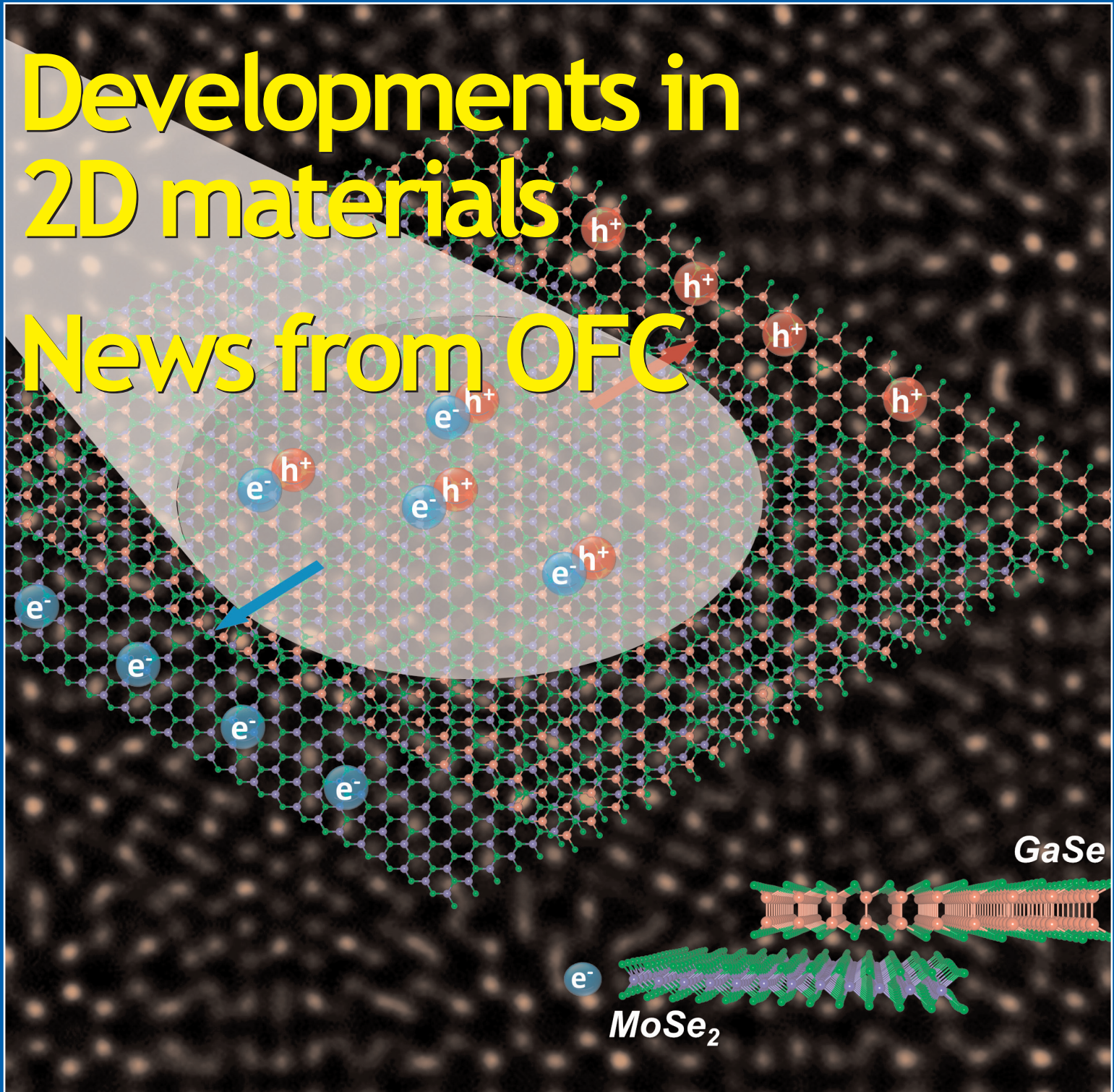


Developments in 2D materials

News from OFC



Qorvo acquiring GreenPeak • IQE joins MIRPHAB project
Kyma boosts AlN template capacity • First QCL on silicon



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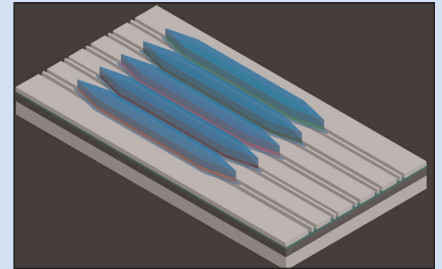
Contact us at www.veeco.com/EPIK700 to learn more.



Veeco's New TurboDisc EPIK700 GaN MOCVD System

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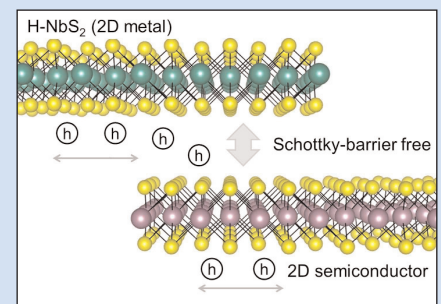
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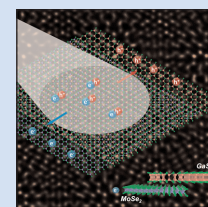
p42 UCSB, the US Naval Research Laboratory and University of Wisconsin, Madison have fabricated the first quantum cascade laser on silicon



p63 A Clean Motion Zbee ultra-light electric vehicle with CIGS solar cells.



p67 NREL has uncovered a way to overcome a principal obstacle in using 2D semiconductors in electronic and optoelectronic devices.



Cover: Researchers led by Oak Ridge National Laboratory have synthesized a stack of two atomically thin monolayers of two different semiconductor materials (GaSe/MoSe₂) that are aligned — despite the mismatch in the crystal lattices — thanks to the binding effect of van der Waals epitaxy. **p68**

Semiconductor convergence

On pages 67–71 of this issue we cover reports of recent research on two-dimensional semiconductor materials. In particular, the USA's NREL has devised a way to use 2D metal electrodes to overcome the Schottky barrier that can present an obstacle to practical application of 2D semiconductors (citing nitrogen-doped graphene and hexagonal phase of niobium disulfide H-NbS₂ for facilitating the transport of electrons and holes, respectively, in tungsten diselenide WSe₂, for example) — see page 61.

The binding between the 2D metal and 2D semiconductor occurs through van der Waals interaction. Likewise, a group led by the USA's Oak Ridge National Laboratory has used van der Waals epitaxy to grow a stack of two atomically thin monolayers of different semiconductors (GaSe/MoSe₂) that are aligned, despite the mismatch in their crystal lattices (see page 68, and the cover pic), broadening the number of materials that can be combined and hence creating a wider range of potential atomically thin devices. Also, the University of California San Diego and the UK's University of Manchester have explored using molybdenum disulfide (MoS₂) 2D material in a 'van der Waals' heterostructure to control excitons at higher temperatures than is possible using gallium arsenide (i.e. above 100K), targeting resistance-free superfluid flow at room temperature and more efficient light emission (see page 70).

Regarding process equipment, Netherlands-based Solmates has sold a system for pulsed laser deposition (PLD) — described as "the next disruptive deposition technology following the adoption of atomic layer deposition (ALD) for thin-film manufacturing" — to Belgium-based nanoelectronic research institute imec (to aid the integration of new materials for next-generation transistors). Solmates has also joined imec's 'Beyond CMOS' Industrial Affiliation Program, which focuses on integration and benchmarking of novel device concepts beyond traditional transistor scaling, including 2D materials such as graphene and MoS₂ (see page 24).

Meanwhile, imec has also just qualified Aixtron's AIX G5+ C multi-wafer (5x200mm) batch metal-organic chemical vapor deposition (MOCVD) platform for manufacturing buffer layers (as a result of a collaboration on high-voltage gallium nitride-on-silicon power device technology).

Also concerning GaN-on-Si, ALLOS Semiconductors of Dresden, Germany has transferred its latest-generation epiwafer technology to a "major international industry player" as part of a joint project to accelerate its GaN-on-Si power semiconductor product development (see page 21).

While Kyma Technologies focuses on manufacturing nitride materials, it has just extended its product range to include epiwafers made of the even wider-bandgap semiconductor material gallium oxide (β-Ga₂O₃), which represents "a new frontier in the continuous search for higher-performance semiconductor devices", the firm says (see page 22).

While such exotic materials as Ga₂O₃ may require niche technology, the compatibility of GaN-on-Si to 200mm silicon fabrication plants and the looming relevance of 'Beyond CMOS' materials to mainstream silicon chip makers is driving increasing convergence of the silicon industry and compound semiconductor technologies. This is manifested by the 11.5% CAGR forecasted for the epitaxy deposition market over 2016–2020 as device makers increasingly resort to using epitaxial deposition (see page 8).

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Semiconductor Today covers the R&D and manufacturing of compound semiconductor and advanced silicon materials and devices

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- conference reports;
- event calendar and event previews;
- suppliers' directory.

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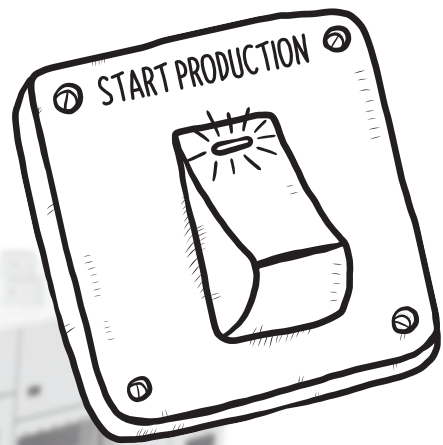
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VCSEL market growing at 21.9% from \$781.6m in 2015 to \$2.1bn in 2020

Fiber data transmission growing at 20.2% from \$246.7m to \$618.2m; analog broadband transmission at 25.8% from \$93.7m to \$295.3m

Following greatly increased use in the optical communications industry over the past 15 years, the global market for vertical-cavity surface-emitting lasers (VCSELs) will grow at a five-year compound annual growth rate (CAGR) of 21.9% from \$781.6m in 2015 to \$2.1bn in 2020, as demand increases for VCSELs in consumer electronics products and other high-end applications, forecasts BCC Research in its new report 'Vertical-Cavity Surface-Emitting Lasers (VCSEL): Technologies and Global Markets' (PHO011B).

Optical fiber data transmission (the largest segment) should grow at a CAGR of 20.2% from \$246.7m in 2015 to \$618.2m in 2020, while analog broadband signal transmission should grow at a CAGR of 25.8% from \$93.7m in 2015 to \$295.3m in 2020, adds the report.

Extensive R&D on VCSELs by companies and defense services worldwide has produced high power-conversion efficiency of

63.4% (compared with typically 20–25% for other types of commercially available lasers, notes BCC). In short-range communication networks such as storage-area networks (SAN) and local-area networks (LAN), VCSELs are expected to be the key light source in the future. With the development of long-wavelength VCSELs, higher bandwidth, lower cost, wavelength tunability and low drive currents, VCSELs are the future for widespread on-site and customer premises deployment for passive optical access networks, the report reckons.

VCSELs should also play an important role in gesture recognition and 3D sensing technology in consumer electronics goods, BCC says. The continuous demand for gesture recognition technology in portable electronic devices is expected to lead to higher deployment of VCSELs in electronic devices. Greater precision in VCSELs is another key market driver that has led to their increased adoption in

medical applications such as medical diagnostics and therapeutics, optical nerve stimulation and computed radiography imaging. Also, superior power efficiency over LEDs has expanded the adoption of VCSELs in proximity-sensing applications.

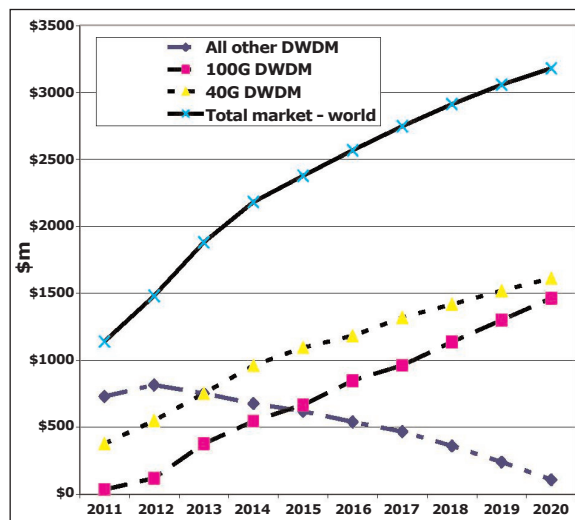
VCSELs have become an attractive technology for many high-volume applications, notes BCC. "VCSELs have been widely adopted in the data communications industry," says BCC Research analyst Sinha Gaurav. "The growth is attributed to increased demand for VCSELs with low-energy optical storage and fast switching in servers and high-capacity data centers. Additionally, the growing demand for VCSELs in ultra-high-density magnetic storage and industrial heating, including paint curing and commercial print shops, is further expected to contribute to the growth of the market," he concludes.

www.bccresearch.com/market-research/photonics/vcsele-tech-markets-report-pho011b.html

DWDM market to grow from \$9.2bn in 2016 to \$11.4bn in 2020

The global dense wavelength division multiplexing (DWDM) market will grow from \$9.2bn in 2016 to \$11.4bn in 2020, according to Information Gatekeepers Inc in its report 'Network of the Future — with Equipment Forecasts'. In addition to the DWDM market, the report also provides detailed analysis and forecasts for ROADMs (reconfigurable optical add-drop multiplexers), routers and switches in North America and worldwide.

There has been a great deal of turmoil in the area of telecommunications, much of it leading to spec-



Worldwide DWDM market by channel speed.

tacular changes and advances, notes the report. Turmoil has been created by technological changes, by regulatory changes, by the development of new products and applications, by the introductions of new flavors of services, and by the entry of non-traditional competitors, notes the report.

<http://igigroup.com/st/pages/networkoffutur.html>

Lumileds only top-10 packaged LED maker market to grow revenue in 2015, overtaking Samsung into 3rd Everlight leapfrogs Cree to 6th in ranking

When it comes to pricing and market expectations, 2015 was another tough competitive year for packaged LED vendors, with challenges in both backlighting and lighting, comments Jamie Fox (principal analyst for Lighting and LEDs at IHS Technology) in an analysis and commentary on the latest packaged LED company rankings (excluding Epistar, San'an and other die vendors) from the market research firm's LED Intelligence Service.

The US dollar was much stronger in 2015 than 2014 — against almost every major currency — which largely explains why packaged LED revenue fell so much last year, says IHS. Measured in Yen and Euro, the packaged LED market grew 5% and 10%, respectively. (Had exchange rates remained the same as they were in 2014, the market would most likely have been much flatter measured in US dollars.)

As global LED revenue fell 8% in 2015 Lumileds was the only LED maker ranked in the top 10 to report positive growth in 2015, gaining share as well as ranking position. Despite the firm suffering significant uncertainty last year (as Philips attempted to sell the business), Lumileds has surpassed Samsung in every quarter since fourth-quarter 2014. The firm continues to offer a strong competitive

Ranking by packaged LED revenue (GaN + AlInGaP + standard).

Company	2014	2015
Nichia	1	1
Osram Opto	2	2
Lumileds	4	3
Samsung Electronics	3	4
Seoul Semiconductor	5	5
Everlight	7=	6
Cree	6	7
LG Innotek	7=	8
MLS	9	9
Lumens	10	10

position in automotive LED, general lighting and mobile-camera flash categories, and its market share continues to benefit from having only a small position in the soft backlighting market, which includes mobile phones, notebooks, tablets and monitors.

Revenue share for Cree, LG Innotek and Everlight declined in 2015 compared to 2014. However, Everlight improved its ranking position, while the others did not. Everlight's rise comes despite losing market share, because the revenues of Cree and LG Innotek fell even further.

Cree and the major Korean players all experienced double-digit revenue declines in 2015. Cree is increasingly focused on its lighting business, as

its component business is no longer growing as quickly as it once was. The firm has long positioned itself — with some justification — as a higher-quality vendor than others, says IHS.

