were grown on sapphire by metal-organic chemical vapor deposition (MOCVD) — see Table 1. Square μLEDs were fabricated (Figure 1), beginning with an electron-evaporated indium tin oxide (ITO) transparent conductor on the top p-GaN layer. The square mesas of the μLEDs were formed using reactive-ion etching down to the n-GaN layer.

Table 1. Structural details of μLED.

Layer	Thickness
Magnesium-doped p^+-GaN	17nm
Magnesium-doped p-GaN	120nm
Magnesium-doped AlGaN EBL	26nm
6x InGaN/GaN MQW	2.4nm/22nm
30x silicon-doped InGaN/GaN	3nm/3nm

An omni-directional reflector (ODR) was created using ion-beam deposition of silicon dioxide and tantalum pentoxide, capped with aluminium oxide. The dielectric ODR both reflected light from the metal layers and electrically isolated the n- and p-contacts. The reflectance of the ODR was 95.5% in the blue wavelength range 430–450nm.

Passivation consisting of 50nm silicon dioxide was applied by using either PECVD or ALD processes. Windows for aluminium/nickel/gold contacts were cut into the passivation by hydrofluoric acid (HF) or inductively coupled plasma (ICP) etch.

The μLEDs were singulated into 750μm x 750μm dies. The test devices were mounted on silver headers with wire bonding and resin encapsulation.

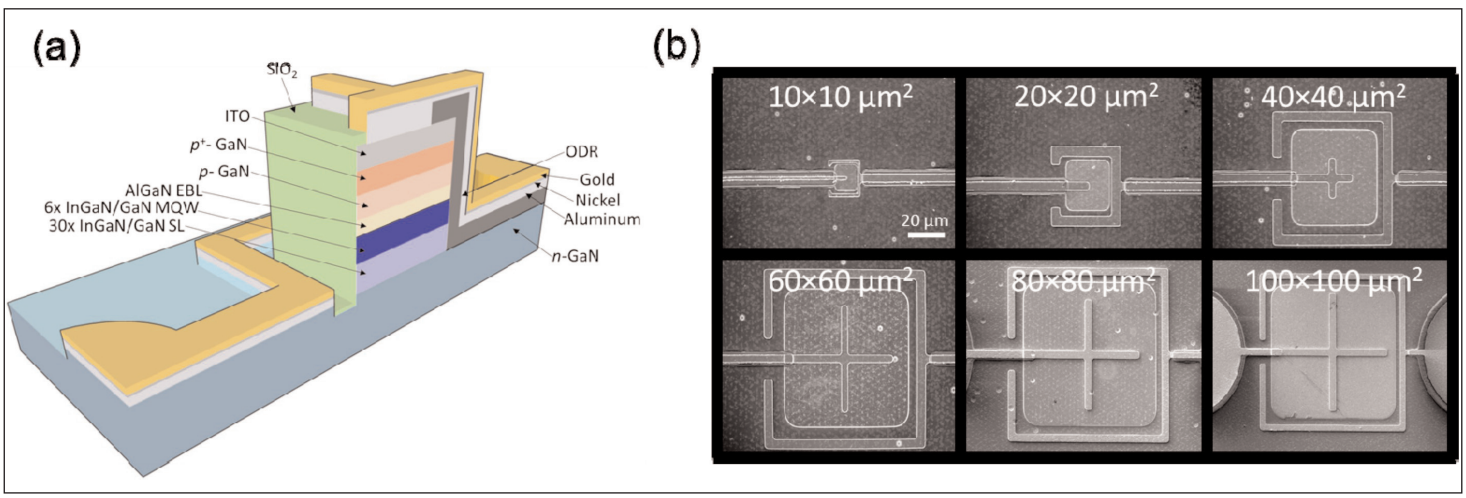


Figure 1. (a) Cross-sectional schematics of μLED design and (b) scanning electron microscope images of six μLEDs.

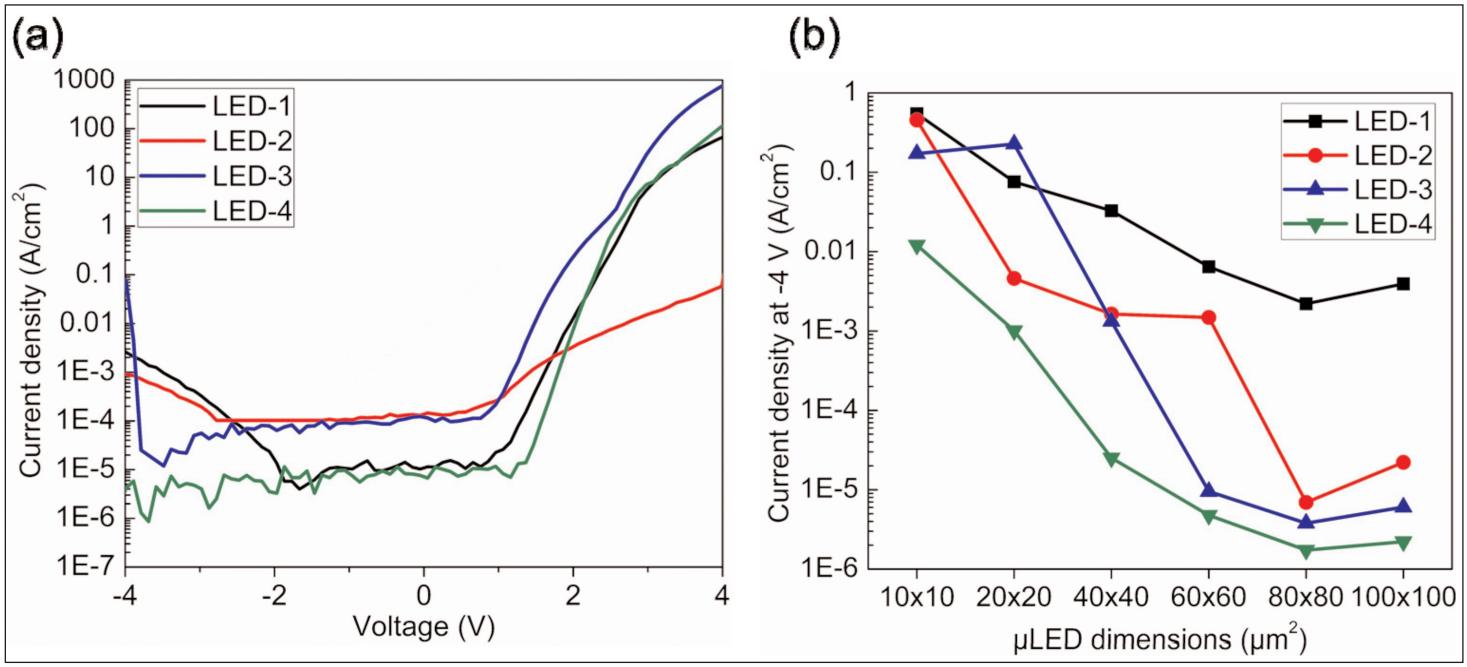


Figure 2. (a) Current density–voltage characteristics from –4V to +4V of 20μm x 20μm μLEDs with different sidewall passivation techniques and (b) dependence of leakage current at –4V on dimensions of μLEDs with different sidewall passivation methods.

Four types of μLED were produced:
1) without sidewall passivation;
2) with ICP-etched ALD passivation;
3) HF-etched PECVD passivation; and
4) HF-etched ALD passivation.

Missing from this list were ICP-etched PECVD passivation devices. Such devices were found to have extremely low light output and poor electrical performance.

For the unpassivated μLED-1, the larger area device (>60μm x 60μm) light output crowded towards the edges. The light output became more uniform in the smaller devices due to better current spreading in the ITO transparent oxide. However, the light output density was lower in the sub-60μm x 60μm LEDs due to the increased influence of non-radiative surface recombination from etch damage and non-passivation.

μLED-2 and μLED-4 demonstrated uniform light emission for all sizes between 10μm x 10μm and 100μm x 100μm. Also, the density of light emission remained high for all sizes. This was in contrast to μLED-3 (PECVD passivation), whose light emission became very dim for the smaller devices. The emission was also non-uniform for the brighter, larger devices.

The passivation also increased light extraction — the higher index of refraction of the dielectric compared with air increases the critical angle for total internal reflection in the III–nitride material, allowing more photons to escape. The light output was increased in 20μm x 20μm μLEDs-2 and -4 by about 40% over the unpassivated μLED-1 at 20A/cm^2 current density injection. At 95A/cm^2 the improvement was 20%.

The PECVD passivation of μLED-3 suffered from reduced transparency of the ITO layer, according to the researchers. The PECVD process releases hydrogen radicals that attack the ITO material, leaving metallic indium and tin oxide. The use of metal-organic precursors in the ALD process avoids the generation of hydrogen radicals.

Current leakage under –4V reverse bias was least for μLED-4 at all device sizes. The density of current leakage increased for smaller devices due to the device sidewall area/volume ratio being greater.

Scanning electron microscope (SEM) inspection suggested that the ICP etching damaged the ITO layer more than the HF process. The HF etch is more selective to silicon dioxide over ITO than ICP. The ITO damage introduced extra current leakage over that of the HF process.

The peak external quantum efficiency (EQE) of 100μm x 100μm devices ranged from 36% to 41% (Figure 2). The peak came around the same injection current density of~5A/cm^2. The EQE drooped to around 25% at 100A/cm^2. There was a wider spread of EQEs in the mid-range and the μLED-4 process initially drooped more quickly.

For 20μm x 20μm μLEDs, the EQE was lower (33% for μLED-4) but the droop effect was also much reduced — in μLEDs-4 and -2 almost absent, and for μLED-3 the EQE increased up to 100A/cm^2. The unpassivated μLED-1 showed a more conventional 40% droop and the peak efficiency was only 24%. The researchers attribute the improvement in the passivated μLEDs-2/-4 to increased light extraction and reduced leakage current. ■

https://doi.org/10.1364/OE.26.021324

Author: Mike Cooke

Amber light for zinc tin nitride boost from InGaN wells

Simulations suggest a more than 200x increase in efficiency for 600nm-wavelength light emission.

Md Rezaul Karim and Hongping Zhao of Ohio State University in the USA are proposing the use of zinc tin nitride ($ZnSnN_2$) as a means to improve the efficiency of indium gallium nitride (InGaN) light-emitting diodes (LEDs) at longer wavelengths in the amber 600nm range [J. Appl. Phys., vol124, p034303, 2018]. Although the work is theoretical, professor Zhao heads up a laboratory with access to a range of metal-organic chemical vapor deposition (MOCVD), low-pressure chemical vapor deposition (LPCVD) and chemical vapor deposition (CVD) equipment (https://u.osu.edu/zhao2592).

InGaN LEDs need higher indium compositions to create the narrower bandgaps required to access longer wavelengths. Unfortunately, indium is more volatile than

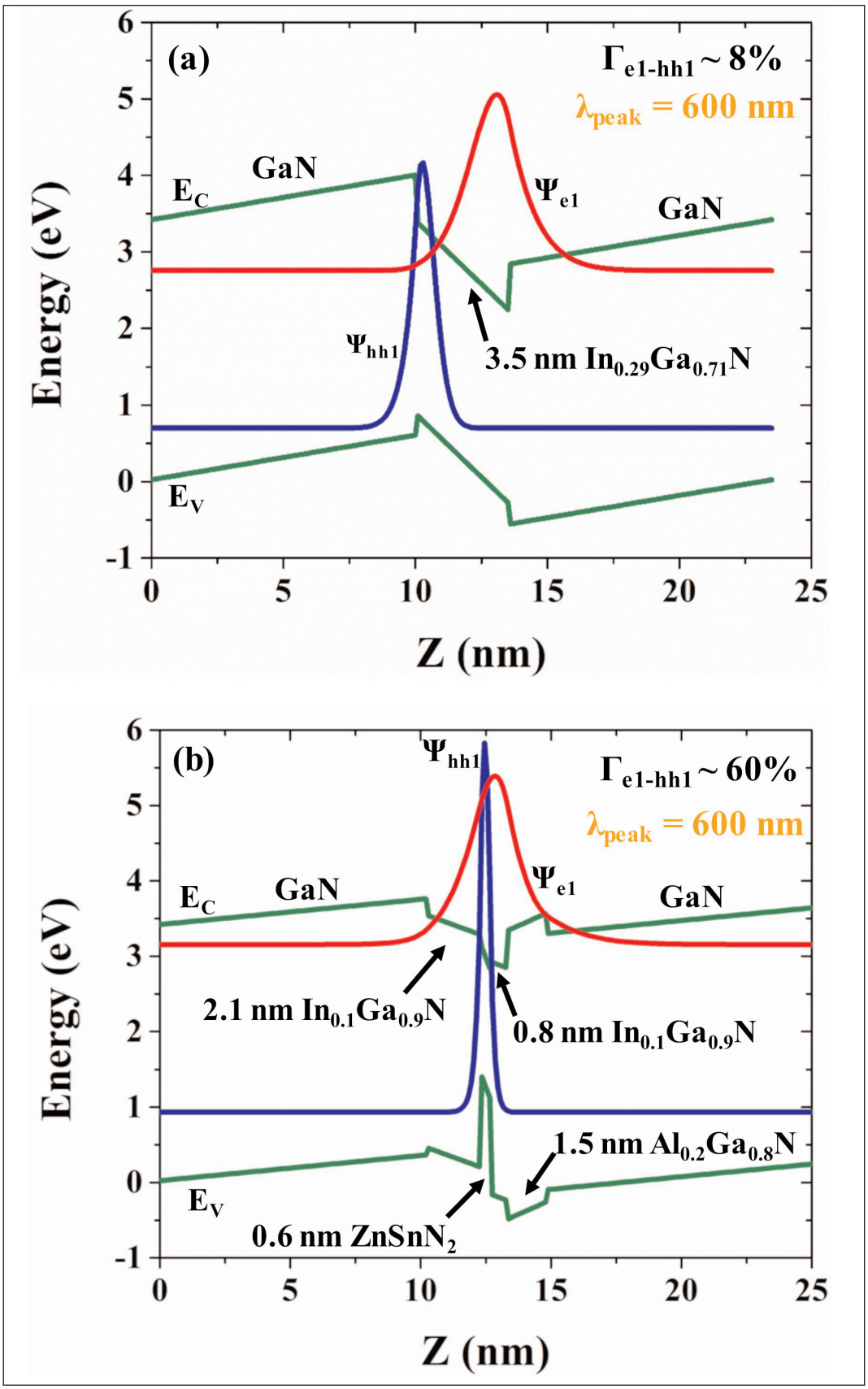


Figure 1. Energy-band alignment, and electron and hole wavefunctions, for first confined energy states in (a) conventional GaN/InGaN/GaN and (b) GaN/InGaN/$ZnSnN_2$/InGaN/AlGaN/GaN QWs. The thin aluminium gallium nitride layer improves electron confinement in the QW active region.

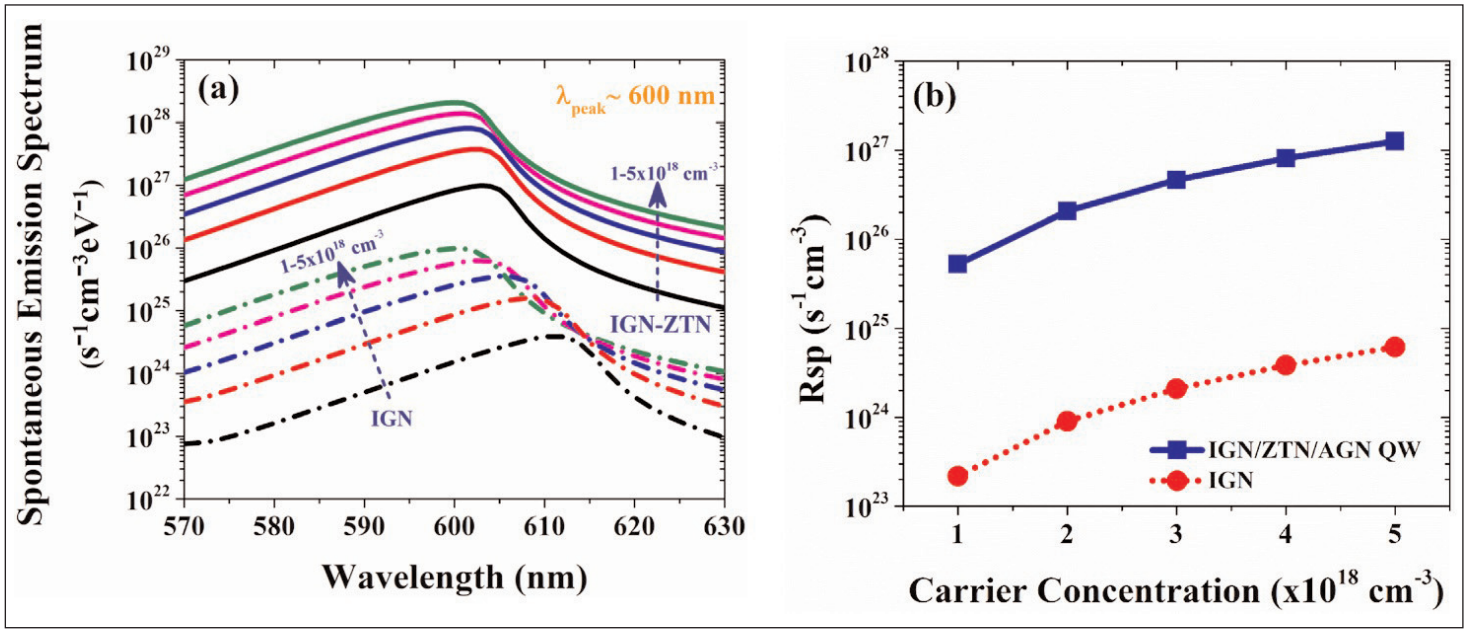


Figure 2. (a) Spontaneous emission spectra and (b) spontaneous emission radiative recombination rates of IGN and IGN–ZTN QWs for a range of carrier concentrations.

gallium in III–nitride growth processes. To maintain indium in the crystal structure, growth temperatures must be kept relatively low, reducing quality.

At the same time, differences in the charge polarization of the III–nitride bonds lead to large spontaneous and strain-dependent (piezo-) electric fields that tend to separate electron and hole wavefunctions, impeding recombination into photons. A further problem with high-indium-content InGaN is a tendency for phase separation, creating uneven distributions of indium concentration.

Karim and Zhao see $ZnSnN_2$ as a means of confining holes within InGaN quantum well (QW) structures, based on a 1.4eV valence-band offset between the materials, according to "recent first principles calculations". At the same time, the conduction-band offset is relatively small at –0.3eV.

The hole confinement is predicted to increase the overlap with the electron wavefunction on the basis of self-consistent 6-band k.p calculations (Figure 1), compared with an InGaN QW without $ZnSnN_2$. Improved overlap should lead to more efficient conversion of the electrons and holes into photons. In addition, the reduced indium component (10% versus 29%) should enable higher growth temperatures and hence better heterostructure quality.

Integrating the spontaneous emission over the spectral range gives a 210–235x enhancement of the IGN–ZTN QW emission over that of the conventional IGN structure... If we take into account the expected lower non-radiative recombination in the IGN–ZTN QW, one can expect even larger enhancement

Some theoretical work involving professor Zhao at Case Western University in Ohio on InGaN QWs containing zinc germanium nitride ($ZnGeN_2$) layers demonstrated increases in radiative efficiency for blue (485nm) and green (530nm) light emission [Lu Han, Kathleen Kash, and Hongping Zhao, Appl. Phys., vol120, p103102, 2016]. Germanium is situated in the same 'Group IV' column of the periodic table as tin. The $ZnGeN_2$ valence-band offset was ~1.1eV, but a large conduction band offset tended to reduce the electron–hole wavefunction overlap.

Karim and Zhao's further calculations (Figure 2) suggest that InGaN–$ZnSnN_2$ (IGN–ZTN) QWs would have 210–250x enhancement over conventional InGaN QWs for the peak intensity for spontaneous emission of 600nm-wavelength light. Both structures show some blue-shift as the carrier concentration increases from $1x10^{18}/cm^3$ to $5x10^{18}/cm^3$ due to screening effects, but the IGN–ZTN shift is only 3nm, compared with 11nm for the conventional IGN QW. Integrating the spontaneous emission over the spectral range gives a 210–235x enhancement of the IGN–ZTN QW emission over that of the conventional IGN structure.

Karim and Zhao comment: "Note that the internal quantum efficiency (IQE) of LEDs is determined by the ratio of radiative recombination rate and the total recombination rate which includes both the radiative and non-radiative components. Here, if we take into account the expected lower non-radiative recombination in the IGN–ZTN QW, one can expect even larger enhancement of the IQE from the novel QW design." ■

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Author: Mike Cooke

Structures to enhance light extraction in InGaN LEDs

Micro-hole arrays and sidewall texturing can overcome the narrow photon escape cone from gallium nitride into air.

Yu-Lin Lee and Wen-Chau Liu of Taiwan's National Cheng Kung University have been working to enhance light extraction from indium gallium nitride (InGaN) light-emitting diodes (LEDs) by using texturing of the mesa top surface and sidewalls [IEEE Transactions on Electron Devices, published online 4 July 2018]. In particular, the researchers created a micro-hole array on the top surface and either 45° saw-tooth or convex patterning of the sidewalls.

The aim of these measures is to increase the probability that photons will escape from the structure into the outside world. InGaN-based devices are prone to reflect light back into the device at GaN/air interfaces. Total internal reflection occurs due to the large difference in refractive index between GaN and air, giving a relatively narrow escape cone for photons. The texturing is designed to reduce total internal reflection, boosting light extraction efficiency.