While this strategy has suffered as the market has commoditized, Korean companies managed to position themselves successfully as the low-cost option in general lighting in 2012 and 2013, notes the market research firm. Even so, this strategy faced difficulties in

2014 and 2015, as MLS and other Chinese companies offered even lower prices with similar quality. In 2015 Samsung, LG Innotek and Lumens were caught in the middle — offering neither the lowest price nor the best quality — with no obvious business strategy to address the issue.

Seoul Semiconductor is a pure-play LED company that is committed to the market and has more experience in LEDs than the other major Korean players, says IHS. While the firm gained share in 2015, revenue fell slightly. Japan's Nichia, Germany's Osram Opto Semiconductors and MLS all maintained their share in 2015, declining slightly in revenue (in line with the market).

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Perovskite solar cells to be commercialized in 2019–2021

Hailed as the next generation of photovoltaic material, it is hoped that perovskite solar cells will drive adoption in new applications. While there are challenges to be overcome, perovskites offer opportunities for partnerships with universities ahead of a likely commercial deployment between 2019 and 2021, according to market analyst firm Lux Research in its report 'The Rise of Perovskites: Identifying the Best Academic Partners to Work With' (part of the Lux Research Solar Intelligence service).

The diverse compound materials have seen dramatic achievements in solar energy conversion efficiency in academic labs: from a mere 3.8%, the cells have risen rapidly to a record 21.0%, compared with 21.7% for competing copper indium gallium diselenide (CIGS) solar cells, which have been in development for decades.

"While the efficiency question has been answered, there remain issues in stability, cost, and the feasibility of real-world efficiencies that must be

addressed before commercialization can occur," says Lux Research associate Tyler Ogden (lead author of the report). "Still, demonstration of their potential for high performance by academic labs has caused research groups to consider spinning off start-ups, meaning companies need to consider opportunities now."

Lux analysts evaluated the existing state of perovskite solar cells and identified opportunities for firms to partner with academia. Among their findings are the following:

- Partnerships are emerging from labs. Dyesol has partnered with Michael Grätzel's lab at Switzerland's EPFL (École Polytechnique Fédérale de Lausanne), which achieved the record efficiency of 21.0% in December. The UK's Oxford Photovoltaic Ltd is working with Henry Snaith of Oxford University, while Poland's Saule Technologies has roots in the University of Valencia, and Front Materials has roots in the National Taiwan University.

- Opportunities are still available. Many leading researchers have clear partnerships, but opportunities are still present with Nam-gyu Park of South Korea's Sungkyunkwan University and Yang Yang of University of California Los Angeles (UCLA). Israel's Weizmann Institute of Science and Singapore's Nanyang Technological University are also promising developers.

- China is top academic publisher. China is the leading publisher on perovskite solar cells, accounting for a quarter of all academic publications, but more impactful research is coming out of Israel, Switzerland, Singapore, and the UK. China is followed by the USA and South Korea. However, European countries — the UK, Italy, Switzerland, Germany, Spain, Sweden, France, Greece and Belgium — together account for 24% (almost equivalent to China).

www.luxresearchinc.com/coverage-areas/solar

Epi deposition market growing at 11.54% CAGR to 2020

The global epitaxy deposition market will rise at a compound annual growth rate (CAGR) of 11.54% during 2016–2020, forecasts a market research by Technavio.

Semiconductor companies are moving to the fabless model, mainly to reduce overhead expenses related to the operation and maintenance of foundries. Most are concentrating on the design and development of their solutions and are subcontracting their fabrication and other foundry-related activities to specialized companies. Due to this, the ratio between foundries and fabless companies is 1:11 in the global semiconductor market. Companies are also considering mergers and acquisitions (M&A) to increase their production facilities and market shares.

The report 'Global Epitaxy Deposition Market 2016–2020' says the ever-increasing features and applications

of smart devices such as smartphones and notebooks have created the need for high-performance semiconductor devices. Due to this, over the last decade semiconductor manufacturers have increased the use of epitaxial deposition on the wafer.

In 2015, the epi deposition market was dominated by the foundry segment (almost 63% market share). By geography, the Asia-Pacific (APAC) comprised more than 71% of the epi deposition market, driven by foundries such as Samsung and TSMC. APAC is also the largest consumer of semiconductor devices, contributing over half of total semiconductor industry revenue. During the 2016–2020 forecast period, demand for electronic devices including laptops, tablets, gaming consoles, smartphones in APAC countries will continue to rise. In turn, demand will grow from original equipment manufacturers for

semiconductor devices (logic, analog, optoelectronics and sensors).

Key players in the epi deposition market include Applied Materials Inc, ASM International, Hitachi Kokusai Electric Inc, Lam Research Corp, and Tokyo Electron Ltd. Other prominent vendors covered by the report are Aixtron, Canon Anelva Corp, IQE, and Veeco Instruments. The epitaxy deposition market is open and has considerable potential for new vendors, reckons the report. However, market entry is difficult due to the high initial investment, adjustment required by constant technological advances, and the cyclical nature of the semiconductor industry. Also, due to technology advances and mergers & acquisitions, the competitive environment is expected to increase.

www.technavio.com/report/global-semiconductor-equipment-epitaxy-deposition-market

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Qorvo to acquire ultra-low-power, short-range RF system-on-chip firm GreenPeak

Qorvo expanding into highly integrated RF solutions and SoCs for connected home and Internet of Things markets

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has agreed to acquire privately held fabless semiconductor/system firm GreenPeak Technologies of Utrecht, The Netherlands, which specializes in ultra-low-power, short-range RF communication technology. Qorvo says that the acquisition will allow it to expand into highly integrated RF solutions and systems-on-a-chip (SoCs) for the connected home and the rapidly growing Internet of Things (IoT).

"The acquisition of GreenPeak Technologies will complement Qorvo's market-leading high-power RF portfolio with innovative ultra-low-power, short-range wireless personal area network (WPAN) SoCs, ZigBee and Bluetooth solutions," believes James Klein, president of Qorvo's Infrastructure and Defense Products

(IDP) group. "GreenPeak brings a world-class technical team and solutions to Qorvo, allowing us to increase our presence in the rapidly expanding IoT market," he adds.

"Qorvo will be a great environment for the GreenPeak team to grow as part of a much larger company serving many more global customers," believes GreenPeak's founder & CEO Cees Links. The firm will become part of Qorvo's IDP group and will be headed by Links.

Market research firm Gartner forecasts that Smart Home networking and IoT markets addressed by 802.15.4, ZigBee and Bluetooth Low Energy (BLE) technology will grow to \$2.3bn by 2020, and related smart markets such as retail, agriculture, automotive, lifestyle and commercial lighting will grow to \$4.9bn by 2020. Beyond smart home networking, demand is growing to connect a variety of devices

including HVAC (heating, ventilation and air conditioning), energy, security, home health, and remote controls utilizing ultra-low-power wireless data communication SoCs.

GreenPeak adds to Qorvo a legacy of engineering and system-level expertise in wireless RF technology, and offers a broad range of proprietary antenna diversity and multiple receiver architecture technologies. GreenPeak's solutions are claimed to offer superior range, robustness and best-in-class WiFi interference rejection with no latency in production-ready reference designs that can allow quick time to market for integration into smart home and IoT applications. In 2015, the firm shipped its 100 millionth ZigBee chip to the smart home market.

The acquisition is expected to close in second-quarter 2016.

www.greenpeak.com

www.qorvo.com

Qorvo offers maximum upstream bandwidth with new DOCSIS 3.1-ready reverse-path amplifiers

Qorvo has added ten DOCSIS 3.1-ready reverse-path amplifiers to its portfolio, enabling cable broadband service providers with the fastest data-rate capabilities required for high-bandwidth content uploading.

"Qorvo's reverse-path products equip cable providers with next-generation technology that is 'future-proof', offering faster upstream data-rate capability than the standard set forth by the current phase of DOCSIS 3.1," says Kellie Chong, director, CATV and Broadband Access products.

"Now, cable operators utilizing FTTH (fiber-to-the-home) and HFC (hybrid fiber coaxial) networks can provide higher bandwidth to meet the increasing subscriber demand for upstream and interactive content."

The new products for HFC and FTTH applications include the RFCA8830 and RFCA1008 reverse-path power amplifiers capable of operating up to 300MHz — well beyond the current return-path requirement of 204MHz. The newly released RFCM5304 includes integrated functionality such as power down, adjustable gain control (AGC), configurable current, first-stage amplifier bypass, and an on-chip thermal pin to sense IC temperature during operation.

Qorvo's reverse-path amplifiers are available in standard HFC; SOT-115J form factor; miniaturized multi-chip module (MCM); and monolithic microwave integrated circuit (MMIC) packages, including QFN and SOIC. These products

accelerate the deployment of high-speed CATV DOCSIS 3.1 networks while providing cable designers more flexibility in product design.

Qorvo claims that it offers the most DOCSIS 3.1-ready products, with more than 60 components including pre-driver gain blocks and push-pull and power doubler amplifiers employing the latest high-performance process technologies, including gallium nitride HEMTs, delivering superior linearity, output power and reliability. Qorvo's forward-path amplifiers operate from 45MHz to 1.2GHz with very high output (capable of 76dBmV composite power), extremely low distortion (lower than 70dBc), and input and output return loss of -20dB (typical).

Peraso raises \$20m Series C funding to boost WiGig sales

Fabless wireless chipset firm Peraso Technologies of Toronto, Canada, which develops wireless Gigabit (WiGig) chip-sets, has raised \$20m in a Series C funding round co-led by semiconductor manufacturer Integrated Device Technology Inc (IDT) of San Jose, CA, USA and existing investor Roadmap Capital, with additional financing from iNovia Capital.

Peraso is in production with WiGig IC solutions, addressing both next-generation WiFi opportunities in the consumer electronics (CE) space and outdoor devices in the 60GHz wireless infrastructure space compliant with the IEEE 802.11ad specification. The funding will be used to increase the capacity to address customer interest in all of the targeted market opportunities, including smartphones and virtual reality (VR).

"Multi-Gigabit wireless connectivity is something that more and more CE and wireless infrastructure manufacturers are seeking to incorporate in their products," says president & CEO Ron Glibbery. "Raising this capital allows Peraso to take our sales to the next level. Participation by IDT provides further validation of the market opportunity, and continued participation from Roadmap as well as iNovia speaks to the tremendous success the company has demonstrated in getting our first ICs to market," he adds.

"As wireless video and data volumes continue to explode, we believe WiGig will offer significant capabilities in addressing customer demands," says Sailesh Chittipeddi, chief technology officer and VP of global operations at IDT. "Peraso has demonstrated its ability to

develop the WiGig ecosystem that can address the demands of tomorrow."

"Peraso has demonstrated interoperability with a variety of available WiGig products which are based on either Intel or Qualcomm chips; this is an achievement which is essential to create a robust WiGig ecosystem," comments Imed Zine PhD, principal at Roadmap. "Additionally, Peraso is the only company offering a WiGig USB stick solution for legacy devices — something which is necessary for backward compatibility of existing WiFi equipment," he adds. "Peraso has demonstrated excellent product execution, which has resulted in leadership in multiple markets," comments Hugh Cleland, Roadmap co-founder & Peraso board member.

www.perasotech.com

Presto and Peraso co-developing 60GHz chip-set test

Presto Engineering Inc of San Jose, CA, USA (which provides product engineering & test and supply chain management) is collaborating with Peraso to develop a comprehensive test solution for Peraso's new 60GHz semiconductor products.

The Peraso chipset is currently in full mass production, with Presto providing test services at volumes of tens of thousands of parts per month. The new solution is the first phase of a project that will culminate in a high-efficiency test solution — 40x faster and capable of supporting high-volume production (millions of devices per month) for the consumer electronics market — planned for later in 2016. The 60GHz spectrum provides the foundation for WiGig technology and, with the increased demand for faster wireless connectivity, is quickly changing how users stream and connect to the Internet.

"Presto contributed expertise in high-frequency RF testing that was absolutely essential in our collaboration," says Peraso's CEO Ron

Glibbery. "Together, we were able to develop an innovative solution that provides reliable testing at speeds and costs sufficient to support our infrastructure integrated circuits. We are well on our way to completing a test solution that will reduce the cost of test by another 40x and support the high growth we anticipate with the introduction of products into the consumer electronics market," he adds.

"Collaboration with Peraso allowed us to combine our extensive experience in RF test with Peraso's expertise in 60GHz ICs to develop a solution for high-speed/low-cost testing where none previously existed," says Presto's CEO Michel Villemain. "We have already made significant progress in the next phase of the development that will offer significantly reduced test times and an overall lower cost," he adds. "Successful collaboration demonstrates the benefits we provide to fabless manufacturers, ranging from test services to comprehensive supply chain management."

The Peraso X610 WiGig chip-set constitutes a complete baseband to 60GHz solution and is compliant with the single-carrier modulation and coding schemes of the IEEE 802.11ad specification. Incorporating the PRS4601 WiGig baseband IC and the PRS1126 WiGig transceiver, the chip-set provides the core functionality for a low-cost, high-performance multi-gigabit per second solution that operates across the industrial temperature range. As manufacturers continue to seek solutions to bring WiGig-enabled devices quickly to market, Presto and Peraso aim to drive down the cost and implementation time with the new test solution.

The testbed consists of a set of custom hardware components mounted on an automated test equipment (ATE) load board, and associated test programs, that together provide comprehensive automated testing of both baseband (~2GHz) and high-frequency (60GHz) functionality.

www.presto-eng.com

Skyworks unveils SkyLiTE 2.0 front-end for carrier aggregation in LTE smartphones

Analog and mixed-signal semiconductor manufacturer Skyworks Solutions Inc of Woburn, MA, USA has unveiled SkyLiTE 2.0, its next-generation front-end solution powering LTE devices. The highly integrated platform provides smartphone makers with a complete front-end system that meets today's carrier aggregation (CA) design challenges.

Building on Skyworks' first-generation solution, the devices are baseband agnostic and incorporate amplification, switching, Wi-Fi filtering and coupler functionality required to support all major FDD/TDD bands. SkyLiTE 2.0 addresses new global downlink CA performance standards with integrated diplexer and harmonic filtering functionality and is optimized for regional use, providing OEMs with scalable and reconfigurable architectures for faster time to market. China-based global electronics and technology service provider OPPO is the first OEM to leverage the new SkyLiTE 2.0 in support of smartphones launched in April.

"Skyworks' newest family of SkyLiTE solutions enable us to offer smartphone manufacturers a high-performance, low-cost platform that delivers ultimate flexibility while addressing carrier aggregation challenges," says VP of marketing Carlos Bori. "With the enhanced capabilities of SkyLiTE 2.0, Skyworks is once again pushing the performance envelop and helping to simplify our customer's design process via fully integrated modules. We're particularly proud of our initial product engagement with OPPO and look forward to further enhancing their product offerings," he adds.

According to a September 2015 GfK Projector Model Report, LTE will represent about 49% of total handsets by 2016, up from 22% of total handsets in 2014.

SkyLiTE 2.0 addresses new global downlink CA performance standards with integrated diplexer and harmonic filtering functionality

Skyworks' SkyLiTE 2.0 solution targets this fast-growing market segment.

The SkyLiTE 2.0 platform comprises the following products:

- SKY77927-11 — a transmit/receive front-end module that offers a complete power amplifier and switching solution for 2G/3G/4G cellular handsets.
- SKY77928-11 — a transmit/receive front-end module that offers a complete power amplifier and switching solution for 2G/3G/4G cellular handsets with dual antenna.
- SKY77651-11 — a multi-mode multi-band power amplifier module that supports 3G/4G handsets and operates efficiently in CDMA, WCDMA and LTE modes. The module is fully programmable through a Mobile Industry Processor Interface (MIPI).
- SKY77652-11 — a multi-mode multi-band power amplifier module that supports 3G/4G handsets and operates efficiently in CDMA, WCDMA, TD-SCDMA and LTE modes. The module is fully programmable through a MIPI.

www.skyworksinc.com

Skyworks reduces year-on-year energy usage by 14%, water consumption by 17% and hazardous waste generation by 33%

Skyworks has released its 2015 Sustainability Report, a voluntary non-financial public document that addresses the firm's commitment to sustainable business practices. The report highlights continued efficiency improvements and provides an overview of Skyworks' initiatives in multiple areas, from its environmental efforts and labor practices, to its supply chain, health & safety programs, ethics policies and stewardship activities.