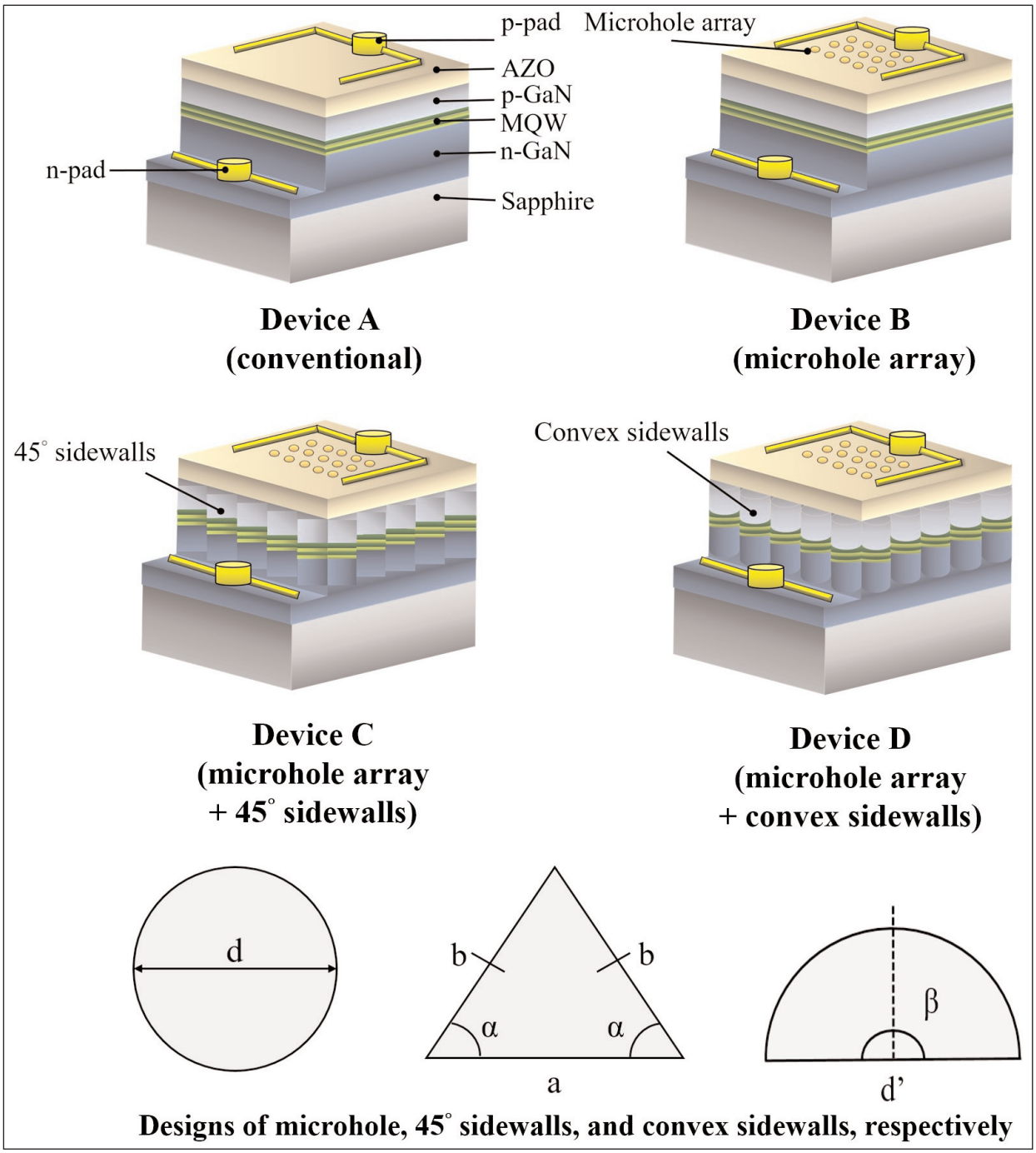

Figure 1. Schematic cross-sectional diagrams and corresponding geometric designs of devices A–D.

One such structure demonstrated increases of 20.9%, 24.3%, 20.5% and 21.3% in light output power, luminous flux, external quantum efficiency and wall-plug efficiency, respectively, over a reference device without micro-hole array or sidewall texturing.

Metal-organic chemical vapor deposition (MOCVD) on c-plane sapphire produced an LED wafer with a 2μm undoped GaN buffer, 2μm silicon-doped n-GaN contact, 15-period InGaN/GaN active multiple quantum wells (MQWs), and a 0.3μm magnesium-doped p-GaN contact.

Fabricated devices (Figure 1) had varying mesa sidewall structures: flat (A and B), 45° saw-tooth (C), and convex (D). Also, devices B–D included a micro-hole array on the top surface. The mesa and micro-hole etching included inductively coupled plasma (ICP) and wet processes. The circular micro-holes were 7μm in diameter. The saw-tooth sidewalls of device C consisted of 45° (angle α) isosceles triangles with a 10μm hypoteneuse (side a). The diameter of the convex sidewall of device D sections was 10μm.

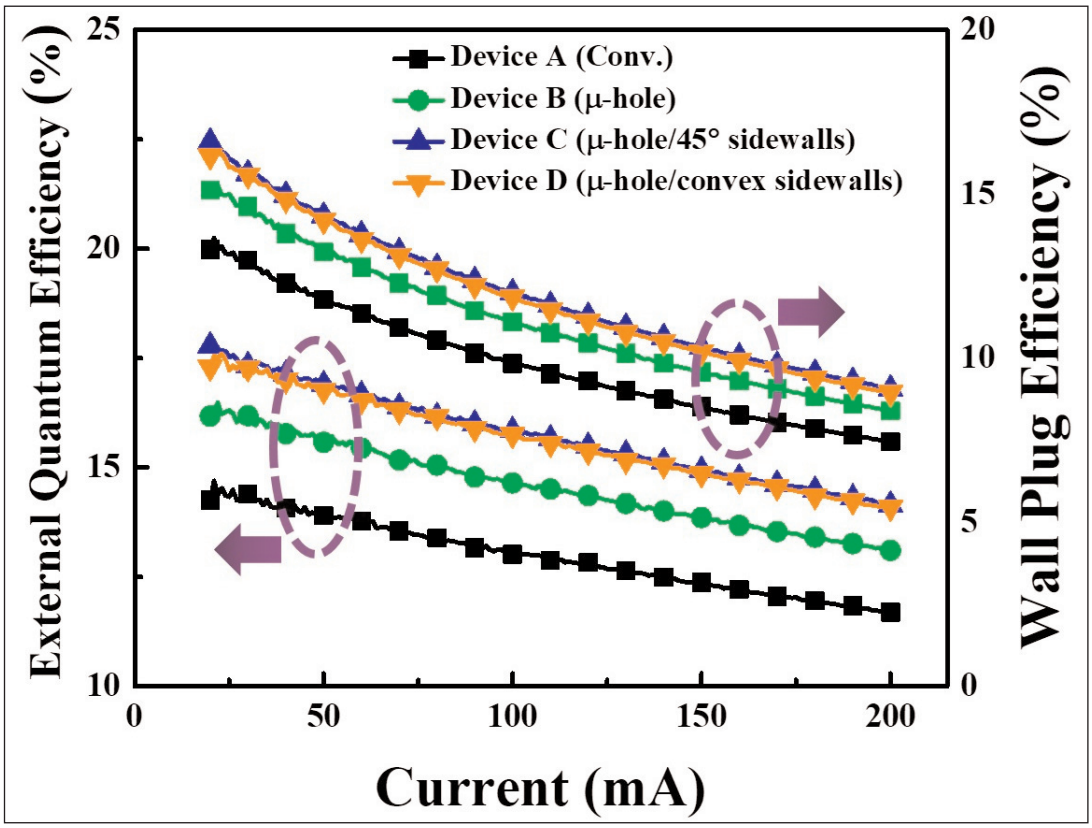

Figure 2. External quantum efficiency and wall-plug efficiency as functions of operating current.

Table 1. Performance characteristics at 200mA injection.

Characteristic	A	B	C	D
Light output power	65mW	72.8mW	78.6mW	78.2mW
Luminous flux	2.18lm	2.55lm	2.71lm	2.69lm
Luminous efficacy	2.5lm/W	2.9lm/W	3.1lm/W	3.0lm/W
External quantum efficiency	11.7%	13.1%	14.1%	14%
Wall-plug efficiency	7.5%	8.4%	9.1%	8.9%

The fabrication process flow included cleaning, ICP definition of the LED mesa, sidewalls and micro-hole array, sputtering of a 500nm aluminum-doped zinc oxide (AZO) current-spreading layer (CSL), wet etching of the AZO current-spreading layer to expose the micro-hole array, annealing of the AZO current-spreading layer, and the deposition of chromium/platinum/gold n-pads and p-pads.

After processing, the micro-holes had 7μm diameter at the GaN surface and 16μm diameter at the AZO surface. The use of the AZO current-spreading layer avoided problems associated with indium tin oxide (ITO) as transparent conductor in terms of cost, toxicity and thermal stability, among other properties. The 650μmx550μm LED chips were attached and bonded onto TO-3 submounts for testing.

All the devices had a forward voltage of 2.95V for 20mA injection. This increased to 4.35V for 200mA. The leakage at –5V reverse bias was 13.3nA.

The light output power at 200mA injection ranged from 65mW for device A, through 72.8mW (B) and 78.2mW (D), reaching 78.6mW for device C. These improvements are also reflected in terms of the luminous flux, the luminous efficacy, the external quantum efficiency and the wall-plug efficiency (see Figure 2 and Table 1). In all cases, the devices C and D show significant improvement over the reference device A, with device C having a slight edge over device D.

The increased light emission from the enhanced sidewall structures was reflected in increased far-field divergent angles over that of device A (132°): 139° for B, 141° for C, and 141° for D. ■

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Author: Mike Cooke

Advancing InGaN VCSELs

Mike Cooke reports on progress towards filling the green gap and improving tunnel junctions as alternatives to indium tin oxide current-spreading layers.

Vertical-cavity surface-emitting lasers (VCSELs) promise advantages over the more traditional edge-emitting lasers, such as the potential for reduced manufacturing costs, integrated electronics, parallel array structures, and lower input power operation. VCSELs have been produced for a long time using aluminium gallium arsenide (AlGaAs) technology, but such devices are restricted to red-infrared wavelengths longer than 650nm. For shorter wavelengths one naturally looks to III–nitride (III–N) materials, where the III stands for metals such as gallium (Ga), indium (In) and aluminium (Al).

However, there are many difficulties in developing VCSELs, particularly for the longer green-yellow-orange wavelengths that would extend the reach of the red devices. The problems are the often cited ones for III–N light emitters in general: lattice mismatches leading to defects; different charge polarizations of the various ionic bonds between the group III metals and nitrogen, creating electric fields that inhibit electron–hole recombination into photons; difficulties of incorporating indium for the longer wavelengths, and so on.

VCSELs offer desirable characteristics such as compactness, low thresholds, large modulation bandwidth, narrow linewidths, and circular beam patterns. Along with 'green gap' filling, moving to shorter ultraviolet wavelengths could challenge bulky gas and solid-state lasers such as 325nm helium-cadmium lasers, 355nm neodymium-doped yttrium aluminium garnet (Nd:YAG) lasers, and excimer lasers for applications.

Possible uses could be for high-resolution laser printers, laser lighting, visible light communication (free-space and plastic fiber) and bio-sensing

Other possible uses could be for high-resolution laser printers, laser lighting, visible light communication (free-space and plastic fiber) and bio-sensing.