"As the world becomes increasingly connected, Skyworks is committed to delivering innovative solutions that meet our customers' challenges and reduce our footprint on the environment," says

Bruce J. Freyman, executive VP of worldwide operations. "We drive our sustainability efforts across all of our business practices, from the launch of our products to their end of life," he adds. "We are proud of our accomplishments in 2015 and our progress over the past five years. Skyworks remains focused on achieving further environmental improvements."

In 2015, Skyworks continued its trend of manufacturing products with decreased environmental impact. Year-on-year, Skyworks has:

- reduced its energy usage rate by 14%, saving 33 million kilowatt hours (enough energy to power 2100 households for one year);

- decreased its water consumption rate by 17%, saving 51 million gallons (enough indoor water for use by 351 families of four for one year);

- lowered its hazardous waste generation rate by 33% (eliminating the creation of nearly 1 million pounds of hazardous waste);
- completed a Sustainability risk assessment of all of its major suppliers; and
- dropped its total recordable incident rate by 11%.

A complete copy of the report and additional information can be found at the web link below.

www.skyworksinc.com/downloads/investors/skyworks_sustainability.pdf

TowerJazz adds 300GHz S4 process to SiGe Terabit Platform, enabling high-speed wireline communications

Specialty foundry TowerJazz (which has fabrication plants at Tower Semiconductor Ltd in Migdal Haemek, Israel, and at its subsidiaries Jazz Semiconductor Inc in Newport Beach, CA, USA and TowerJazz Japan Ltd) has announced its SiGe Terabit Platform, targeting high-speed wireline communications for the terabit age.

Wireline data traffic is increasing dramatically, with traffic at Google notably increasing by 50 times over the last 6–7 years (75% per year). Estimates vary, but experts agree on double-digit compound annual growth rates (CAGRs) and a 2020 market for high-speed optical components in excess of \$9bn.

TowerJazz says that it is addressing this market through a family of customized foundry silicon-germanium (SiGe) BiCMOS technologies and is now announcing availability of its highest-performance process to date: S4. Customers include manufacturers of components for carrying high-speed data traffic, such as Broadcom, Inphi, MACOM, Maxim, Maxlinear and Semtech.

Terabit Platform: HX, H2, H3, H4, S4

The SiGe Terabit Platform includes advanced CMOS, together with low-noise, high-speed and high-power SiGe devices and unique patented features that enable what is said to be best-in-class performance for the most demanding ICs in high-speed communication links. These components include trans-impedance amplifiers (TIAs) on the receive path and laser drivers on the transmit path.

The addition of S4 to the SiGe Terabit Platform extends the firm's history of process technologies that include HX and H2 (for 10–28Gbps), H3 with SiGe speeds of 280GHz (for up to 100Gbps) and now H4 and S4 with transistor speeds that exceed 300GHz and can cut power consumption by nearly an order of magnitude.

TowerJazz says two demonstrations, both in H3 technology, showcase the value of the SiGe Terabit Platform.

The first is the demonstration by University of California, Irvine (UCI) of TIA performance at 50Gbps, as reported at the 2015 IEEE Bipolar/BiCMOS Circuits and Technology Meeting (BCTM). "We measured up to 70Gbps data rate, using a NRZ

(non-return to zero) architecture with an eye of 50Gbps," notes Dr Payam Heydari, IEEE Distinguished Lecturer & Full Professor of Electrical Engineering and Computer Science. "We estimate this chip will consume less than 0.5mW per GHz."

The second is Bell Labs (the innovation engine of Nokia) with its demonstration of a 112Gbps transceiver, as reported at the 2015 IEEE Compound Semiconductor IC Symposium (CSICS). "This is the world's first demonstration of a >100GBs serial datalink built with a silicon IC," says lead author Dr Shahriar Shahramian (Bell Labs technical manager). "56GBaud, 4-PAM transmission over 2km of SSMF (single-mode fiber) has been experimentally demonstrated," he adds.

"These demonstrations used our H3 process and each represents record performance in data rate, as well as demonstrating new standards in data transmission over single-mode fiber," says TowerJazz executive director & fellow Dr David Howard. "S4 enables the SiGe Terabit Platform to deliver higher speed and lower power."

www.towerjazz.com

Anokiwave launches X-band front-end IC

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) and active electronically scanned array (AESA) markets, has extended its X-band IC product line with the gallium arsenide (GaAs)-based AWMF-0106 front-end IC, completing the firm's family of X-band radar solutions for commercial radar and 5G communications markets.

The AWMF-0106 is an integrated power amplifier (PA), low-noise amplifier (LNA), limiter and T/R (transmit/receive) switch intended to provide a low-noise, medium-power front end for the silicon-based AWS

-0103 and -0105 high Rx-input-linearity X-band core IC solutions.

The device also includes Tx output power detection, active bias of the power amplifier stages, and active self-bias of the low-noise amplifier stages. Dual Rx outputs are provided to enable dual-Rx beam phased-array applications. Used with the firm's core IC solutions, the front-end IC enables planar antenna design at X-band with reduced system size, weight and cost.

"This new IC, together with the AWS-0103 X-band core IC, completes a plug-and-play chip-set for X-band radars," says CEO Robert Donahue. "The parts are designed to work together with the requisite

beam-steering and taper controls, output PA, input LNA, and front-end switch and limiter," he adds. "We believe this solution is the most integrated X-band AESA solution available on the market."

The AWMF-0106 is packaged in a 56-lead PQFN low-profile surface-mount plastic package with dimensions of 7mm x 7mm x 0.9mm, easily fitting within the typical 15mm lattice spacing at 10GHz. The device features ESD protection and is realized in 0.25µm GaAs technology.

Pilot production deliveries are available now, with full production quantities available in September.

www.anokiwave.com

ACCO raises \$35m in funding round led by Bpifrance Funding to support launch of newest generation of RF CMOS front-ends and R&D on next-generation products

ACCO Semiconductor Inc of Sunnyvale, CA, USA, a fabless provider of RF front-end components manufactured using standard high-volume bulk CMOS processes for smart-phone and Internet of Things (IoT) applications, has closed a \$35m funding round — claimed to be one of the largest funding commitments to a private semiconductor company in the last 12 months. ACCO, a French-American company whose main R&D center is based near to Paris, is currently accelerating its business into various brands of LTE smart phones now found in several countries in Asia and Europe.

ACCO has developed and patented RF front-end technology for mobile communications devices (power amplifiers and antenna switches) that uses standard complementary-metal-oxide-semiconductor (CMOS) processing. The firm's bulk CMOS cellular power amplifier offers highly linear performance yet can operate at high power without breakdown or degradation, which was previously considered impossible, it is claimed. The use of CMOS in the RF front-end improves functionality at a reduced size and cost for both smart-phones and the Internet of Things, as well as leveraging the mature, reliable, high-volume CMOS supply chain.

Strategy Analytics estimates that the mobile power amplifier (PA) market at \$3.5bn, representing a significant business opportunity for ACCO. The growth projections for cellular-connected IoT devices will further expand this potential. "Designing the RF front-end of an LTE phone to support regional and global cellular bands has gotten extraordinarily difficult," notes Christopher Taylor, director of RF & Wireless Components at Strategy Analytics. "Starting with monolithic integration of the PAs and switches, bulk CMOS has great potential for simplifying the RF front-end and making it more space efficient and less costly — satisfying a critical need in the cell-phone industry," he adds.

This latest round is led by the French national industrial bank Bpifrance, through its growth fund Large Venture, with participation from investors in both the USA and France including Foundation Capital, Pond Ventures, Partech Ventures, Omnes Capital, Siparex Group and A Plus Finance. The investment is timed to support the launch of ACCO's newest generation of industry-standard RF front-end CMOS solutions and will provide working capital as well as R&D funds for next-generation products while enabling the company to add incre-

mental local support for its increasing customer base.

ACCO's cellular radio component "dramatically reduces cost and complexity," says Nicolas Herschtel, investment director at Bpifrance Large Venture. "We believe ACCO's highly integrated technology perfectly fits the industry requirements and that this new equity round will enable the company to scale and achieve its commercial goals," he adds.

"ACCO's proprietary and patented high-breakdown voltage CMOS transistor has broken the code on size and power efficiency in 4G power amplifiers," comments Rich Redelfs, general partner at Foundation Capital and chairman of ACCO. "ACCO now has the resources to scale and obsolete expensive GaAs power amplifiers used in today's mobile phones," he adds.

"The commitment from Bpifrance and other participating investors validates the importance of building the RF front-end in bulk CMOS — the process used in nearly the entire electronics industry," says ACCO's president & CEO Greg Caltabiano. "Not only is this important for smart phones, but also critical to IoT where highly integrated, highly functional, low-cost solutions will drive success of the entire market."

www.acco-semi.com

Skyworks launches front-end low-noise amplifiers for set-top box applications

Skyworks has launched two new broadband 75Ω monolithic microwave integrated circuit (MMIC) front-end, low-noise amplifiers (LNAs) designed specifically for set-top box applications.

Fabricated using silicon-germanium (SiGe) BiCMOS technology, the SKY65450-92LF (with bypass mode) and the SKY65452-92LF provide high linearity and what is claimed

to be excellent gain over a wide frequency range (40MHz to 1GHz) with minimal external components, enabling OEMs to leverage cost efficiencies through lower bill of materials.

In addition, Skyworks' new LNAs offer low current consumption and low noise figure (2.9dB typical), delivering energy-saving features, and are packaged in compact

6-pin SC-70 (SC-88, SOT-363) footprint of 2.0mm x 2.2mm x 0.95mm.

The devices can also be used for cable modem and cable home gateways, personal video recorder (PVR) and digital video recorder (DVR) applications.

www.skyworksinc.com/Product/3145/SKY65450-92LF

www.skyworksinc.com/Product/3146/SKY65452-92LF

Peregrine's new RF switch exceeds linearity requirements for dual-band DOCSIS 3.1

Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has launched the UltraCMOS PE42723, an RF switch with what is claimed to be the highest linearity specifications on the market.

As an upgraded version of the PE42722, the new RF switch offers enhanced performance in a smaller package. Like its predecessor, the PE42723 exceeds the linearity requirements of the DOCSIS 3.1 cable industry standard and enables a dual upstream/downstream band architecture in cable customer premises equipment (CPE) devices.

The cable industry faces the challenge of supporting the consumer's increasing demand for more high-speed home data. The rapid adoption of video-streaming services is compounding the problem and putting enormous strain on the broadband ecosystem, from CPE devices to cable infrastructure, says Peregrine. As predicted in the Cisco Visual Networking Index (VNI), 5 million years of video content will cross the Internet each month in 2019. This means nearly a million minutes of video will be streamed or downloaded every second. To keep up with consumer demand, in October 2013 the cable industry announced the DOCSIS 3.1 standard, offering multi-gigabit throughput.

The standard set an ambitious goal for the industry, and one of the tasks challenges was to support the new linearity requirements and harmonics.

The PE42722 and PE42723 switches offer what is claimed to be a unique approach to solving the DOCSIS 3.1 linearity challenge when supporting a dual upstream/downstream band architecture. CPE devices (such as set-top boxes, cable modems and home gateways) previously supported only one upstream/downstream band combination. The PE42722 and PE42723 are said to be the only RF switches that enable dual upstream/downstream bands to reside in the same CPE device. By using this dual-band architecture, CPEs can comply with the DOCSIS 3.1 cable industry standard, and multi-service operators (MSOs) have the flexibility to offer customers new and expanded services. MSOs also benefit from the switches supporting both DOCSIS 3.0 and 3.1 requirements, allowing a simple and cost-effective transition to DOCSIS 3.1.

"DOCSIS 3.1 represents a giant leap forward in achieving multi-gigabit data rates," comments Jim Koutras, director of product management at RF/analog and mixed-signal semiconductor firm MaxLinear of Carlsbad, CA, USA. "With their exceptional linearity, Peregrine's PE42722 and PE42723 RF switches simplify the transition from DOCSIS 3.0 to 3.1," he adds.

"The ability to support dual upstream/downstream bands in the same CPE device is a critical enabler to making DOCSIS 3.1 a reality."

Before the introduction of the PE42722 in 2013, no switch had met the linearity requirements necessary to support a dual upstream/downstream band architecture, says Peregrine. To create this architecture, the switch is placed directly at the cable modem (CM) F-connector before the filters and must comply with the stringent DOCSIS 3.1 CM spurious emissions requirements of -50dBmV . Such a low spurious level requires the switch harmonic performance to be greater than -115dBc . The PE42722 and PE42723 are the only RF switches available that can achieve these high harmonic requirements, it is reckoned.

Covering a frequency range of 5–1794MHz, the PE42723 is a reflective SPDT RF switch that delivers high linearity and exceptional harmonic performance. At 17MHz, the second harmonic is -121dBc and the third harmonic is -140dBc . The switch's low insertion loss (0.3dB at 1218MHz) preserves noise figure and receiver sensitivity and achieves superior signal quality, along with providing high isolation of 54dB at 204MHz. The PE42723 has 3kV ESD protection on all pins.

www.psemi.com/products/rf-switches/pe42723

Peregrine's dual upstream/downstream-band RF switches designed into multiple DOCSIS 3.1-certified cable modems

Peregrine's high-linearity RF switches have been designed into multiple DOCSIS 3.1-certified cable modems. CableLabs, the R&D consortium that develops the DOCSIS specification, has certified the first DOCSIS 3.1 cable modems. Of these, Peregrine's UltraCMOS PE42722 and PE42723 RF switches have been designed into the cable

modems that feature a band-select feature.

"As the world-wide cable industry transitions from DOCSIS 3.0 to 3.1 technologies, MSOs need to future-proof their CPE devices with higher flexibility in addition to backward compatibility," says Duncan Pilgrim, VP & general manager of Peregrine's high-performance analog (HPA)

business unit. "Peregrine's high-linearity RF switches rise to the challenge and deliver a key selling feature for cable modem vendors," he adds. "By offering a dual-band architecture, our switches enable a simple transition from DOCSIS 3.0 to 3.1 service."

www.psemi.com/products/rf-switches/pe42722

Raytheon UK and Newcastle University produce SiC-based analog circuitry for high-temperature and harsh-environment monitoring applications

Lateral small-signal JFET enables high-temperature, low-noise amplifier circuits

The Semiconductor's business unit of Raytheon UK in Glenrothes, Scotland (a subsidiary of Raytheon Company of Waltham, MA, USA) and Newcastle University's School of Electrical and Electronic Engineering have collaborated to produce silicon carbide (SiC)-based amplifier circuitry with operational amplifier (op amp)-like characteristics. Once integrated and packaged into a single device, the amplifier has the potential for use in monitoring and closed-loop control circuitry applications within a variety of harsh-environment industries, such as aerospace, oil & gas, geothermal energy and nuclear, says Raytheon.

"To date, the focus on silicon carbide semiconductors has been power electronics and exploiting the material's ability to dissipate internally generated heat," notes Dr Alton Horsfall, reader in Semiconductor Technology at Newcastle University. "For this project though we've focussed on creating circuitry that can operate in high temperature and other harsh environments. This could therefore lead to condition monitoring circuitry mounted on gas turbines or within the primary coolant loop of a nuclear reactor,

which runs at about 350°C," he adds.

At the heart of the amplifier circuit is a lateral small-signal junction field-effect transistor (JFET). This offers a significant improvement in reliability in hostile environments, because of the lack of a gate oxide layer. This results in greater stability in the threshold voltage and a reduction in the intrinsic noise, making these structures suitable for the realization of high-temperature, low-noise amplifier circuits. The current circuit is a fully differential, three-stage amplifier, with a source follower final stage, optimized to operate on a $\pm 15V$ supply. Modifications enable voltage supplies of $\pm 45V$ to be utilized to increase the voltage headroom of the circuit.

Laboratory tests have shown the amplifier circuit has an open-circuit gain over 1500 at room temperature. A high-temperature gain of 200 has been recorded at 400°C, but this is limited by the passive components used in the circuit.

The recent monolithic integration of the amplifier into a single chip should deliver the kind of op amp capabilities with which electronics engineers the world over are famil-

iar, says Raytheon.

"Though we're not the only ones to be exploring the suitability of silicon carbide for control and monitoring applications in harsh environments, we believe this amplifier circuit represents the furthest anyone has gone down the lab-to-fab route," states Phil Burnside, business development manager of Raytheon UK's Semiconductors Business Unit. "In this instance, it is Newcastle University's design expertise and understanding of harsh environments, combined with our silicon carbide processing expertise, that have the potential to result in the full commercialization of a high-temperature version of a fundamental electronic building block, the humble op amp."

A technical demonstrator of the amplifier circuit is on Raytheon UK's stand at Power Conversion Intelligent Motion (PCIM) Europe 2016 in Nuremberg, Germany (10–12 May). Also at PCIM Europe, on 11 May in the Industry Forum Area, Raytheon UK is on a panel session, organized by Yole Developpement, regarding the use of power electronics in high-temperature applications.

www.raytheon.co.uk

Advantech Wireless awarded Via Satellite Excellence Award for 'Vertical Impact – Military' sector

At the Satellite 2016 conference in National Harbor, MD, USA (7–10 March), Advantech Wireless received the Via Satellite Excellence Award for 'Vertical Impact – Military', recognizing it for innovation in support of the military sector.

One of Advantech Wireless' accomplishments this year was the introduction of second-generation GaN products for tactical markets.

These are high-performance block-up converters and high-power amplifiers that have overall size, weight and power reductions of about 50% of previous versions. For example, applying these amplifiers in troposcatter communications enables a new class of man-portable terminals, enabling new communications applications for tactical operations to reduce size and

weight, while increasing effectiveness of military wireless networks.

"We began our GaN technology initiative because we knew that ever-increasing bandwidth demands would require better performance," says CEO David Gelerman. "We continue to invest in research and development to produce higher-power and more efficient products."

www.advantechwireless.com

US Air Force offering \$13.5m cooperative agreement to develop large-diameter SiC substrates and epi

AFRL targeting affordable, high-quality, large-diameter SiC substrates and epi from pure-play supplier

The US Department of Defense's Air Force Research Laboratory, Sensors Directorate, Devices for Sensing Branch (AFRL/RYYD) has issued a Request For Information (RFI) titled 'Development of Large Diameter Silicon Carbide Substrate and Epitaxial Processes' (solicitation number RFI-AFRL-RQKS-2016-0002) to obtain information about potential sources with demonstrated expertise and experience to meet the Air Force's technical development requirements in large-diameter silicon carbide substrates and epitaxial processes.

The Air Force need for sensors extends from DC to the radio-frequency spectra focusing on microwave through sub-millimeter wave (300MHz-300GHz). Exploitation of homo/hetero-epitaxial devices fabricated on SiC holds promise for revolutionary improvements in the cost, size, weight and performance of a broad range of military RF and power management and distribution components, it adds.

Gallium nitride high-electron-mobility transistors (HEMTs) are rapidly becoming the technology of choice for high-power RF applications, but GaN RF devices are dependent on the use of high-quality, semi-insu-

lating silicon carbide (SiC) substrates, notes the RFI. The combination of high voltage and current handling as well as switching frequency capabilities make SiC-based power devices a viable alternative to silicon technology, it adds.

The fabrication of SiC power devices requires homo-epitaxial growth of precisely doped SiC layers ranging in thickness from a few microns to >100µm, depending on the voltage requirements. Critical to the realization is the availability of affordable, high-quality, large-diameter SiC substrates and epitaxy from a pure-play supplier.

AFRL says that it is therefore interested in advancing the technological state-of-the-art with respect to SiC growth and fabrication.

Key technical requirements related to the RFI include:

- to demonstrate the axial gradient transport (AGT) crystal growth process to enhance quality, producibility and furnace throughput for conducting (N-doped) and semi-insulating (V-doped) SiC boules up to 200mm diameter;
- to demonstrate vanadium as a background dopant to achieve uniform boule radial and lateral resistivity

of >10¹²Ω-cm for 4H- and 6H-SiC boules up to 200mm diameter;

- to demonstrate the fabrication and polishing of conducting and semi-insulating SiC substrates up to 200mm diameter that exceed existing state-of-the-art practices;
- to demonstrate substrate and epi defect reductions that are an order of magnitude below existing industry availability, enabling cost reductions in excess of 50% for both substrates and epiwafers; and
- to demonstrate SiC epi growth rates exceeding 60µm/hr of high-quality epitaxial layers with uniform thickness and doping densities on wafers up to 200mm diameter that are supportive of a broad range of device structures, including but not limited to Schottky diodes, metal-oxide-semiconductor field-effect transistors (MOSFETs), junction field-effect transistors (JFETs), and bipolar junction transistors (BJTs).

The deadline for responding to the RFI was 18 April. The maximum award for funding under a cooperative agreement resulting from the RFI is \$13.5m.

www.fbo.gov/spg/USAF/AFMC/AFRLWRS/RFI-AFRL-RQKS-2016-0002/listing.html

Advantech Wireless named finalist of Les Mercuriades 2016

The Fédération des Chambres de Commerce du Québec (FCCQ) for Innovation and International Market Development has named Advantech Wireless Inc of Montreal, Canada (which manufactures satellite, RF equipment and microwave systems) as a finalist in the 36th edition of the Les Mercuriades 2016 business contest for innovation and international market development of its second-generation gallium nitride-based satcom systems and advanced satellite networking technologies.



Mario Leclerc of La Coop fédérée and Joe D'Onofrio, David Gelerman, Harry Jiao and Yves Lamontagne of Advantech Wireless.

Since 1981, Les Mercuriades has celebrated entrepreneurship and outstanding achievements of Québec businesses, rewarding small- & medium-sized enterprises (SMEs) and large companies, especially for the quality of management, development strategies, long-term vision and impact on the community, in a total of 12 categories. Winners of Les Mercuriades will be announced at the grand gala evening on 16 May at Palais des Congrès de Montréal.

www.advantechwireless.com

CISSOID delivers prototypes of three-phase 1200V/100A SiC MOSFET intelligent power modules to Thales

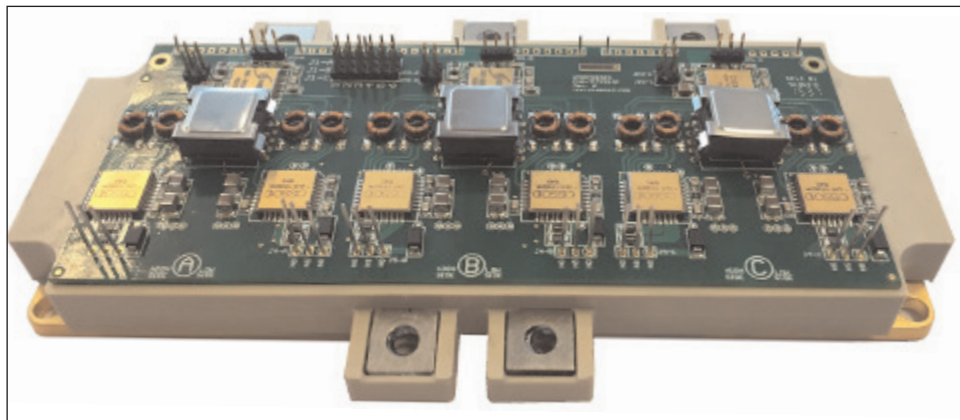
Module to boost power converter density in 'More-Electrical Aircraft'

Fabless high-temperature and extended-lifetime semiconductor firm CISSOID of Mont-Saint-Guibert, Belgium has delivered the first prototypes of a three-phase 1200V/100A silicon carbide (SiC) MOSFET intelligent power module (IPM) to Thales Avionics Electrical Systems. Developed with the support of Clean Sky Joint Undertaking, the module will help to increase power converter density (by decreasing weight and size) for power generation and electromechanical actuators in 'More-Electrical Aircraft'.

CISSOID says that the IPM offers optimal integration of the gate driver together with power transistors in order to take advantage of the full benefits of SiC, i.e. low switching losses and high operating temperature. Leveraging its HADES2 isolated gate driver (which incorporates years of development in driving SiC transistors), it combines advanced packaging technologies, enabling reliable operation of power modules in extreme conditions, the firm adds.

For the new aerospace module, a three-phase power inverter topology was selected while other topologies are being investigated for hybrid electric vehicle (HEV) and railways projects. In this three-phase topology, each of the six switch positions includes a 100A SiC MOSFET transistor and a 100A SiC Schottky free-wheeling diode. The devices can block voltages up to 1200V, which provides enough headroom against over-voltages in a 540V aerospace DC bus, and the module is designed to be easily upgraded with 1700V/150A SiC devices. The transistors have a typical on-resistance of 12.5mΩ or 8.5mΩ, depending on their current rating (either 100A or 150A).

During the design of the module, special care was placed on thermal aspects, says the firm. First, all the materials have been selected to



allow reliable operation at high junction temperatures (up to 200°C, with peaks at 225°C) in order to decrease cooling requirements. This materials selection also enables high case and storage temperatures (up to 150°C). Finally, the module is based on high-performance materials such as an AlSiC base-plate, AlN substrates and silver sintering in order to offer near-perfect CTE (coefficient of thermal expansion) matching with SiC devices and high robustness against thermal and power cycling.

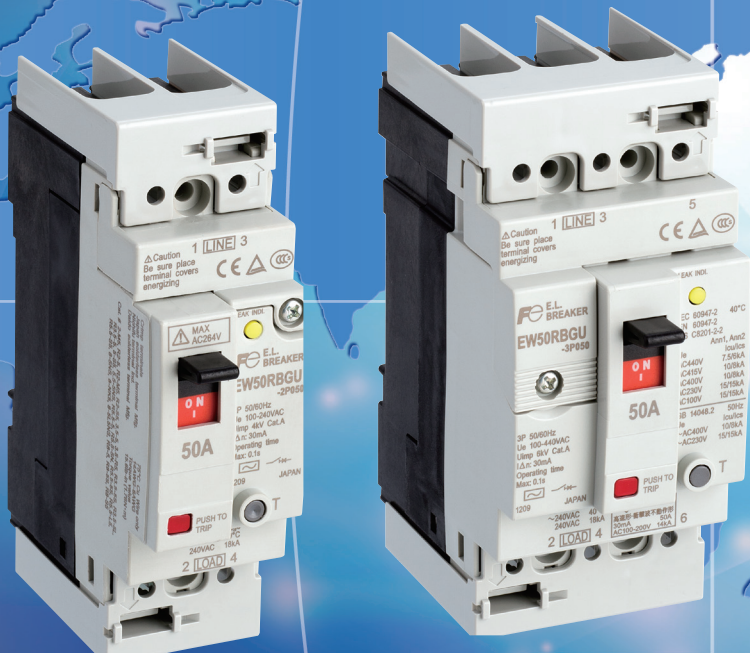
Minimizing parasitic inductances allows faster SiC transistor switching and lower switching losses. An IPM also offers a plug-and-play solution to power electronic designers, who can hence save a lot of time in the design of the gate driver board (which is particularly challenging with SiC transistors). They can then focus on the design of high-density power converters, taking advantage of SiC

Co-designing the gate driver with the power module in a single IPM allowed CISSOID to optimize the gate driver circuit, taking into account parasitic inductances of the power module while minimizing them when possible. Minimizing parasitic inductances allows faster SiC transistor switching and lower switching losses. An IPM also offers a plug-and-play solution to power electronic designers, who can hence save a lot of time in the design of the gate driver board (which is particularly challenging with SiC transistors). They can then focus on the design of high-density power converters, taking advantage of SiC.

"It was a pleasure to work with CISSOID team in the frame of this Clean Sky program. They showed a great flexibility in proposing us solutions addressing the requirements of the next generation of high-density power converters for the More-Electrical-Aircraft," comments Taoufik Bensalah, Power Converter Design Team Manager at Thales Avionics. "We thank Clean Sky for making this cooperation possible, which is a good example of CISSOID combined expertise in packaging and circuit design," adds Etienne Vanzieleghem, VP engineering at CISSOID. "This project was also an opportunity to strengthen our cooperation with PRIMES platform in Tarbes, which is hosting the CISSOID packaging team."

www.cissoid.com

Fuji Electric Lambda Series New, Compact, Powerful



The New Generation of Low Voltage Earth Leakage Circuit Breakers

- ① Compact! Ground Fault Protection Built in One Unit for Space Saving Designs
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Freebird partners with EPC to develop radiation-hardened GaN power conversion systems for satellite and harsh-environment applications

Freebird Semiconductor Corp of North Andover, MA, USA, which manufactures high-reliability gallium nitride (GaN) high-electron-mobility transistor (HEMT) products for power semiconductor technologies in the commercial space-flight high-reliability sector, has signed an agreement to develop products for use in high-reliability, space and harsh-environment applications based on the enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistor (FET) technology of Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA.

"Freebird is focused upon developing components and circuits to be used in highly efficient, radiation-hardened power conversion systems for use in harsh environment and space applications," says Freebird's president & CEO Dr Simon Wainwright. "GaN technology will permit space applications to utilize the latest in high-performance semiconductor material, whereas when using silicon-based components in these applications produces systems that are behind the latest performance curves," he adds.

"The superior conductivity and switching characteristics of GaN

devices allow designers to greatly reduce system power losses, size, and weight," notes EPC's CEO & co-founder Dr Alex Lidow. "Given GaN's superior state-of-the-art performance, coupled with its demonstrated ability to operate reliably under harsh environmental conditions and high radiation, GaN devices have a very bright future in space applications," he believes.

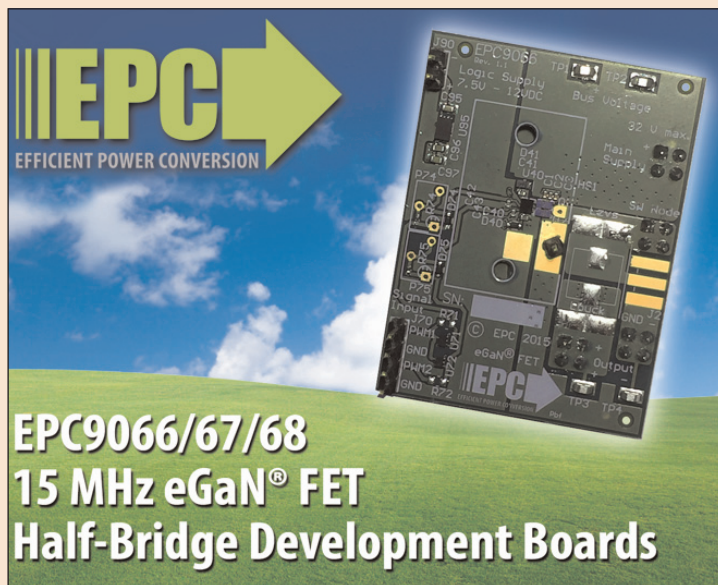
In addition to collaborating on power systems product development, the two firms aim to publish the results of their work and give joint presentations at conferences.

www.freebirdsemi.com

EPC offers 15MHz half-bridge development boards using eGaN FET synchronous bootstrap augmented gate drive

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, has made available the EPC9066, EPC9067 and EPC9068 development boards (featuring 40V-rated EPC8004, 65V-rated EPC8009 and 100V-rated EPC8010 eGaN FETs, respectively), which can be configured as either a buck converter or as a ZVS class-D amplifier.

The firm says that the boards provide an easy-to-use way for power systems designers to evaluate the performance of GaN transistors, enabling designers to get their products into volume production quickly. All three boards feature a zero reverse recovery (QRR) synchronous bootstrap rectifier augmented gate driver to increase efficiency at high-frequency operation, up to 15MHz. The boards can produce a maximum output of 2.7A in the buck and ZVS class-D amplifier configurations. Loss



reduction is realized across the entire current range.

The boards are 2" x 1.5" and are laid out in a half-bridge configuration. Each board uses the Texas Instruments LM5113 gate driver with supply and bypass capacitors. The gate driver has been configured with a synchronous FET bootstrap circuit featuring the 100V, 2800m_A EPC2038 eGaN FET, which eliminates the driver losses

induced by the reverse recovery of the internal bootstrap diode. The boards have various probe points and Kelvin measurement points for DC input and output. In addition, they provide the capability to install a heat-sink for high-power operation.

The EPC9066/9067/9068 development board are priced at \$158.13 each and are available now from distributor Digi-Key. Quick Start Guides, containing set-up procedures, circuit diagram, bill of material, and Gerber files for the boards are provided on-line.