Near-green lasing

Xiamen University and Suzhou Institute of Nano-Tech and Nano-Bionics

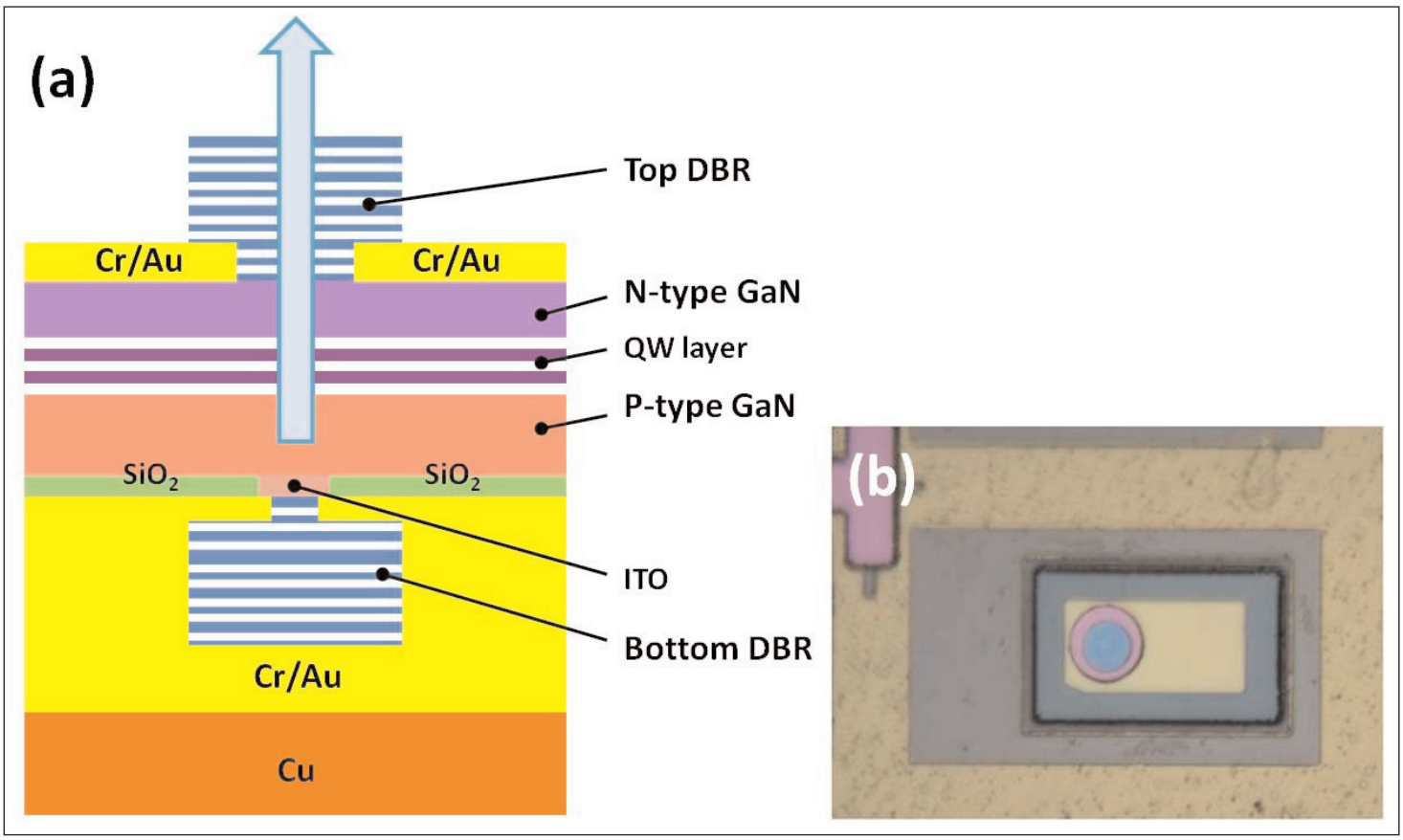

Figure 1. (a) Cross-sectional schematic of VCSEL. (b) Optical image of real device.

(SINANO) in China have developed near-green VCSELs using material that is mainly luminescent in the blue 445nm part of the spectrum [Rongbin Xu et al, IEEE Transactions on Electron Devices, vol 65, issue 10 (October 2018), p4401].

The researchers engineered the cavity resonance so that it favored the near-green 493nm-wavelength emissions from InGaN. Efficient green laser diodes are highly desired to plug the 'green gap' for red-green-blue full-color display systems. Presently, green laser light is produced using a combination of a longer-wavelength lasers and frequency-doubling materials, increasing complexity, system sizes, and cost.

The active region consisted of a double quantum well of $In_{0.18}Ga_{0.82}N$, of 2.5nm each, separated by 6nm of GaN. Normally, such material is expected to emit blue wavelengths around 445nm. The wells were capped with an electron-blocking layer of 20nm $Al_{0.2}Ga_{0.8}N$ to prevent carrier overflow into the p-type layers. The metal-organic chemical vapor deposition (MOCVD) of III–nitride material was performed on c-plane sapphire.

The epitaxial material was fabricated into a VCSEL (Figure 1) with distributed Bragg reflector (DBR) mirrors defining the cavity and silicon dioxide (SiO_2) defining the current aperture. The DBRs used titanium oxide (Ti_3O_5) and SiO_2 dielectric pairs — 13.5 for the bottom mirror and 11.5 for the top. Indium tin oxide (ITO, 30nm) was used for current spreading in the aperture. The p- and n-electrodes were both chromium/gold (Cr/Au). The structure was flipped onto a copper (Cu) heatsink.

At low 15mA current, the emission centers on the ~440nm blue range of the InGaN quantum well material (Figure 2). As the current increases to the 32mA (~18kA/cm^2) threshold, the wavelengths in the cavity resonance region of 493nm become stronger, based on emissions from indium-rich localized narrow-bandgap regions. At higher 45mA current injection, the ~440nm wavelengths are suppressed and a narrow lasing peak emerges with 0.55nm linewidth in the blue-green 493nm region. The output power at 50mA was estimated to be ~178μW.

Previously, researchers from Xiamen, along with East China Normal University, SINANO, Technical University of Berlin in Germany and Taiwan Chiao Tung University reported quantum dot VCSELs in the green region (491.8–565.7nm), but with only ~10μW light output power [Yang Mei et al, Light: Science & Applications, vol6, pe16199, 2017]. At the time, the longest wavelength of 565.7nm and threshold currents as low as 0.52mA (0.66kA/cm^2) constituted records for green VCSELs. The devices also depended on the effect of cavity length on the lasing wavelength.

The optical polarization of the emitted light from the more recent quantum well VCSEL was 71% at 1.09x the threshold current injection.

The cavity resonance compensates for the lower

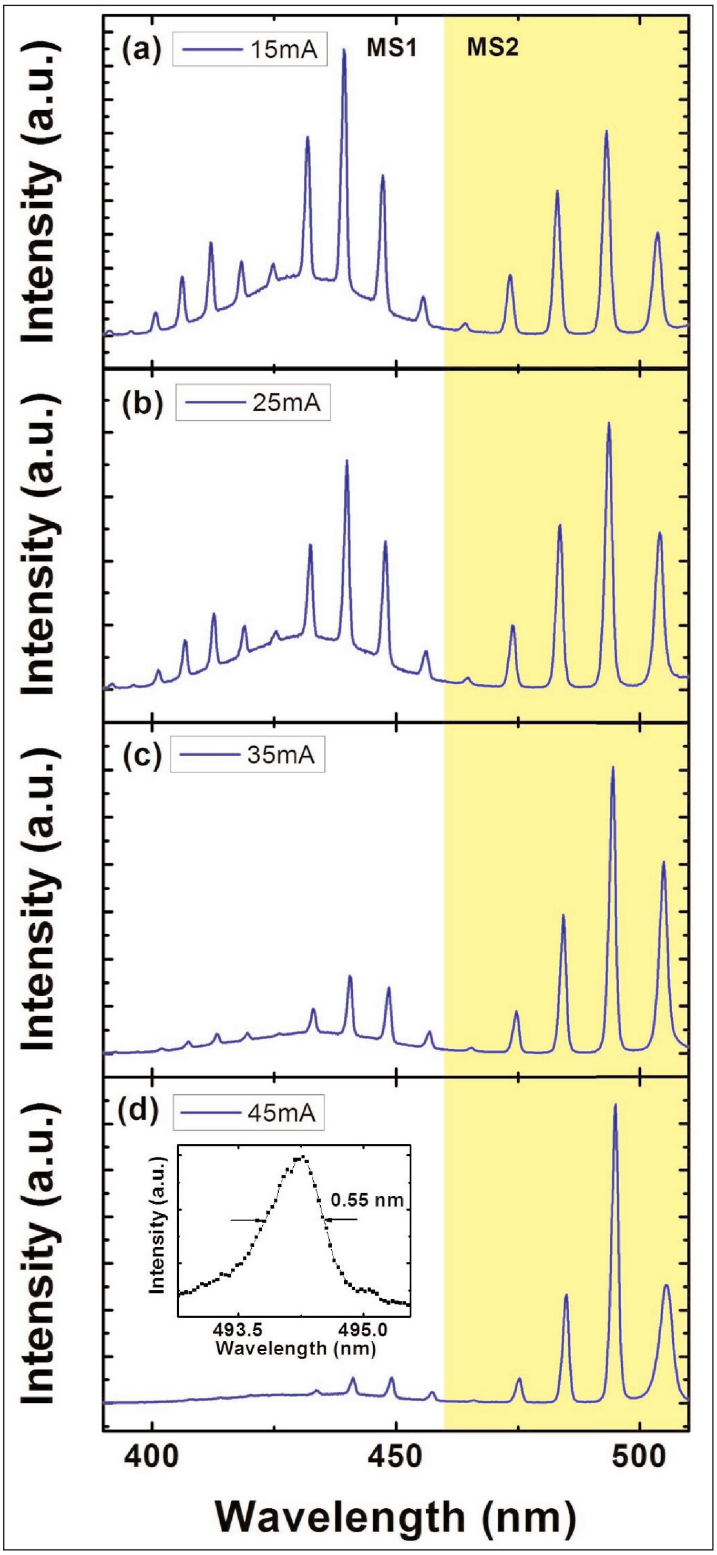

Figure 2. Electroluminescence spectra of the VCSEL measured at four different currents: (a) 15mA, (b) 25mA, (c) 35mA, and (d) 45mA. Inset: linewidth of lasing peak measured with higher resolution.

density of indium-rich localized narrow-gap regions, reducing the lifetime for recombination into photons. The researchers comment: "The short lifetime indicates a high carrier capture efficiency and can compensate the low density of emission centers, resulting in stronger emission intensity."