<http://digikey.com/Suppliers/us/Efficient-Power-Conversion.page>
<http://epc-co.com/epc/Products/DemoBoards.aspx>

VisIC launches 650V half-bridge evaluation board

VisIC Technologies Ltd of Nes Ziona, Israel, a fabless developer of power conversion devices based on GaN metal-insulator-semiconductor high-electron-mobility transistors (MISHEMTs) founded in 2010, has introduced a half-bridge evaluation board using its VT15R65A GaN Power ALL Switch (Advanced Low Loss Switch) in a 'work horse' half-bridge power conversion circuit.

The VT15R65A-EVBHB exhibits 98.5% power conversion efficiency operating at a switching frequency of 200kHz. Silicon MOSFET-based systems with similar efficiencies in this power range are limited to 60kHz or less, and competitive GaN devices have only shown similar efficiency at 100kHz, the firm claims.

The evaluation board can be easily configured into any half bridge-based topology such as synchronous boost or buck conversion. It can also operate in a pulsed switching configuration for evaluating transistor waveforms. VisIC's GaN ALL Switch is driven by industry-standard high-frequency drivers.

Providing power conversion system designers with a complete, working power stage, the evaluation board includes high-frequency drivers for two VT15R65A power switches in a half-bridge configuration, the gate driver power supply, and a heat-sink. With what is claimed to be the lowest R_{dson} among 650V GaN transistors or switches, the VT15R65A achieves extremely efficient power conversion

with switching transitions exceeding 100V/nS, the firm adds.

Configured as shipped with V_{IN} up to 400V_{DC}, the VT15R65A-EVBHB supports 2kW loads. The half-bridge evaluation board has a built-in planar inductor but also has connections for external power inductors and capacitors to allow users to operate the board in higher power modes.

The user needs to provide an external 15V_{DC} AUX voltage at a two-pin input. On-board voltage regulators create the required voltages for the logic circuits and gate drives. The high-voltage DC BUS input is connected using screw connections and the output bus is also connected via screw-type connection.

www.visic-tech.com

ALLOS transfers GaN-on-Si power semiconductor epitaxial technology to customer

Engineering & licensing firm ALLOS Semiconductors GmbH of Dresden, Germany has transferred its latest-generation gallium nitride on silicon (GaN-on-Si) epiwafer technology to what it describes as a major international industry player that has systematically invested in GaN-on-Si epitaxy and device processing in recent years, as part of a comprehensive joint project to accelerate the customer's GaN-on-Si power semiconductor product development.

ALLOS has completed the first phase of the customer project to develop market-ready GaN-on-Si power semiconductor products. The project aims to improve the performance of upcoming products and accelerate time-to-market.

In the first project phase, ALLOS transferred its newest GaN-on-Si power semiconductor epi technology to the client in less than 12 weeks, including comprehensive training of engineers, detailed documentation, and proof of reproducibility.

"ALLOS capability to make a complete technology transfer possible in just 12 weeks, our guarantee of

wafer spec achievement, and ALLOS independent IP platform makes a decisive difference not only for newcomers but also for experienced players in the GaN-on-Si field," says CEO Burkhard Slischka.

The customer was the first to receive this latest generation of ALLOS' technology, which has been developed and fundamentally improved over the last 18 months. The technology is designed for manufacturability and combines what is said to be excellent crystal and electrical properties with processing properties such as zero melt-back, zero cracks and controlled wafer bow. Enabled by good yield, fast growth times and the use of various multi-wafer reactor platforms, production cost per wafer area is on the same level as for existing GaN-on-sapphire LED wafers, it is reckoned, opening the way for GaN to compete with established power semiconductor technologies. "You need to combine and balance these properties in a wafer technology platform right from the beginning," believes chief technology officer Dr

Atsushi Nishikawa regarding ALLOS' manufacturability strategy. "Many organizations who work on GaN-on-Si epitaxy achieve promising results on R&D level but don't reach the quality and reproducibility required in order to progress towards production."

In the second project phase, ALLOS' and the customer's joint team are now improving the existing device technology to market-readiness.

"In addition to ALLOS' established role as a provider of turn-key GaN-on-Si epiwafer technology, a main part of ALLOS' contributions to the project is in working on device processing and characterization topics in joint teams with the customer," says Slischka. "Results from the project already show that the team can successfully combine ALLOS' technology and independent IP platform with the very good development achievements of the customer from the recent years... The customer is able to achieve product development results faster and with significantly reduced cost and risk, while leveraging prior R&D investments."

www.allos-semiconductors.com

Wolfspeed's GaN RF devices demonstrate reliability for harsh space environments

Wolfspeed of Research Triangle Park, NC, USA says that its GaN-on-SiC RF power transistors have completed testing to demonstrate compliance with NASA reliability standards for satellite and space systems. The firm's proven GaN-on-SiC fabrication processes have delivered over 100 billion total hours of field operation with a best-in-class FIT (failure-in-time) rate of less than 5 per billion device hours for discrete GaN RF transistors and multi-stage GaN MMICs.

Wolfspeed partnered with RF & microwave component firm KCB Solutions LLC of Shirley, MA, USA to conduct a comprehensive testing program to demonstrate that its GaN-on-SiC devices meet NASA EEE-INST-002 Level 1 reliability and performance standards, derived from the MIL-STD requirements for Class S and Class K qualifications.

"Customers now have the ability to specify our GaN RF devices in the most critical aerospace, military, and satellite electronics systems," says RF & microwave director Jim Milligan. "Our proven GaN-on-SiC technology enables design engineers to make

smaller, lighter, more efficient and more reliable solid-state power amplifiers than are possible with conventional traveling-wave tube (TWT) amplifiers or those designed with gallium arsenide devices. Now, aerospace designers can achieve higher-performance radar and communications systems with a significantly lighter payload and longer operating life," he adds.

"As an AS9100-certified facility with an extensive history of supplying Class S and Class K devices for aerospace and satellite electronic systems, KCB Solutions implemented a comprehensive testing program in conjunction with Wolfspeed to ensure that their GaN process was capable of producing devices that meet these demanding NASA standards," notes KCB's president Ralph Nilsson. "This testing regime was derived from the established MIL-STD qualification requirements of Class S and Class K and included evaluation for ESD, intrinsic reliability, SEM analysis, and radiation hardness."

The testing program consisted of five test procedures conducted by KCB on Wolfspeed's 25W GaN-on-SiC

HEMT CGH40025F and its 25W two-stage X-band GaN MMIC CMPA801B025F devices, which are produced using Wolfspeed's proven 0.4 μ m G28V3 fabrication process. Both demonstrated no significant RF performance change after undergoing all the test procedures, including exposure to a cumulative dose of radiation exceeding 1Mrad.

Almost all space and satellite equipment manufacturers require electronic components to meet established high-reliability military qualification standards in order to be specified into their communications and radar systems, notes Wolfspeed. These standards include MIL-PRF-38535 Class S for single chips and MIL-PRF38534 Class K for multichip modules. Collaboration with KCB allows Wolfspeed to upscreen its GaN devices to ensure they are compliant with the NASA EEE-INST-002 level 1 standards based on Class S and K. As a result of KCB's testing, several firms have already specified Wolfspeed's GaN devices for their space applications.

www.kcbolutions.com
www.wolfspeed.com/RF

Kyma adds gallium oxide epiwafers to product portfolio

Kyma Technologies Inc of Raleigh, NC, USA (which provides crystalline nitride materials, crystal growth and fabrication equipment, and power switching electronics) has added β -Ga₂O₃ epitaxial wafers to its growing range of materials.

Crystalline beta gallium oxide is a promising wide-bandgap semiconductor (WBG) material due in part to its large bandgap of 4.8–4.9eV, its high breakdown field of 8MV/cm and its high dielectric constant of 10 which, together with its electron mobility of up to 300cm²/V-s, translate to a high-voltage Baliga figure of merit (HV-BFOM) that is over 3000 times greater than that of silicon, over 8 times greater than

that of silicon carbide (4H-SiC), and more than 4 times greater than that of gallium nitride. Also, its high-frequency Baliga figure of merit (HF-BFOM) is ~150 times that of silicon, ~3 times that of 4H-SiC, and 50% greater than that of GaN.

Benefiting from a long-time collaborative partnership with leading scientists in the Sensors Directorate of the Air Force Research Laboratory (AFRL) at Wright Patterson Air Force Base, Kyma's technical team recently began developing processes for the growth of β -Ga₂O₃ on a number of substrates including homoepitaxial growth on commercially available bulk β -Ga₂O₃ substrates. The team has so far demonstrated high

growth rates (>3 μ m/hr) and high-quality epilayers of several microns in thickness. Undoped films show semi-insulating behavior, and n-type films appear to be well behaved, with electron concentrations in the range 10¹⁷–10¹⁸cm⁻³. More detailed characterization of these materials is ongoing.

Kyma believes β -Ga₂O₃ represents a new frontier in the continuous search for higher-performance semiconductor devices. "It is exciting to be able to leverage our core competencies to address this exciting newcomer to the advanced semiconductor materials and device technology space," says CEO Keith Evans.

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Aixtron's AIX G5+ C qualified for manufacturing of high-voltage GaN-on-Si materials in joint project with imec

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany says its G5+ C multi-wafer batch metal-organic chemical vapor deposition (MOCVD) platform has been qualified for the manufacturing of specific buffer layers as a result of the collaboration on high-voltage gallium nitride (GaN) power device technology with nanoelectronics research center imec (Interuniversity Microelectronics Centre) of Leuven, Belgium.

In combining their expertise, Aixtron has joined imec's industrial affiliation program for high-power GaN-on-Si device technology. Within the framework of this program, Aixtron's 5x200mm G5+ MOCVD platform was qualified to integrate imec's proprietary high-voltage dispersion-free buffer technology to the 5x200mm G5+ MOCVD platform. Aixtron says that this goal has been reached in a very short time span and demonstrates the high level of technology readiness of the AIX G5+ C system.



"The accomplishment was mainly based on the rapid implementation of the portfolio of qualified layer processes by the epitaxy teams of imec and Aixtron building up the complex epitaxial material stack targeting high-voltage switching applications," says Dr Frank Wischmeyer, VP marketing & business development Power Electronics at Aixtron.

"imec targets high-performing and reliable GaN power devices requiring a concerted effort between device and material engineering," says Rudi Cartuyvels, senior VP Smart Systems and Energy Technologies at imec. "As the AIX G5+ C enables exactly this, we are

pleased with the fast transfer of our device structure processes onto the new platform," he adds. "We are happy that Aixtron is part of imec's GaN industrial affiliation program and look forward to a continuation of the successful collaboration".

It is claimed that the G5+ C is the first fully automated GaN-on-Si production system including a cassette-to-cassette wafer loading system and automated reactor in-situ clean, and that the Planetary batch AIX G5+ C system demonstrated highest uniformity control of layer properties and lowest particle.

Based on a portfolio of qualified MOCVD processes at Aixtron tailored for the needs of the GaN-on-Si power HEMT industry, typical challenges like strain engineering of the AlGaIn/GaN material on 200mm silicon substrates, high-quality AlN nucleation on Si substrates and the pit-free growth of high-quality buffer layers could be addressed in the cooperation with imec.

www.imec.be
www.aixtron.com

Solmates wins order for PLD system from imec and joins 'Beyond CMOS' Industrial Affiliation Program

Solmates of Science Park Twente in Enschede, The Netherlands (a spin-off from the MESA+ Institute of Nanotechnology) has received an order for one of its pulsed laser deposition (PLD) equipment systems from nanoelectronics research center imec of Leuven, Belgium, for delivery in second-quarter 2016.

Solmates says that its PLD equipment can help to accelerate the entry of new processes into commercial products, playing a role in the development of future chip designs and the integration of new materials for next-generation transistors.

Solmates will become a member of imec's 'Beyond CMOS' Industrial Affiliation Program (IIAP), which

focuses on the integration and benchmarking of novel device concepts beyond traditional transistor scaling. These include piezoelectrics for alternative computing devices and two-dimensional (2D) materials such as graphene and MoS₂ for ultimate scaling.

"This important and significant deal fits our roadmap towards mainstream CMOS compatibility," says Solmates' CEO Arjen Janssens, "Imec is a world-leading center for nanoelectronics with significant global partnerships and therefore represents the perfect gateway to this key market."

Solmates (which owns key patents related to PLD technology

and processes) claims that its PLD platform is the next disruptive deposition technology following the adoption of atomic layer deposition (ALD) for thin-film manufacturing. The technology uses a laser to create a plasma of the material to be deposited, enabling industrial-quality deposition of new-generation materials. An automated tool offers high-yield customized deposition of various 'More than Moore' materials on a wide variety of different substrates. The technology is already in use at customer sites, and several processes are qualified for (piezo) MEMS, LED and power IC applications.

www.solmates.nl

Accuracy of LayTec EpiTT Gen3's XRD-referenced nk database improved for InP and related materials

Together with Dr Tony SpringThorpe's team at National Research Council of Canada and Christoph Hums and his co-workers at Fraunhofer HHI (Heinrich Hertz Institute) in Berlin (a research center for communication systems, digital media and services), in-situ metrology system maker LayTec AG of Berlin, Germany has further improved the accuracy level of its nk database for the two quaternary material systems InGaAsP (indium gallium arsenide phosphide) and InGaAlAs (indium gallium aluminium arsenide).

Indium phosphide-based materials exhibit higher electron mobility and higher frequency response compared to gallium arsenide (GaAs). This makes the InP heterojunction bipolar transistor (HBT) a good candidate for next-generation transimpedance amplifiers in optical fiber communications and for 5G applications. Moreover, since an InP HBT's base bandgap energy is much lower than that of a GaAs HBT's, the InP-based device's turn-on voltage and related power consumption are significantly lower.

However, high-yield metal-organic chemical vapor deposition (MOCVD) growth of device-grade quaternary InGaAsP and InGaAlAs structures precisely lattice matched to InP is rather challenging, especially on larger wafers. The solution is in-situ process control based on accurate high-temperature quaternary nk data, says LayTec.

Figure 1 gives selected examples. Figure 1a shows the 633nm refractive index of InGaAsP and InGaAlAs in the full composition range at three relevant growth temperatures, $T_1 < T_2 < T_3$. With $n(x, T)$ and $k(x, T)$ available for the full range of lattice-matched quaternary compositions, precise and quantitative process control becomes straightforward, says LayTec. Figure 1b demonstrates the smooth fit to in-situ reflectance of a device structure. In-situ sensing of wafer bow (green line in Figure 1b)

using LayTec's EpiCurveTT system validates the lattice-matched growth.