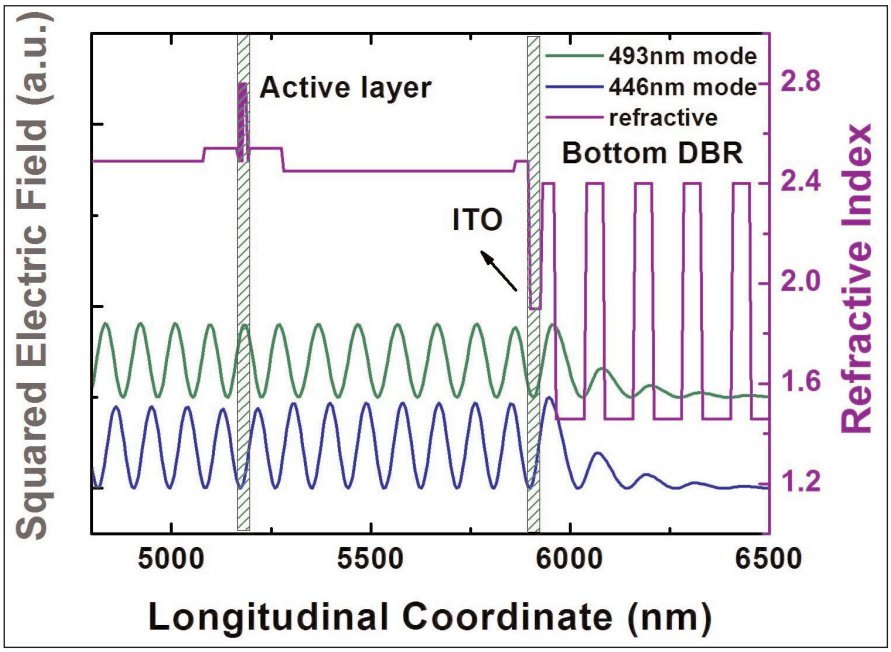

Figure 3. Refractive index and distribution of optical field for 446nm and 493nm cavity modes of VCSEL.

Simulations of the optical field also suggest that the active region lines up with an anti-node (maximum) of the standing-wave pattern for 493nm-wavelength emissions (Figure 3). By contrast, the 446nm mode gives a node (minimum) at the active layers. The gain enhancement factor is calculated at 1.82 for 493nm and 0.21 for 446nm. The researchers also point out that the longer lasing wavelength also benefits from less absorption loss in the active region.

Lowering thresholds

Xiamen also claims the lowest threshold energy density so far reported for an optically-pumped VCSEL based on InGaN technology [Jin-Zhao Wu et al, IEEE Transactions on Electron Devices, vol 65, issue 6 (June 2018), p2504]. The ultra-low 413μJ/cm^2 threshold was enabled by using a very short cavity, the knock-on effects of which included lower optical losses and higher gain. The team hopes its work will help guide III–nitride VCSEL improvements in the future.

MOCVD on sapphire created a laser structure with a multiple quantum well (MQW) active layer (Figure 4). A 16.5-period Ti_3O_5/SiO_2 distributed Bragg reflector (DBR) was electron-beam evaporated before flipping the structure and bonding to a quartz substrate. This bottom DBR had a 99.9% reflectivity.

A lift-off process using 248nm excimer laser light removed the sapphire substrate. The cavity was then tuned to six wavelengths with "cautious" inductively coupled plasma etching and chemical mechanical polishing (CMP), giving a smooth surface with 0.1nm root-mean-square roughness. The structure was completed with 12.5-pairs of Ti_3O_5/SiO_2 for the top DBR. The MQW was placed at the antinode of the standing wave in the laser cavity to increase coupling with the gain medium (~1.7x enhancement).

The excitation consisted of 355nm-wavelength light from a Nd:YAG laser focused on a 50μm-diameter spot. The very short 6-wavelength cavity enabled a low laser threshold power density of 413μJ/cm^2 (8.12nJ/pulse, Figure 5). The wavelength was 415.9nm.

The researchers report that a previous 18-wavelength device had a 15x higher threshold of 6.3μJ/cm^2 (compared with 0.413mJ/cm^2 = 413mJ/cm^2, Figure 6). The researchers also estimate that the spontaneous emission factor increased by a factor of 7.7. They also calculate that the short-cavity gain was enhanced 3x and the round-trip optical absorption reduced 3x.

The polarization degree of the laser light was 91% at 2.2x threshold excitation.

Tunnel junctions

University of California Santa Barbara (UCSB) in the USA claims the first demonstration of a III–nitride semiconductor VCSEL with a tunnel junction (TJ) on the p-side using only MOCVD material growth [SeungGeun Lee et al, Appl. Phys. Express, vol11, p062703, 2018].

Tunnel junctions are seen as an alternative to indium tin oxide as a current-spreading material on the p-side of light-emitting III–nitride devices. Indium tin oxide

Gain medium	p-GaN	200nm
MQW	5x($In_{0.01}Ga_{0.99}N/In_{0.12}Ga_{0.88}N$)	5x(4nm/4nm)
Gain medium	n-GaN	3μm
Buffer	GaN	2μm
Nucleation	Low-temperature GaN	30nm
Substrate	Sapphire	

DBR	12.5x(Ti_3O_5/SiO_2)
Gain	n-GaN
MQW	5x($In_{0.01}Ga_{0.99}N/In_{0.12}Ga_{0.88}N$)
GaIn	p-GaN
DBR	16.5x(Ti_3O_5/SiO_2)
Substrate	Quartz

Figure 4. (left) Epitaxial structure; (right) VCSEL structure.

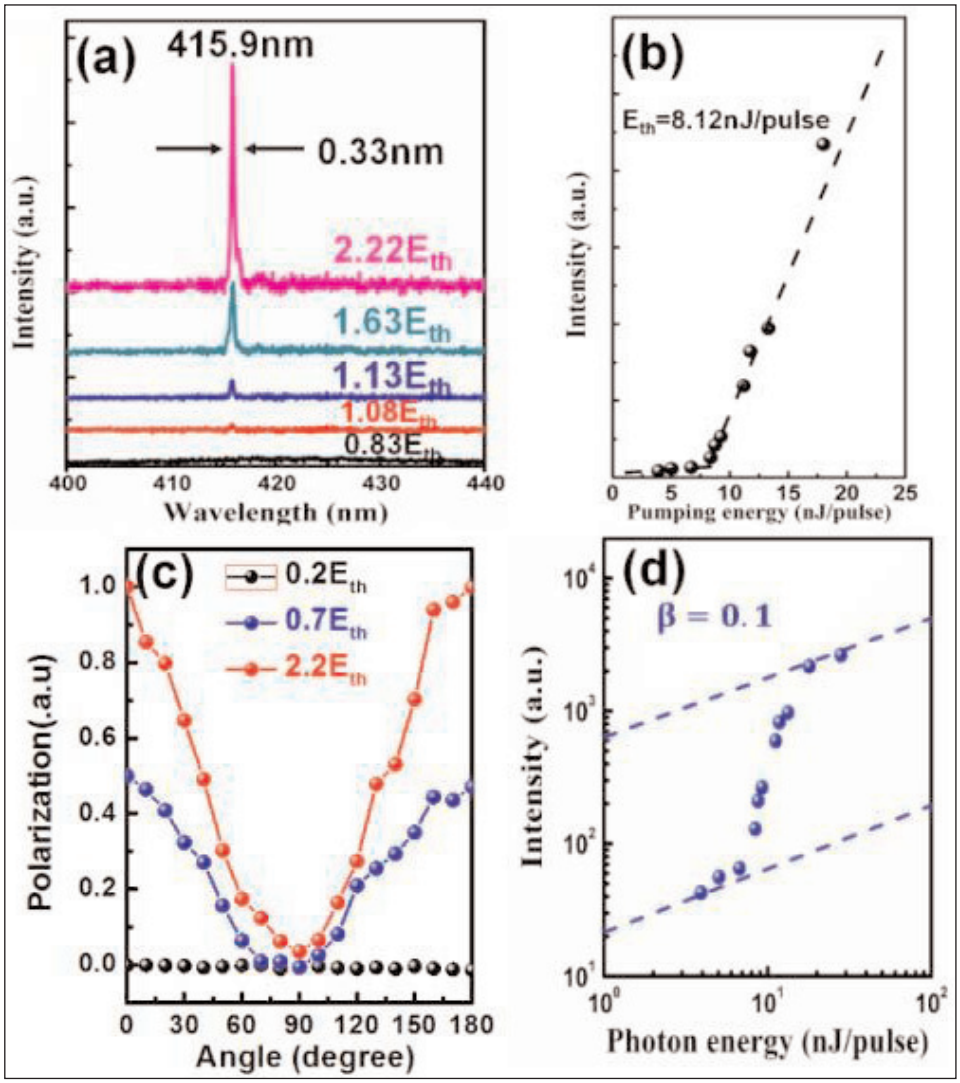

Figure 5. (a) Emission spectra dependence on pumping energy. (b) Emission intensity as a function of pumping energy. (c) Polarization characterization on pumping energy. (d) Spontaneous emission factor.

increases laser threshold currents and absorbs light, reducing efficiency.

Tunnel junctions of heavily doped p- and n-type material have been created before for VCSELs, but the UCSB team reports that these have used hybrid growth processes involving MOCVD and molecular beam epitaxy (MBE). An MOCVD-only process is preferred, since MBE is performed at lower temperatures, leading to higher defect density and impurity incorporation. Defects and impurities increase non-radiative recombination, reducing efficiency.

The VCSEL epitaxial material consisted of layers grown by MOCVD on bulk m-plane GaN, miscut –1º in the c-direction. Growth was carried out in two steps to allow activation of the buried p-type layers. Such layers suffer from hydrogen passivation, which hampers the acceptors from grabbing electrons to create holes in the valence band. An important aspect of activation is to drive out the hydrogen, usually with thermal annealing. Buried layers have less surface area — just the sidewalls — through which hydrogen can escape.

Between the initial growth and re-growth, the p^{++}-GaN was treated with buffered hydrofluoric acid (BHF) to remove excess magnesium, reducing diffusion into the subsequent n^{++}-GaN layer. When the wafer was returned to the MOCVD chamber, the temperature was held at 750ºC for 5 minutes to activate in-situ the p-GaN material before MOCVD regrowth at 900ºC.

The tunnel-junction structure was optimized with several experimental processes. A test structure with in-situ activation annealing had a 1.1V reduced forward voltage for a 1kA/cm^2 current density. The performance of the in-situ activation was similar to a structure grown using a standard ex situ anneal at 600ºC for 10 minutes in air (less than 0.1V difference over the test range).