For this highly precise nk database, growth rate and lattice match were carefully matched to ex situ x-ray diffraction (XRD). Wafer temperatures were measured using the EpiTT tool, which had been previously

calibrated using LayTec's Absolute temperature calibration tool.

www.laytec.de/inp

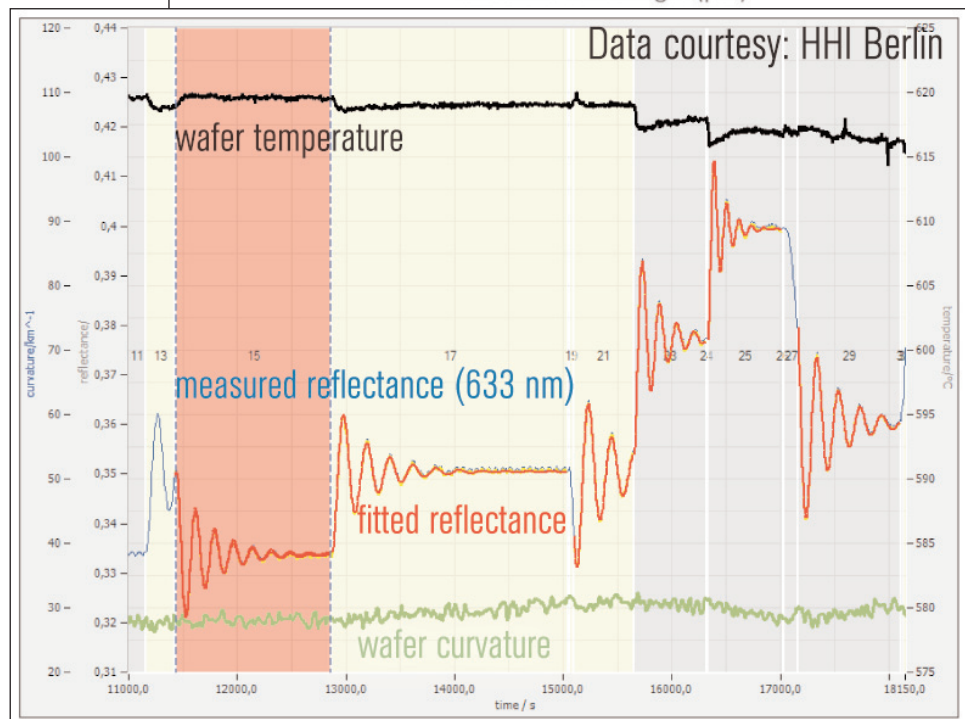
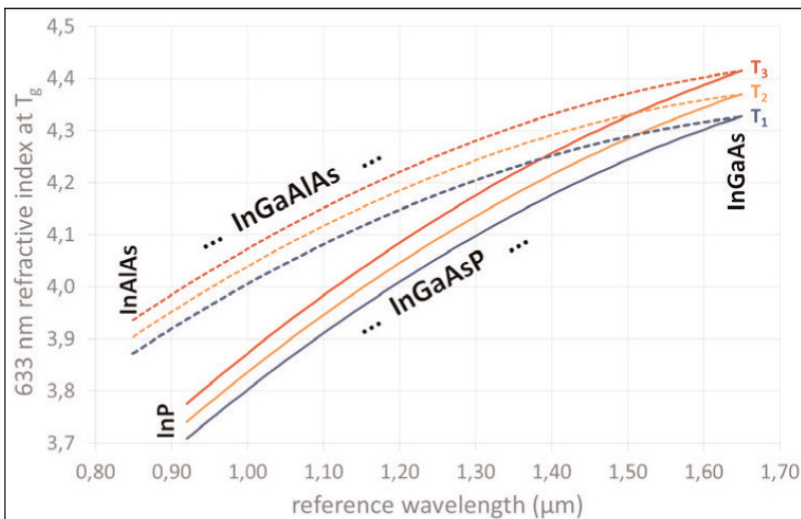


Fig. 1: Control of device-related InGaAsP and InGaAlAs film growth on InP. When lattice-matched growth is validated by in-situ wafer bow sensing, both quaternary material systems can be treated as an effective quasi-ternary mixture: $(\text{InGaAs})_x(\text{InP})_{1-x}$ and $(\text{InGaAs})_x(\text{AlGaAs})_{1-x}$ respectively. (a) The respective composition range ($x=0\dots 1$) covers the reference (PL) wavelength range 0.92–1.65 μm for InGaAsP and 0.85–1.65 μm for InGaAlAs. The three lines for each material system give the 633nm refractive index at three wafer temperatures. (b) The quaternary/ternary layers (steps 17–29) are lattice matched to InP (step 15), as can be seen from the unchanged wafer curvature (green line). Hence, the measured 633nm reflectance data (blue line) of an InP/InGaAsP device structure can be exactly fitted (red line), yielding all compositions x and all growth rates. The -3K reduction in wafer temperature due to the changed As/P ratio is a real effect.

Japan's SAMCO adds local sales staff for North American, European and Asian locations

Semiconductor process equipment maker SAMCO Inc of Kyoto, Japan is employing about 20 more people at its locations in North America, China, Taiwan and Singapore, as well as its subsidiary Samco-UCP in Liechtenstein, in order to better provide services and support to overseas customers.

"Increasing the number of Samco employees abroad is part of the company's larger strategy to optimize our current sales structure while actively growing our customer base across the globe," says president, chairman & CEO Osamu Tsuji.

Samco offers systems and services that revolve around three major technologies, namely thin-film deposition with plasma-enhanced chemical vapor deposition (PECVD), metal-organic

chemical vapour deposition (MOCVD) and atomic layer deposition (ALD) systems; microfabrication with inductively coupled plasma (ICP) etching, reactive ion etching (RIE) and deep reactive ion etch (DRIE) systems; and surface treatment with plasma cleaning and ultra-violet (UV) ozone cleaning systems.

"We've seen an increase in laser diode, MEMS and power device-related inquiries from abroad," says Tsuji. "Systems for research and development at universities and research institutions, which is an area Samco specializes in, are also in high demand," he adds.

This includes India, where the growing economy is expected to accelerate in the future. The Indian Institute of Technology (IIT) Bombay recently installed a DRIE system and

collaborated with Samco to host the firm's first thin-film technology workshop in the country. Samco is currently considering offering internships to students at IIT Bombay and has started gathering a team that will focus on cultivating the Indian market, Tsuji says.

Future goals include doubling the firm's on-site staff by July 2018, discussing the possibility of new locations in the future, and ensuring that its overseas sales encompass at least 50% of total net sales within the next 2-3 years. "Semiconductor equipment manufacturers' overseas sales generally account for around 70-80% of their total net sales," says Tsuji. "With these markets, we'll actively expand and reach our goal of at least 10bn yen in total net sales."

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ClassOne completes new round of funding to fulfill order backlogs and address rising demand

ClassOne Technology of Kalispell, MT, USA, which manufactures wet-chemical processing equipment including Solstice electroplating systems (especially for emerging markets and other cost-conscious users of $\leq 200\text{mm}$ substrates), has announced the completion of a major new round of funding from Salem Investment Partners of Winston-Salem, North Carolina. The announcement was made jointly by ClassOne's CEO Byron Exarcos and Salem Investment Partners vice president Meredith Jolly.

"It is evident that 2016 will be another significant growth year for ClassOne Technology," says Exarcos. "With this new funding we will fill order backlogs and address a forecast that is strong and rapidly increasing," he adds.

"This surge in business is coming from the many emerging markets

that build products on 200mm and smaller substrates. These users are looking for advanced plating performance at an affordable price — and that's precisely what Solstice systems are designed for. As a result, more and more of these companies are ordering our tools. And that now includes many of the top-tier manufacturers from around the world," Exarcos says.

"We're delighted to see the exceptional and sustained growth that ClassOne Technology is achieving across the USA, Europe and Asia," comments Jolly. "It's even more

This surge in business is coming from the many emerging markets that build products on 200mm and smaller substrates

remarkable given that the company just introduced the Solstice system two years ago."

The Solstice electroplating line serves cost-sensitive markets such as MEMS, sensors, LEDs, optoelectronics, and RF. Designed specifically for $\leq 200\text{mm}$ wafer processing, the systems are available in three different models and can electroplate a range of metals and alloys, either on transparent or opaque substrates. Also, in March the firm unveiled its Plating-Plus capability, which allows Solstice to perform additional processing — such as metal lift-off, resist strip and UBM (under-bump metallization) etch — along with plating, all on a single tool. In addition to plating equipment, ClassOne also provides spin rinse dryers, spray solvent tools, and advanced software.

www.classone.com/products

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www.WaferWorld.com

Monocrystal to double sapphire polishing capacity in 2016

In response to increased demand for 4- and 6-inch sapphire substrates, Monocrystal Inc of Stavropol, Russia (which manufactures large-diameter sapphire substrates and cores for LEDs, optical products and RFIC applications) plans to significantly ramp up its polishing capacity to 14 million 2-inch equivalent wafers (TIE) by the end of 2016.

Last year the firm's shipments of

large-diameter polished wafers grew by 30%, and crystal growing capacities reached 53 million TIE. Monocrystal says that this allowed it to maintain its status as the world's largest sapphire growing company.

"2015 was a challenging year for the whole sapphire industry, some key players were forced to leave the market," notes CEO Oleg Kachalov. "However, Monocrystal

managed to increase its market share due to constant improvements in its cost structure and several technological breakthroughs," he adds. "This year we will maintain the momentum and strive to double wafer production capacities to support our customers by providing reliable supply of large-size high-quality wafers."

www.monocrystal.com

Kyma increases AlN template manufacturing capacity

Kyma Technologies Inc of Raleigh, NC, USA (which provides crystalline nitride materials, crystal growth and fabrication equipment, and power switching electronics) has increased its capacity for manufacturing aluminium nitride (AlN) templates, including diameters ranging from 2" up to 150mm and 200mm.

Kyma manufactures AlN templates using its patented plasma vapor deposition of nanocolumns (PVDNC) technology. The firm says that blue, green and white LEDs makers are choosing its PVDNC AlN templates as a replacement for bare sapphire substrates and patterned sapphire substrates (PSS). Feedback from customers indicates that Kyma's

AlN-on-sapphire templates provide significant improvements in LED brightness, reverse voltage, and electro-static discharge (ESD) yield. Also, the firm's AlN-on-silicon (Si) templates have been demonstrated to support high-performance GaN transistor manufacturing for both RF and power switching applications.

While Kyma demonstrated large-diameter AlN on both silicon and sapphire substrates several years ago, most customers have ordered primarily 2" and 4" diameter products. Recently however, to drive down device manufacturing costs, customers have shown growing interest in larger-diameter AlN template products. In response,

Kyma has added large-diameter PVDNC manufacturing capacity which, together with proprietary enhancements in its PVDNC process and equipment design, has enabled Kyma to move down the manufacturing cost curve for all of its AlN template products.

"We have listened to our customers and have responded to their needs," notes Kyma's director of sales Ms Tamara Stephenson. "We are excited to be able to offer more aggressive pricing as well as increased volume availability of all of our AlN template products, including larger-diameter products including 150mm and 200mm."

www.kymatech.com

Cambridge Nanotherm appoints Canaccord Genuity's LED expert Jed Dorsheimer to board

Cambridge Nanotherm Ltd of Haverhill, Suffolk, UK, producer of nanoceramic thermal management technology, has appointed solid-state lighting expert Jed Dorsheimer to its board of directors.

The firm says that Dorsheimer's role as managing director of equity research, display and lighting at US-based investment banking and institutional research firm Canaccord Genuity makes him a suitable candidate to help develop its strategic direction. As an expert with is reckoned to be a unique perspective of both the current state and the future direction of the solid-state

lighting industry, Dorsheimer was ranked as the fifth most influential person in the lighting industry by Lux Magazine.

"As LED manufacturers switch their focus to general lighting, LEDs are getting brighter and this is causing them to heat up," notes CEO Erwin Wolf. "This isn't good for the LED chip, which degrades rapidly when too hot. Getting the heat out of the chip as effectively as possible is critical and that's where Cambridge Nanotherm's industry-leading thermal management solutions come in," he adds.

"Jed's unique combination of tech-

nical and commercial knowledge, coupled with industry-leading financial expertise, will go a long way to helping us to capitalise on the market," Wolf continues. "Jed is a perfect fit for Nanotherm as we progress to the next stage in our growth strategy."

"It's a great time to be joining the board of directors of Cambridge Nanotherm as the company continues its rapid growth," says Dorsheimer. "The company is uniquely positioned to take advantage of the developments in the LED market driven by the general lighting segment."

www.camnano.com

HC SemiTek collaborates to explore BluGlass' RPCVD for low-temperature p-GaN in green LEDs and AlN-on-sapphire for HB-LEDs

BluGlass to deposit RPCVD films on 4-inch wafers from HC SemiTek

BluGlass Ltd of Silverwater, Australia is beginning a collaboration in which LED epitaxy and chip maker HC SemiTek Corp of Wuhan, China (which supplies full-color ultra-high-brightness LED products throughout China) will review the advantages of its remote plasma chemical vapor deposition (RPCVD) for low-temperature deposition of p-GaN in green LEDs and will also explore low-temperature deposition of aluminium nitride (AlN) on sapphire substrates for use in high-brightness LEDs. HC SemiTek will supply 4-inch wafers to BluGlass to deposit RPCVD films, then HC SemiTek will fabricate LED devices for testing.

Spun off from the III-nitride department of Macquarie University of Sydney, Australia in 2005, BluGlass developed a low-temperature process using RPCVD to grow

materials including gallium nitride (GaN) and indium gallium nitride (InGaIn) on glass substrates. By growing critical semiconductor materials at lower temperatures, manufacturers can produce higher-performing devices such as LEDs and power electronics at lower cost, BluGlass says. The firm holds patents in key semiconductor markets including the USA, China, Europe and Japan.

We now have three industry evaluations in place with companies that have respected leadership positions in their relative markets. This forms part of our key strategy to complete our industry acceptance phase

Commercial interest is building in the capability of RPCVD technology, says managing director Giles Bourne. "We now have three industry evaluations in place with companies that have respected leadership positions in their relative markets," he adds. "This forms part of our key strategy to complete our industry acceptance phase as we progress towards commercializing our proprietary RPCVD technology."

The new agreement with HC SemiTek is expected to take several iterations to demonstrate the performance capability, and will involve BluGlass' new RPCVD chamber (designed to improve the uniformity of the RPCVD deposition). This chamber is expected to be commissioned in the coming months.

www.bluglass.com.au
<http://en.hcsemitek.com>

Rubicon comments on director nominations from Paragon Technologies

Rubicon Technology Inc of Bensenville, IL, USA (which makes monocrystalline sapphire substrates and products for the LED, semiconductor and optical industries) has confirmed that investment firm Paragon Technologies Inc of Easton, PA, USA, which owns 30,000 (about 0.1%) of the outstanding shares of Rubicon, has submitted notice to nominate two candidates, Hesham M. Gad and Jack H. Jacobs, to stand for election to Rubicon's board of directors at the 2016 Annual Meeting of Stockholders.

"Rubicon is open to constructive input from all stockholders and has been engaged in an ongoing dialogue with Paragon," says Rubicon's CEO Bill Weissman. "Our board of directors and management team

respect the rights of stockholders to nominate director candidates, but we are disappointed that Paragon has chosen to proceed in this manner. The Nominating and Governance Committee interviewed and thoroughly vetted Paragon's proposed director candidates and indicated our willingness to appoint Mr Jacobs to the Rubicon board to avoid a costly proxy contest. Unfortunately, Paragon rejected our constructive offer and instead demanded the appointment of both of its nominees," he adds.

"The board noted as part of its vetting process that, in addition to serving as chairman and CEO of a Paragon portfolio company subject to an involuntary bankruptcy proceeding, Mr Gad previously pleaded

guilty to theft from a prior employer and was separately charged with making false statements to a government authority. We believe that these factors, among others, render him unfit to serve on the Rubicon board," continues Weissman.

Rubicon's board will present its recommendations with respect to the election of directors in its proxy statement, which will be filed with the Securities and Exchange Commission (SEC) at a later date. The date of the 2016 Annual Meeting of Stockholders has not yet been announced, and stockholders are not required to take any action at this time.

www.pgntgroup.com
www.rubicon-es2.com

Plessey signs license agreement with PhytoLux for solid-state horticultural growth lighting solutions

UK-based Plessey has signed a global exclusive license agreement to manufacture and sell the horticultural lighting solution of UK firm PhytoLux.

Plessey has taken on PhytoLux's operational, technical and commercial activities. The collaboration combines design engineering to provide LED plant growth lighting solutions for the global market.

"Plessey, one of the UK's most prestigious engineering brands, is at the forefront of the global LED Lighting revolution," comments PhytoLux's founder & managing director Steve Edwards, now head of the LED lighting solutions division of Plessey. "We are looking forward to delivering our unique solution to the global horticultural market over the coming months and years," he adds.

"Steve and the team at PhytoLux have built an impressive record of innovation and proof of concept with the researchers and industrial growers in the UK," says Plessey's



Plessey's PhytoLux Attis-7 LED horticultural lights, used by a commercial strawberry grower near Colchester, UK for season extension.

CEO Michael LeGoff. "The horticultural market is a key growth area for solid-state lighting and is without a significant dominant player... We have an opportunity to be that dominant player with the PhytoLux end-product," he believes. "Our MaGIC [Manufactured on GaN-on-Si I/C] GaN-on-silicon technology for

power LED applications is perfect for these kinds of directed lighting applications where we have very tight wavelength control. The next-generation Plessey LEDs with integrated electronics and optics will further add to the intrinsic advantages of

the PhytoLux range of products."

LeGoff describes plant growth as one of the fastest-growing sectors for LED lighting. A recent market research report by Wintergreen Research projects that the horticultural LED lighting market is set to reach £3.6bn by 2020.

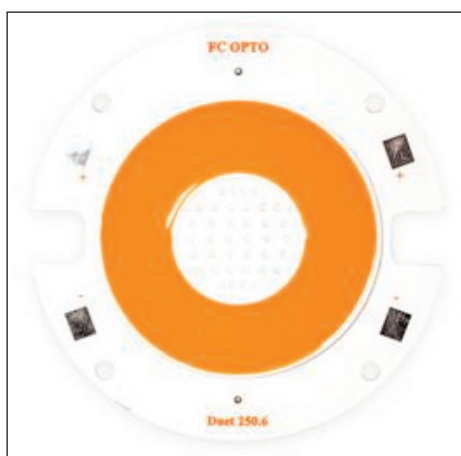
www.phytolux.com

Flip Chip Opto introduces mid-power horticultural chip-on-board LEDs

LED lighting technology firm Flip Chip Opto Inc of Fremont, CA, USA has introduced mid-power solutions for the horticultural industry.

The Duet F series consists of 100W, 150W, 200W, 250W and 300W versions of the flip-chip chip-on-board (COB) LED. Offering five different photosynthetic photon flux density (PPFD) ratios under dedicated spectrums between 450nm royal blue and 600-700nm broadband red allows what is claimed to be unparalleled photosynthesis and corresponds to the various plant growth stages.

The structure of each COB is based on the patented DBR LED flip chip and uses the firm's in-house



Flip Chip Opto's 250W Duet LED.

low-temperature bonding technologies (LTBT), boosting lighting efficacy and decreasing the thermal resistance between the

LED chip junction and the module's metal substrate.

The Duet series features 1/3, 1/6, 1/8, 1/10 and 1/12 ratios in blue and red power consumptions. The PPFD outputs in various ratios allow horticultural applications that focus on different stages of the plant life as photosynthetic absorption rates vary throughout the life cycle. The three selections of red peak spectrum (627nm, 640nm, 650nm) enable growers to choose their preferred broadband. Additionally, it can be substituted in spectrums ranging from correlated color temperatures (CCTs) of 2700-5700K and color rendering index (CRI) of 60-98.

www.fcopto.com

Soraa's LED lighting installed in University of Oxford's Pitt Rivers Museum

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology fabricated on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, says that its LED lamps have been installed at the University of Oxford's Pitt Rivers Museum in the UK (which has more than 400,000 visitors annually). As well as saving energy and money, the museum chose Soraa's LED lamps to illuminate its rare collections of anthropology and archaeology artifacts.

The university installed 500 VIVID MR16 LED lamps, which should save the museum an estimated £45,000 over the next 5 years and reduce its carbon emissions by 44 tonnes each year. Not only does the new LED lighting make the museum more energy efficient and the displays easier to see, it also emits no harmful ultra-violet light, protecting the artifacts from UV light damage. Soraa worked with its UK partners, 4D Lighting, to supply the lamps to the Pitt Rivers Museum.

The lighting designers for the museum chose Soraa's lamps with Violet-Emission 3-Phosphor (VP₃) technology to showcase the space's



The Pitt Rivers Museum at the University of Oxford (photo credit: Redshift Photography).

industrial design and to illuminate the colors and whiteness of the relics on display. Soraa says that, utilizing every color in the rainbow (especially deep red emission), its lamps render warm tones accurately and achieve a color-rendering index (CRI) of 95 and deep red (R9) rendering of 95. Also, unlike blue-based white LEDs without any

such as textiles and paper.

"The Soraa LED lamp produces color rendition that is comparable to a halogen light source," comment's University of Oxford's Robert Gregg. "Utilizing the Soraa SNAP system, we now have the flexibility to adjust the beam angles for our many displays," he adds.

www.soraa.com

violet emission, the lamps have violet emissions to properly excite fluorescing brightening agents, including natural objects like human eyes and teeth, as well as manufactured white materials

Soraa hires former Qualcomm executive as senior VP of marketing to drive go-to-market activities

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology fabricated on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, has appointed marketing veteran Todd Antes as senior VP of marketing, reporting directly to CEO Jeff Parker and working closely with the sales and product development teams.

"Todd brings extensive marketing experience to Soraa and will play a key role in driving the company's next phase of growth into full-spectrum, smart and connected lighting," says CEO Jeffrey Parker.



Todd Antes, Soraa's new senior VP of marketing.

Most recently, Antes was vice president at Qualcomm, responsible for the strategy, product roadmap and go-to-market activities for its Networking, and Connected Home/Office/IoT products. Previously, he was VP of marketing at

Atheros Communications, which grew to become the world's largest supplier of Wi-Fi technology and chipsets prior to its acquisition by Qualcomm in 2011. Also, he has held several executive marketing leadership positions at small start-ups through large, public technology companies, including Philips and AirPrime (acquired by Sierra Wireless).

"I look forward to applying my marketing experiences in IoT and connected products to help the company deliver truly innovative LED lighting to more customers around the world," comments Antes.

Everlight launches UV LED portfolio spanning 365–400nm

At LIGHTFAIR International (LFI2016) in San Diego, CA, USA (26–28 April), Taiwan-based Everlight Electronics Co Ltd is launching a new UV LED portfolio comprising five products covering wavelengths between 365nm and 400nm.

The UV LED market is expected to grow rapidly in 2016, due to upcoming applications (in addition to the established application to printing). Emerging curing applications (such as UV paint and cosmetic curing), medical treatments, domestic disinfection and home appliances (such as photocatalytic air and water purifiers) are as



Everlight's new series of UV LEDs.

appealing as counterfeit checking. All five new UV LED products are based on a special UV ceramic substrate to effectively improve the heat resistance. Three high-power (1.8W) components — EAUVA35352 (3.5mm x 3.5mm x 2.31mm), EAUVA35353 (3.5mm x 3.5mm x 3.51mm) and EAUVA4545 (4.5mm x 4.5mm x 5.0mm) — feature different viewing angles of 120°, 50°

and 30°, respectively. Complementing the high-power range are two lower-power (0.08W) components: EAUVA3020 (3.0mm x 2mm x 0.65mm) has a very uniform light pattern and EAUVA2016 (2.0mm x 1.6mm x 0.75mm) is the smallest option in the new UV LED range.

Samples are available now (upon request). Mass production will start in second-quarter 2016.

Mid-power 2835-packaged LEDs with different voltages

Everlight has updated its range of top-view, white, low- to mid-power LEDs in 2835 form-factor (2.8mm x 3.5mm x 0.7mm) packages by adding versions operating at three voltages 3V, 6V, 9V at 0.5W and two voltages 6V and 9V at 1W. Target applications are mainly general lighting, especially consumer, commercial and professional lighting.

With a low dollar-per-lumen ratio, the 2835 package has been the most popular product of all Everlight's lighting packages. It is an upgrade from standard 3528

packages but, due to a newly designed heat slug, the LED maintains its compact size with an even lower profile and can easily be overdriven to achieve maximum flux. The 2835-ELB, an upgrade from the standard 3528, is a versatile package that can accommodate a wide range of wattages and voltages. Different wattage and voltage ranges are needed to optimize lamp and fixture designs to ensure the best system efficiencies and cost.

For the new 0.5W versions, three different voltage options are avail-

able: 3V, 6V and 9V. In addition, two 1W high-power versions are available: 6V and 9V. Each of these 2835-ELB LEDs has high efficacy, high-CRI (color rendering index) options of >80 or 90Ra, high-R9 options of >0 or 50, and easy-to-use lambertian light patterns. 3SDCM binning is available as well to keep chromaticity coordinates under tight control. These features make the 2835-ELB package suitable especially for general lighting applications such as bulbs, linear lamps and fixtures, or downlights.

www.everlight.com

Everlight adds higher-power F-ELB series to Shwo high-power LED range

Taiwan-based Everlight Electronics Co Ltd has launched the Shwo F-ELB high-power LED series, the latest and most powerful update to its existing high-power and bright Shwo LED Series. F-ELB LEDs features flip-chip technology to enable better overdrive conditions while maintaining high efficiency.

The F-ELB series is a high-power SMD device featuring high lumen density in a compact size, suitable for all kinds of lighting applications

including general illumination, flash, spot, signal, industrial and commercial lighting.

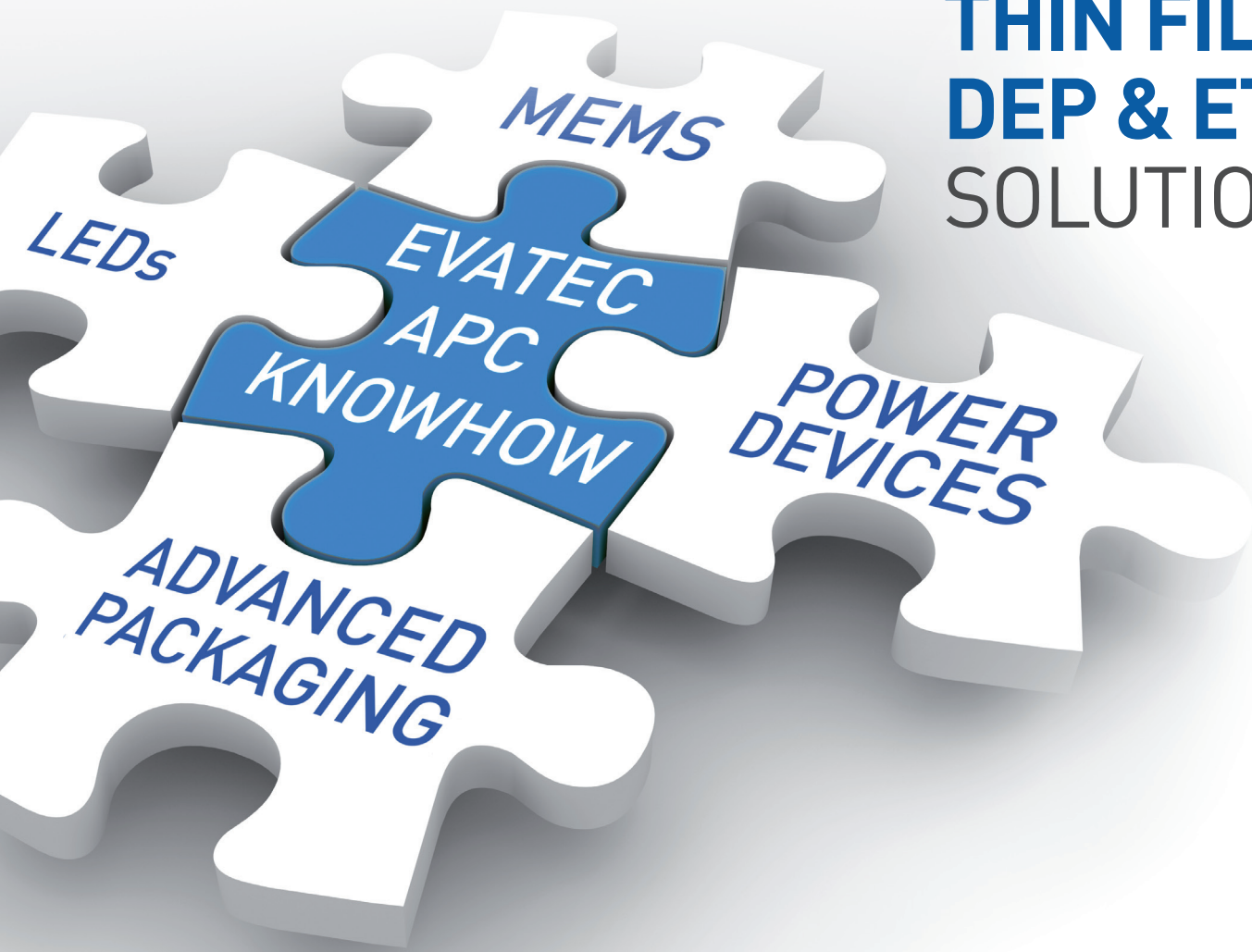
The F-ELB devices can be driven at 1.0W with a standard operating current of 350mA or up to 5W with a standard operating current of 1500mA. Luminous flux of the 1.0W F-ELB is up to 165lm (152lm/W) at 6500K CCT or 130lm (120lm/W) at 3000K CCT when driven at 350mA of current. At 1500mA, it can achieve 545lm at 6500K CCT or 430lm at 3000K CCT.

The high-power SMD device is offered in a compact ceramic package (3.5mm x 3.5mm x 2.36mm). The thermal pad of the device is electrically isolated, providing convenience in thermal and electrical design. The F-ELB series also has a low thermal resistance of less than 5°C/W for optimized heat management.

The new Shwo F-ELB devices are currently available for sampling and mass production.

www.everlight.com

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SemiLEDs improves quarterly margins & cash reserves

For its fiscal second-quarter 2016 (to 29 February), LED chip and component maker SemiLEDs Corp of Hsinchu, Taiwan has reported revenue of \$2.92m, down 36% on \$4.6m a year ago but only 2% on \$2.96m last quarter.

"We have made good progress toward restructuring our business and focus," says chairman, president & CEO Trung Doan. "Compared with the first quarter of fiscal year 2016, cash position and gross margin have

improved and our capital spending has reduced in the second quarter of fiscal year 2016," he adds.

Gross margin was -27%, an improvement on -49% last quarter but still down on -14% a year ago.

On a non-GAAP basis, net loss was \$2.2m, cut from \$3.3m last quarter and better than \$2.5m a year ago.

Capital expenditure has been cut further, from \$0.42m a year ago and \$0.34m last quarter to \$0.14m. However, cash used in operating

activities was \$1m, less than \$1.4m a year ago but up from \$0.6m last quarter. Total free cash outflow hence rose slightly from \$0.9m to \$1.15m (although this is still less than \$1.8m a year ago). Despite this, during the quarter, cash and cash equivalents rebounded from \$3.5m to \$5.3m.

For fiscal third-quarter 2016 (ending 31 May), SemiLEDs expects revenue of \$2.4-3m.

www.semileds.com

SemiLEDs announces reverse stock split to maintain NASDAQ listing

SemiLEDs has effected a one-for-ten reverse split of its outstanding common stock, as approved by the board of directors on 7 January and by shareholders on 12 April. The final ratio of the split was approved by the board on 12 April, and did not require separate shareholder approval as it was within the range previously approved.

As a result, every ten shares of the common stock issued and

outstanding on 15 April has been combined into one issued and outstanding share (reducing the number of shares outstanding from about 29.1 million to about 2.9 million). The firm will pay cash in lieu of any resulting fractional shares. In connection with the reverse stock split, there will be no change in the par value per share of \$0.0000056. Also, the reverse stock split will not reduce the

number of authorized shares of common stock.

The reverse stock split is intended to increase the per-share trading price of the stock to satisfy the \$1 minimum bid price requirement for continued listing on the NASDAQ Capital Market.

Trading of the stock on the NASDAQ Capital Market continued (on a split-adjusted basis) under the existing trading symbol 'LEDS'.

Lumileds launches mid-power LUXEON HR30 LED, resistant to harsh chemical environments

LED maker Lumileds of San Jose, CA, USA has launched the LUXEON HR30 LED, a mid-power device that withstands harsh chemical environments (including chlorine and sulfur) and is designed with robust packaging and industry-best materials to operate for over 100,000 hours continuously. The LED addresses the great need for dependable lighting that will operate in hazardous environments (such as chemical plants, power generation facilities and natatoriums) and be able to withstand extremes of temperature and operating current.

"The LUXEON HR30 is the only LED in its class to provide a service life in the 100,000 hour range [at 105°C] while withstanding corrosive elements like sulfur and chlorine," says



Matthew Everett, senior product director for LUXEON Mid Power Products. The chemical resistance is partially attributed to its gold-plated leadframe and its optimized materials package. The LUXEON HR30 has demonstrated strong performance in chemical resistance tests such as

IEC68-2-43 (15ppm): DLOP<10%, Du'v'<0.006 after 21 days.

"Engineering for chemical resistance is all about selecting the best materials and then testing those materials under harsh conditions," says Everett. "We have leveraged our expertise in materials science and lumen maintenance to produce the industry's most robust mid-power LED," he claims.