The effect of the buffered hydrofluoric acid treatment was a 0.5V reduction of forward voltage at 1kA/cm^2. "We believe that the BHF treatment improved the volt-

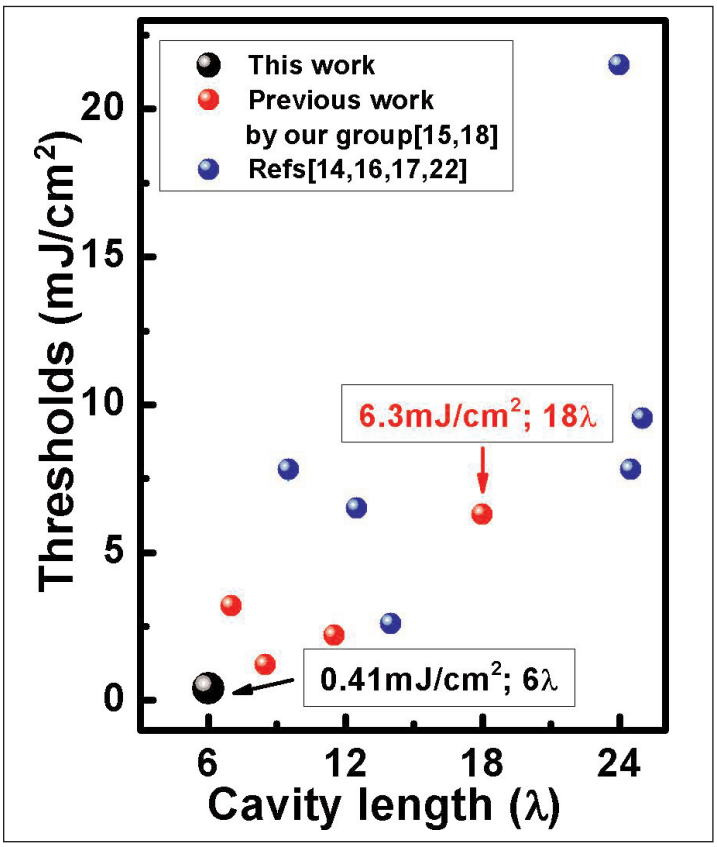

Figure 6. Statistics of thresholds of optical injection VCSEL.

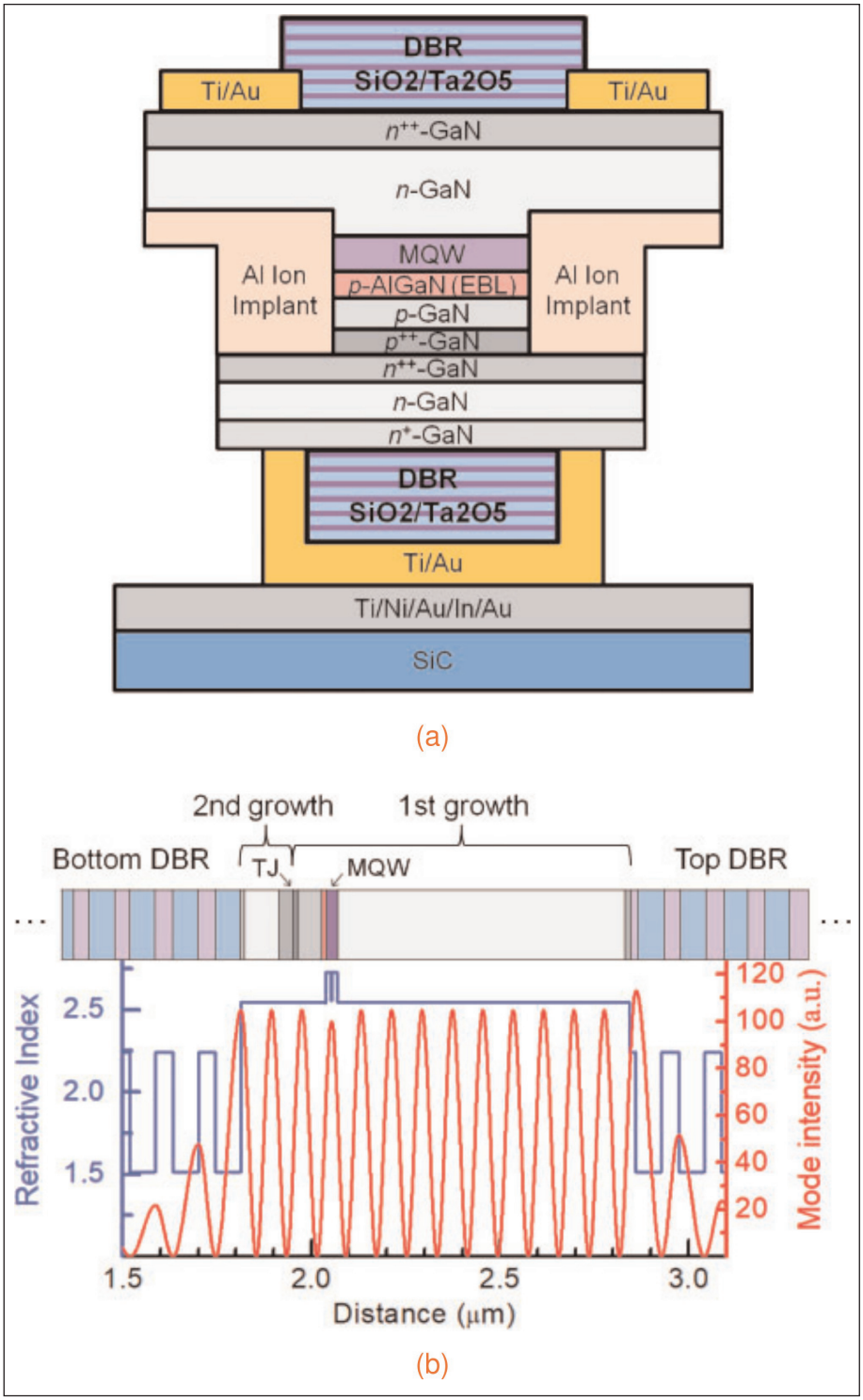

Figure 7. (a) Schematic of flip-chip VCSEL structure with dual dielectric DBRs and MOCVD-grown TJ contact and (b) cavity-mode intensity distribution overlaid with refractive index profile.

age by reducing Mg diffusion into the n^{++}-GaN layer, which could compensate electron carriers required to form an abrupt junction," the researchers comment.

Combining the BHF treatment with in-situ activation gave tunnel junctions with 3.4V forward voltage at 20A/cm^2 and 4.5V at 1kA/cm^2, close to the performance of junctions grown using a hybrid MOCVD/MBE process (3.05V at 20A/cm^2) by a similar research team based at UCSB.

For the VCSEL (Figure 7, Table 1), the epitaxial structure was first grown to the p^{++}-GaN layer, followed by mesa etch and aluminium ion implantation to form the device aperture. Then the tunnel-junction growth was prepared with aqua regia and BHF treatments. After the tunnel-junction growth, a 17-period DBR consisting of SiO_2 and tantalum pentoxide (Ta_2O_5) layers was deposited, followed by titanium/gold (Ti/Au) contact metals.

The device structure was then flipped and bonded onto metal layers consisting of titanium/nickel/gold/indium/gold (Ti/Ni/Au/In/Au) on a silicon carbide substrate. The GaN growth substrate was removed by photo-electro-chemical (PEC) etching of a sacrificial MQW. The VCSEL was completed with deposition of Ti/Au contact metals and a 13-period DBR. The n^{++}-GaN and DBR were separated by a ⅛-wavelength layer of Ta_2O_5.

The VCSEL was characterized using pulsed operation, presumably to avoid self-heating effects. The threshold for lasing occurred at 10kA/cm^2 current density (15mA current) and 7.8V forward bias. The maximum output power was 319μW with 55kA/cm^2 injection and 12V bias. Kinks in the output power behavior were likely due to higher orders contributing to the lasing. The wavelength was 408nm with ~1.9nm full-width at half maximum (FWHM) at 20mA injection. The accuracy of the linewidth was limited by the spectrometer's resolution capability. The differential efficiency reached 0.28%.

The differential resistivity of the tunnel junction was $10^{-4}\Omega$-cm^2, higher than the $5\times10^{-5}\Omega$-cm^2 for the previously reported tunnel junction from a hybrid growth process. "We believe that the low doping concentrations of the current-spreading layers on the p-side are the main cause of the high differential resistivity that limits the device performance", the researchers comment.

Optical microscope inspection of the 14μm-diameter aperture during lasing showed lasing spots that increased in number as the injection current increased (Figure 8). Some of the lasing filaments were at the original frequency; others contributed higher modes. The non-uniformity is attributed by the team to poor current spreading and variations of the tunnel-junction contact resistance. The researchers also suggest that

Table 1. VCSEL epitaxial layer structure grown on m-plane GaN substrate. (UID: unintentionally doped.)

Epitaxial layer	Thickness	Doping concentration	Contribution to internal optical loss
2nd growth			
n^+-GaN	10nm	$10^{19}/cm^3$	1.8%
n-GaN	94nm	$1.3x10^{18}/cm^3$	6.0%
n^{++}-GaN	40nm	$10^{20}/cm^3$	9.4%
1st growth			
p^{++}-GaN	14nm	$2.2x10^{20}/cm^3$	21.7%
p-GaN	61.2nm	$10^{19}/cm^3$	12.8%
p-AlGaN	5nm	$2.2x10^{19}/cm^3$	1.3%
2x(InGaN/GaN) MQW	2x(1nm/14nm)	UID	
n-GaN	759.4nm	$2.3x10^{18}/cm^3$	45.7%
n^+-GaN	15nm	$1.7x10^{19}/cm^3$	1.3%
InGaN (sacrificial QW)	7nm	UID	
n-GaN (template)	~1300nm	$1.3x10^{18}/cm^3$	

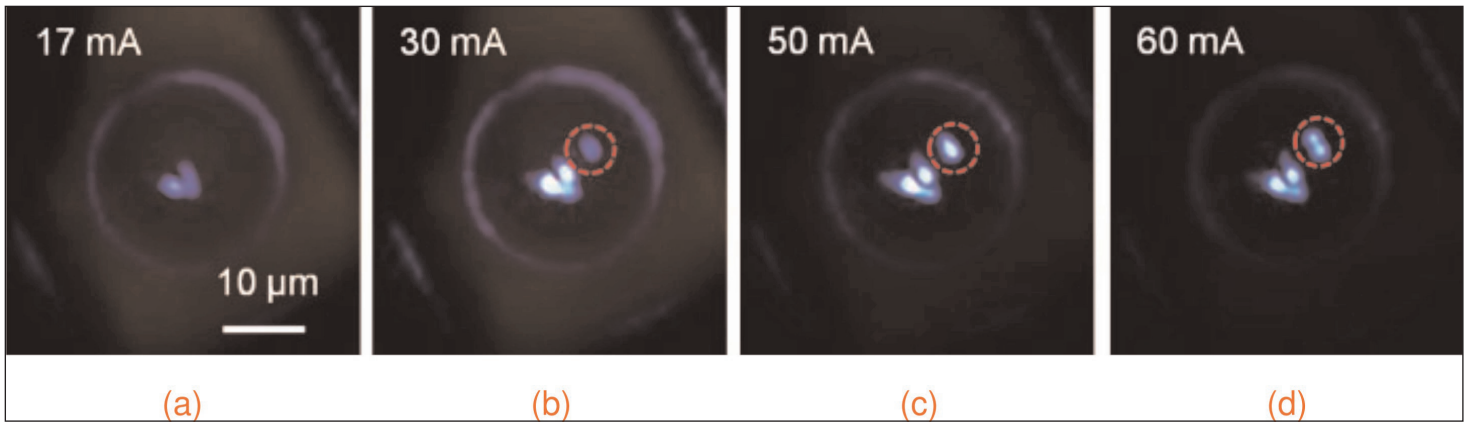

Figure 8. Optical microscopy images of VCSEL as a function of current above threshold (~15mA). Exposure times of the camera were the same for (a) and (b) and reduced for (c) and (d) to obtain clear images. Lasing spots in red circles show switching to higher-order mode.

surface residues such as gallium oxide left after the GaN substrate removal could play a role in the non-uniformity. ■

Author: Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.

Integrating capacitors into p-GaN gate transistors on silicon

On-chip capacitors could help to manage parasitic inductance problems that lead to gate-drive loop over-voltage stress at high-frequency operation.

Hong Kong University of Science and Technology (HKUST) and Taiwan Semiconductor Manufacturing Company Ltd have been jointly developing integrated capacitors for p-type gallium nitride (p-GaN) gate high-frequency power transistors on silicon substrate [Gaofei Tang et al, IEEE Electron Device Letters, vol39, no.9, September 2018, p1362]. GaN transistors with a p-gate enable enhancement-mode operation where transistors are in the current-off state with zero gate potential. This reduces power consumption and allows fail-safe operation.

GaN transistors are being developed for high-frequency power applications with a view to high conversion efficiency and power density. Production on silicon should reduce manufacturing cost.

A problem with p-gate enhancement-mode transistors is parasitic inductance in the gate-drive loop causing over-voltage stress at high frequency. Parasitic inductance can be minimized by on-chip integration of high-voltage power switches and peripheral drive/control modules. Such integration is promoted by the availability of integrated passive devices — resistors and capacitors. Capacitors are used to help de-couple noise in the power supply, shift levels, and pump charge in the gate driver.

Parasitic inductance can be minimized by on-chip integration of high-voltage power switches and peripheral drive/control modules

The material structure for the p-GaN gate capacitors was metal/p-GaN/AlGaN/GaN produced for commercial 650V enhancement-mode power devices. The capacitor used ohmic contacts on the n-side and a Schottky contact on the p-GaN (Figure 1). The p-GaN material bends the underlying band structure upwards, depleting the two-dimensional electron gas (2DEG) that usually forms near the AlGaN/GaN interface, putting the device into an off-switch condition. The researchers modeled their device as back-to-back diodes consisting of the metal/p-GaN Schottky junction and the p-GaN/AlGaN/GaN heterojunction.

Above the threshold for formation of the 2DEG the Schottky diode capacitance is voltage-dependent while the heterojunction capacitance is considered as being voltage-independent. The heterojunction capacitance is dependent on the AlGaN barrier thickness. Below threshold the heterojunction capacitance is negligible, creating a low total capacitance, arising mainly from the fringe/edge regions.

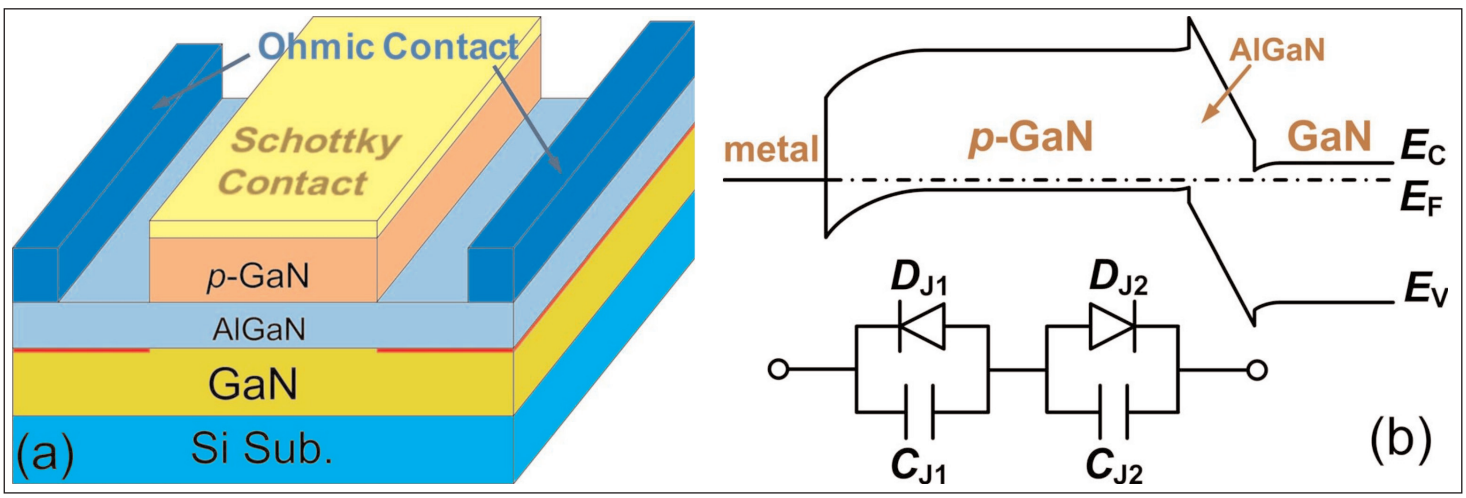

Figure 1. (a) Schematic cross section of fabricated p-GaN gate capacitor. (b) Schematic energy band diagram along depth of gate stack at zero bias and corresponding equivalent circuit.

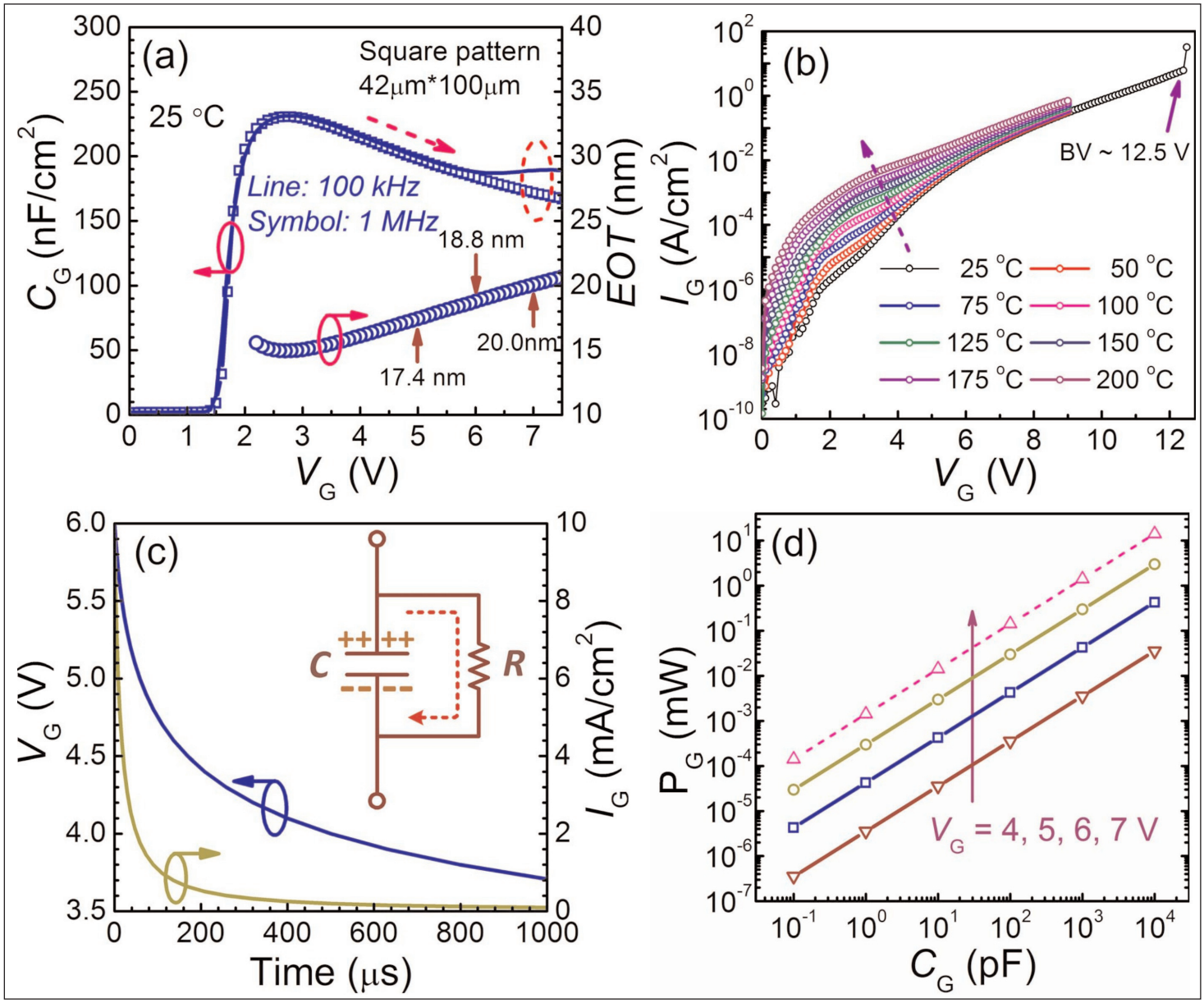

Figure 2. (a) Measured C–V characteristics and extracted equivalent oxide thickness of p-GaN gate capacitor. (b) Measured gate leakage at varied temperatures under positive gate bias. (c) Extrapolated time evolution of gate voltage (V_G) and current (I_G) of charged p-GaN gate capacitor. (d) Calculated power consumption of p-GaN gate capacitor.

A 42μmx100μm rectangular device had a capacitance density of up to ~230nF/cm^2 (Figure 2). The equivalent oxide thickness (EOT) of the stack ranged from 16nm to 20nm, with the respective voltage varying from 4V to 7V. The room-temperature DC breakdown was around 12.5V.

The gate leakage led to self-discharge from 6V to 5V in ~60μs and from 5V to 4V in ~500μs. The researchers comment: "Such a result suggests that the p-GaN gate capacitors are well suited for AC operation at frequencies above 100kHz (with a period less than 10μs)."

The gate-leakage-induced power consumption is calculated at ~30μW at 6V bias and ~4μW at 5V. "Such power consumption is negligible compared to the overall power consumption of the circuits (e.g. gate driver) featuring the capacitors," the researchers comment. The gate-leakage was also found to increase with temperature.

The team suggests that operating voltages should be limited to less than 7V to avoid long-term stress-induced degradation.

The researchers also compared the performance of large-area 250μm-radius circular against interdigitated p-electrodes. The interdigitation consisted of six fingers measuring 54μmx360μm, giving comparable capacitance to the circular device. The aim was to suppress the distribution effect from series resistance to current flow in the 2DEG. The distribution effect limits operating frequency due to slow turn-on. The quality factor was 145 at 5MHz for the interdigitated capacitor, compared with 3.0 for the circular device. ■

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Author: Mike Cooke

Gallium oxide transistors increase breakdown to 1.8kV

Researchers have used atomic layer deposition to improve the field-plate structure in gallium oxide MOSFETs.

University at Buffalo in the USA claims the highest breakdown voltage measured in a lateral β-gallium oxide (Ga_2O_3) metal-oxide-semiconductor field-effect transistor (MOSFET) to date [Ke Zeng et al, IEEE Electron Device Letters, vol 39 (2018), issue 9, p1385].

Gallium oxide is a recent material addition to the research effort towards high-power-density devices. Its high critical field enabled the breakdown voltage to be pushed above 1.8kV. Previous work had managed 750V. The improvement is attributed to an improved field-plate design with a composite dielectric supporting the field-plate metal. Atomic layer deposition (ALD) was used for the expected high-field regions of the dielectric, improving material quality.

The device was fabricated using a semi-insulating iron-doped Ga_2O_3 substrate with two 200nm epitaxial layers of unintentionally doped (UID) and tin-doped (Sn) Ga_2O_3 (Figure 1). Extra Sn doping was applied selectively to the source/drain regions using a spin-on-glass technique. The metal source/drain contacts were annealed titanium/gold.

The gate dielectric consisted of 20nm of ALD silicon dioxide (SiO_2). Support for the field-plate structure was provided by plasma-enhanced chemical vapor deposition (PECVD) and more ALD SiO_2. The stack also included a thin ALD aluminium oxide (Al_2O_3) layer designed to serve as a stop for the gate-trench reactive-ion etch. The Al_2O_3 etch stop was removed from the trench bottom by wet etching. The gate and

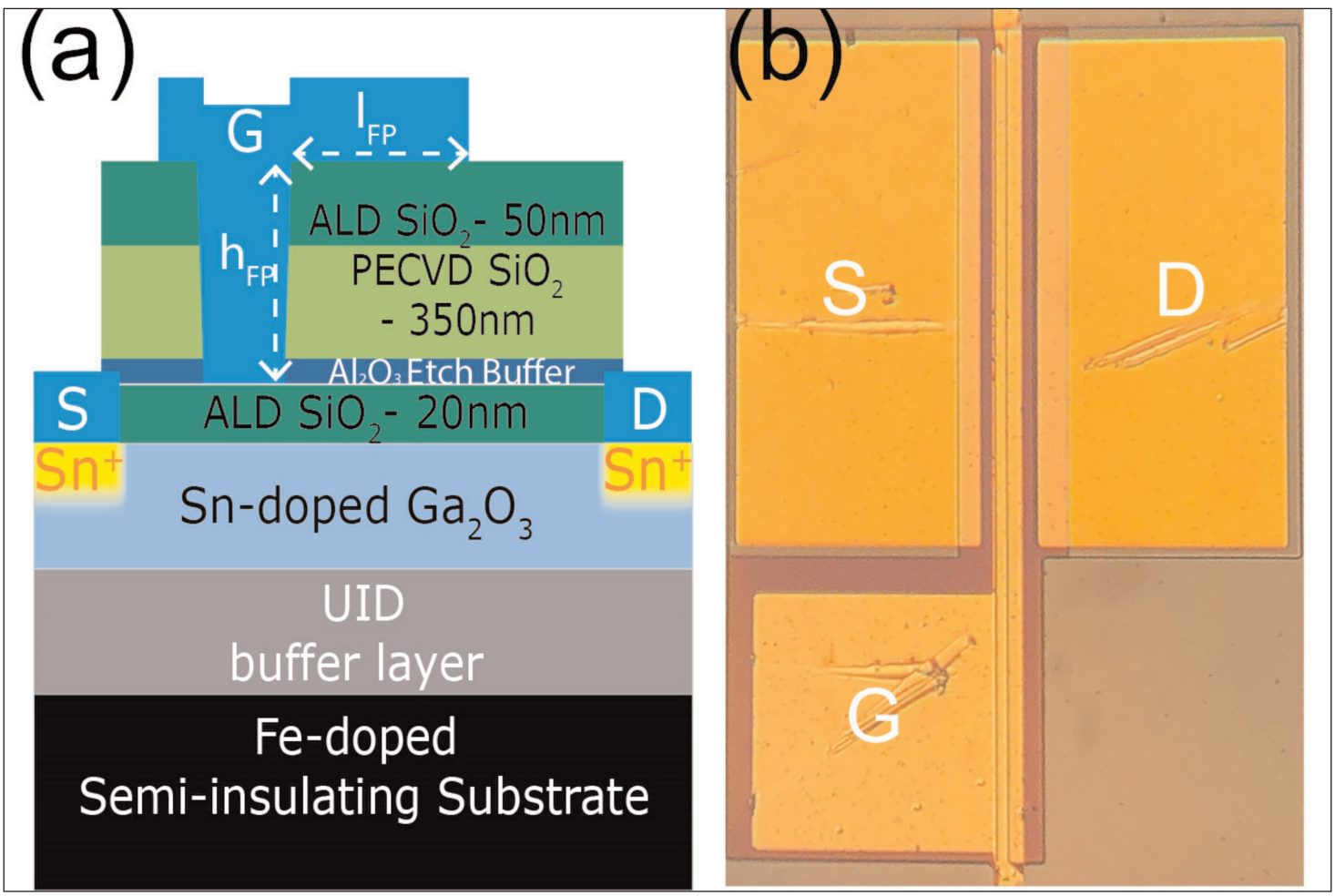

Figure 1. (a) Cross-sectional view and (b) optical image of fabricated field-plated Ga_2O_3 MOSFET with spin-on-glass source/drain doping.

field-plate metal consisted of titanium/aluminium/nickel/gold. Electrical isolation was provided by a ~220nm-deep reactive-ion etched trench around the device.

Catastrophic three-terminal breakdown (V_{BR}) occurred at 1850V in Fluorinert with a gate–drain distance of 20μm. In an air environment, the breakdown occurred at 440V. Devices with various gate–drain distances demonstrated around 4x the breakdown voltage in Fluoinert, compared with air.

Without Fluorinert, the breakdown is 'extrinsic' to the Ga_2O_3, occurring through air or weaker parasitic paths in the field oxide. The team points out: "Air only has a dielectric strength of 30kV/cm, 266 times lower than Ga_2O_3 and 333 times lower than SiO_2."

Reducing the gate-drain distance to 1.8μm (L_{gd}) increased the average electric field in the gate-drain space, calculated as $(V_{BR}–V_g)/L_{gd}$, to 2.2MV/cm. Simulations suggest the peak field was around 3.4MV/cm. The critical field of Ga_2O_3 is predicted to be around 8MV/cm, based on empirical considerations. Other lateral Ga_2O_3 MOSFETs have achieved 3.8MV/cm, while vertical Schottky barrier diodes have managed 5.1MV/cm.

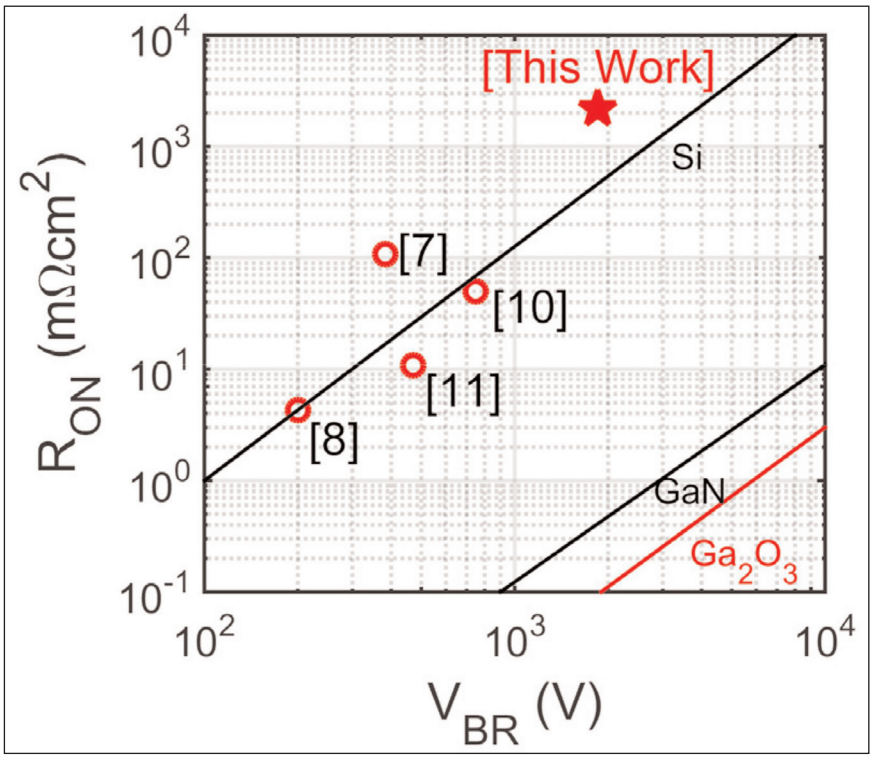

Figure 2. Plot of on-resistance (R_{ON}) versus V_{BR} of device under test against previously published lateral Ga_2O_3 MOSFETs. R_{ON} for the Buffalo work calculated at 10V drain bias.

The researchers compared the performance of their work to other reports on lateral Ga_2O_3 transistors (Figure 2). The overall performance presently seems to hover around the theoretical limit for silicon-based device and falls short of the expected limits for GaN and Ga_2O_3. The team expects that careful device engineering will be able to push the breakdown higher. The use of Fluorinert could be replaced by more careful passivation. ■

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SPIE Photonics West 2019, including OPTO 2019 – Optoelectronic Materials, Devices, and Applications
Moscone Centre, San Francisco, CA, USA
E-mail: customerservice@spie.org
www.spie.org/SPIE_PHOTONICS_WEST_Conference
www.spie.org/SPIE_OPTO_conference

17–21 March 2019
APEC 2019: IEEE Applied Power Electronics Conference and Exposition
Anaheim Convention Center, CA, USA
E-mail: apec@apec-conf.org
www.apec-conf.org

7–9 May 2019
PCIM Europe (Power conversion and Intelligent Motion) 2019
Nuremberg Messe, Germany
E-mail: daniela.kaeser@mesago.com
www.mesago.de/en/PCIM/main.htm

15–17 May 2019
Intersolar Europe 2019
Munich, Germany
E-mail: info@intersolar.de
www.intersolar.de

27–31 May 2019
10th International Conference on Power Electronics (ICPE 2019 – ECCE Asia)
BEXCO, Busan, South Korea
E-mail: icpe2019@icpe2019.org
www.icpe2019.org

24–28 June 2019
PVSC 2019: IEEE 46th Photovoltaic Specialists Conference
Chicago, IL, USA
E-mail: info@ieee-pvsc.org
www.ieee-pvsc.org

8–10 July 2019
2019 Summer Topicals Meeting Series
Fort Lauderdale, FL, USA
E-mail: i.donnelly@ieee.org
www.sum-ieee.org

2–5 September 2019
21st Conference on Power Electronics and Applications (and Exhibition), EPE'19 ECCE (Energy Conversion Congress & Expo) Europe
Genova, Italy
E-mail: info@epe2019.com
www.epe2019.com

6–11 October 2019
22nd European Microwave Week (EuMW 2019)
Paris Expo Porte de Versailles, Paris, France
E-mail: eumwreg@itnint.com
www.eumweek.com

9–11 December 2019
65th IEEE International Electron Devices Meeting (IEDM 2019)
San Francisco, CA USA
E-mail: info@ieee-iedm.org
www.ieee-iedm.org

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