The LUXEON HR30 produces 125 lumens at a luminous efficacy of 134lm/W when driven at 150mA current at a color temperature of 4000K and a color rendering index (CRI) of 70. The LED is available at color temperatures of 4000K, 5000K and 5700K at 70 CRI and 2700K, 3000K, 4000K and 5700K at 80 CRI.

www.lumileds.com/LUXEONHR30



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Cree's quarterly revenue falls 15.8% to \$367m

Recovery to \$370–395m expected next quarter, following delays to new products in commercial lighting

For fiscal third-quarter 2016 (ended 27 March), Cree Inc of Durham, NC, USA has reported revenue of \$366.9m, down 10.4% on \$409.5m a year ago and 15.8% on \$436m last quarter (and 11.5% below the originally targeted \$400–430m).

Specifically, Lighting Product revenue was a lower-than-targeted \$187.7m (51% of total revenue), down 16% on \$224.1m (55% of total revenue) a year ago and down 26% on \$255m (59% of total revenue) last quarter. This is due primarily to lower commercial lighting revenue, driven by three main factors: customer service disruptions related to converting to a new ERP (enterprise resource planning) system; delays in new product launches (which prompted some customers to delay their projects or switch to other products); and weaker market conditions than forecast.

LED Product revenue was \$150.2m (41% of total revenue), down just 3% on \$154.4m (38% of total revenue) a year ago and 2% on \$153m (35% of total revenue) last quarter.

Wolfspeed Power & RF Product revenue was \$29m, down 6% on \$31m a year ago but up 6% on \$28m last quarter.

On a non-GAAP basis, gross margin is down from 31.6% last quarter to 30.6% (below the expected 31.7%). Specifically, Lighting Product gross margin fell back from 28.5% to 26%, due to lower lighting factory utilization, an inventory write-down on LED tubes, and a higher relative mix of consumer sales. However, the LED Product business continue to execute well, with gross margin level at 34.7%. Wolfspeed Power & RF Product gross margin has fallen from 52.2% last quarter to 46.4%, at the lower end of the targeted range due to an unfavorable product mix while new products ramp up.

Operating expenses were \$96m, below the targeted \$100m (due mainly to lower variable costs on

the lower Lighting sales) and cut from \$103m last quarter.

Net income was \$16.9m (\$0.17 per diluted share), almost halving from \$30.5m (\$0.30 per diluted share) last quarter, and below the originally targeted \$0.22–0.29 per diluted share (but above the \$0.13–0.15 forecasted on 5 April).

Cree generated \$15m in cash from operations (down from \$77m last quarter). This was offset by capital expenditure (CapEx) of \$21.3m (down from \$35.2m as planned). Free cash flow was hence –\$6.3m (compared with +\$41.7m last quarter). Also, Cree spent \$17.8m to repurchase an additional 600,000 Cree shares (taking total repurchases to \$150m for 5.8 million shares, leaving \$350m remaining on the share repurchase program). However, Cree borrowed \$20m on the firm's line of credit (leaving \$225m outstanding) and received \$6m from common stock issuances and fixed-asset sales. Hence, overall, cash and investments rose by \$3m to \$620m.

"Operating results were in-line with the preliminary estimates we provided on 5 April," says chairman & CEO Chuck Swoboda.

"We've addressed the root causes that led to our recent Lighting business challenges, but recognize it will take time to rebuild sales momentum," he believes.

"We improved customer responsiveness in March, and we're opti-

mistic that this, combined with new product momentum [with the release of several new commercial lighting products and two new LED products], will drive sequential growth in fiscal Q4."

"In the last several weeks, we've released the expanded family of RSW streetlight products, the Essentia by Cree track and down-light product lines, and SmartCast Manager for our new PoE [Power over Ethernet] intelligent lighting products," says Swoboda.

"Over the next two months, we're scheduled to release performance upgrades and product line extensions for our XSP streetlights, CPY canopy lights and OSQ area lights," continues Swoboda. "We also target releases of SmartCast LN for suspended fixtures, next-generation high-bay fixtures and a troffer performance upgrade in the quarter. We recently released our next-generation XLamp XP-G3 platform, which delivers 31% more lumens than our previous generation as well as improved lumen density, voltage characteristics and reliability. We've upgraded LED performance in Q3 with new versions of our XPL and XP-G2 products that incorporate SC5 technology. We released a new family of XLamp CXA2 high-density LED arrays that double lumen output and deliver the most lumens in the industry for their lightning emitting surface size. We recently announced TrueWhitePlus Technology, which will be available in upcoming LED components as well as new high-end lighting products. The first products are being shown to customers this week at LIGHTFAIR, and take our industry-leading TrueWhite color technology to the next level by optimizing the spectral content of light."

For fiscal fourth-quarter 2016 (ending 26 June), Cree expects revenue to rise to \$370–395m, driven by Lighting Products as

We've addressed the root causes that led to our recent Lighting business challenges. We improved customer responsiveness in March...this, combined with new product momentum, will drive sequential growth in fiscal Q4

► commercial sales grow (more than offsetting lower targeted consumer sales as Cree ramps down the current generation products in advance of launching a new family of bulbs this Fall). Wolfsped sales should also grow further, driven by growth in both Power & RF product lines. LED Product sales should be similar to or slightly lower than fiscal Q3 as competitive market dynamics offset typical seasonal demand improvement. Gross margin should rebound to 31.5%, driven by gross margin improvement in Lighting and Wolfsped. Operating expenses should rise by \$2m to \$98m, due primarily to variable

sales costs from the targeted higher commercial lighting sales. Improved gross margin and operating leverage are expected to yield net income of \$16–22m (\$0.16–0.22 per diluted share).

“While we believe the Lighting ERP implementation issues are mostly behind us, we believe near-term commercial orders will take time to fully recover as we are regaining our customers’ confidence,” says chief financial officer & executive VP Mike McDevitt. “The commercial lighting business lost order momentum in Q3, but I believe we’ve addressed the delivery issues and new-product momentum has

started to improve,” notes Swoboda. “Our consumer lighting business is working on a new generation of premium LED bulbs that are targeted for release during the Fall lighting season,” he adds.

“As we enter our fourth fiscal quarter, we remain focused on taking advantage of the growing market opportunities in Lighting and Power & RF,” says Swoboda. “Our LED business has performed well over the last several quarters, but we need to continue to innovate and expand the number of applications for a high-power technology to help offset a very challenging competitive environment.”

Cree introduces TrueWhitePlus LED technology platform

Cree Inc of Durham, NC, USA has introduced TrueWhitePlus Technology, a development in spectral control. Using Cree LED technology that optimizes the spectral content of the light to deliver lighting that people prefer, TrueWhitePlus Technology is said to

make objects, spaces and any environment more appealing.

According to Cree, TrueWhitePlus Technology will enable LED innovations that are not possible with incumbent technology, leading to better light experiences that help people feel safer, more alert and

more productive. It is targeted to appear in Cree’s LED components and commercial lighting solutions this year.

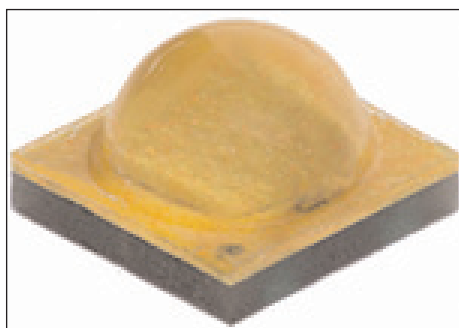
The new technology was demonstrated at LIGHTFAIR International (LFI 2016) in San Diego, CA, USA (26–28 April).

Cree launches XP-G3 LED as next generation of XLamp XPG platform, boosting efficacy by 8% to 205lm/W

Cree Inc of Durham, NC, USA has introduced the XLamp XP-G3 LED, which delivers 31% more lumens and 8% higher lumens-per-watt (LPW) than the XP-G2 LED.

Leveraging key elements of Cree’s SC5 Technology Platform, the high-power XP-G3 LED improves the lumen density, voltage characteristics and reliability of previous XP-G generations, enabling lighting manufacturers to deliver differentiated solutions at lower system costs for applications such as roadway, outdoor area, spot and high-bay lighting.

“We are designing a new series of 130 lumens-per-watt high-performance streetlights, and the choice to use the new Cree XP-G3 LED was clear,” comments Wilbur Tarn, director of LED lighting manufacturer, distributor and installer



OrangeTeK. “The XP-G3 LED delivers high efficacy and high reliability in the familiar XP-G footprint, allowing us to modify elements of an existing design to shorten our design time by half.”

Cree says that it pioneered the industry-standard high-power 3535 form factor with the XP platform, and now the XP-G3 delivers over 205 LPW at 350mA and up to 863lm at 2A. Regarding reliability and lumen maintenance, the XP-G3

LED has 6000 hours of LM-80 data immediately available that provides L90 lifetimes well beyond 50,000 hours, even at an extreme 105°C, 1500mA test condition.

“The XP-G3 is the first LED in its class to shatter the 200 LPW barrier, setting a new benchmark for the XP-G class of LED and joining Cree’s other high-power LEDs that deliver this level of performance,” says Dave Emerson, Cree’s VP & general manager, LEDs.

The new LEDs are characterized and binned at 85°C, available in ANSI White, EasyWhite 3- and 5-step color temperatures (2700–6500K) and color rendering index (CRI) options of 70, 80 and 90. Product samples are available now and production quantities are available with standard lead times.

www.cree.com/xlamp/xpg3

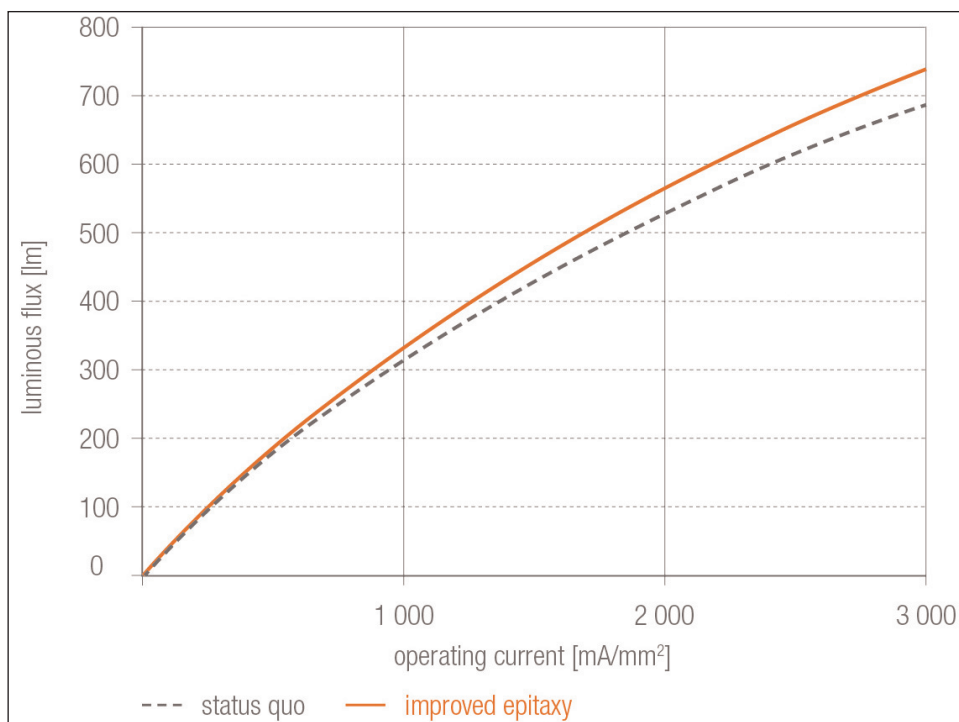
Osram boosts luminous efficacy of white and blue high-power LEDs by 7.5%

Improved epitaxy reduce droop in LEDs based on UX:3 chip

Osram Opto Semiconductors GmbH of Regensburg, Germany has improved the luminous efficacy of its high-power LEDs by as much as 7.5% by reducing the unwanted effect of efficiency droop at high currents. This development was made possible by optimized epitaxial processes.

The unwanted drop in efficiency as the current density increases (i.e. droop) limits the maximum luminous efficacy of indium gallium nitride (InGaN)-based LEDs and is hence the subject of intense R&D activities worldwide. Osram Opto has now been able to reduce this effect considerably and therefore achieve a significant increase in the efficiency of the LEDs.

Under laboratory conditions and at a current density of $3\text{A}/\text{mm}^2$, a typical luminous flux of 740lm was verified in a QFN (quad flat no lead) LED package — an improvement of about 7.5% compared with previous typical values (6200K, Cx 0.319, Cy 0.323, single-chip version LDxyz). At low current densities of $0.35\text{A}/\text{mm}^2$, the benefit of the optimized LEDs is still around



At $3\text{A}/\text{mm}^2$ the luminous efficacy of white LEDs is boosted by 7.5%.

4%. "We have been able to reduce the droop effect considerably by extensively revising and improving the epitaxy," says project manager Dr Alexander Frey.

The new processes are being used in all Osram Opto LEDs based on

UX:3 chip technology and will also have a positive impact on other high-power products. The results will now be integrated step by step in the existing product portfolio, says the firm.

www.osram.com

Distributor Digi-Key expands standard catalogue to include Excelitas' opto and photonic sensor technology

Excelitas Technologies Corp of Waltham, MA, USA, which provides customized photonic solutions for the lighting, detection and optical technology needs of OEMs worldwide, has announced a new distribution agreement with Digi-Key Electronics of Thief River Falls, MN, USA, a global, full-service provider of both prototype/design and production quantities of electronic components,

Select products from Excelitas' broad portfolio of illumination, optoelectronic and sensor/detection products are now available for

online purchase at Digi-Key's global websites.

"Adding Excelitas' products to our global product offering makes it easier for engineering teams to explore and purchase from a full selection of lighting and detection solutions for their designs," says David Stein, VP, global semiconductor at Digi-Key. "Our customers can now find even more of the components they need for their R&D and product development projects from a single, convenient source."

Initially, Digi-Key will add a selection of more than 100 Excelitas

products to its catalogue. This will include photonic detectors, thermal infrared sensors, and a variety of LED, xenon, flashlamp and arc lamp illumination solutions covering the spectrum from infrared (IR) to ultraviolet (UV).

"Digi-Key's renowned, global customer base and reach will help us market our leading-edge solutions to an expanded audience of designers and users," says Excelitas Technologies' senior VP Danny Miller.

www.excelitas.com

www.digikey.com

DENSO invests in laser startup TriLumina

Automotive supplier targets LiDAR and driver monitoring systems

DENSO International America Inc of Southfield, MI, USA (a subsidiary of Japan-based automotive technology, system and component supplier DENSO Corp) has invested in TriLumina Corp of Albuquerque, NM, USA, which manufactures and integrates vertical-cavity surface-emitting laser (VCSEL) array light sources for LiDAR (light detection and ranging) and interior illumination products.

DENSO aims to speed adoption of LiDAR and driver monitoring technologies in Advanced Driver Assistance systems (key technologies in autonomous vehicles). The strategic investment enables TriLumina to gain broader access to the automotive market.

TriLumina has developed eye-safe near-infrared (IR) emitters for high-power laser radar, depth sensing and smart illumination applications. As well as targeting depth sensing and gesture control for the industrial robotics, commercial and consumer electronics markets, the firm aims to help accelerate the automotive industry's adoption of semi-autonomous and autonomous vehicles by providing lasers for 100% solid-state LiDAR products and advanced driver monitoring systems (DMS).

"As a supplier of advanced driver assistance systems, DENSO is eager to work closely with TriLumina to bring high-performance, cost-effective light source solutions to the market," says Tony Cannestra, director of corporate ventures for DENSO International America Inc.

"It is critical to work with leading tier-1 suppliers like DENSO as we introduce and deploy technology that will shape the automotive industry for years to come," reckons TriLumina's CEO Kirk Otis. "It is a tremendous endorsement of our technology to have DENSO engage as one of our tier-1 partners, work with us to become qualified, and help fuel development."

DENSO International America's Silicon Valley office actively works with startup companies and, through these types of partnerships, expects to gain access to new technologies in the areas of autonomous drive, electric vehicles,

transportation, batteries, and energy storage while also expanding the company's overall presence and visibility within entrepreneurial networks.

www.trilumina.com
www.globaldenso.com



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IQE joins €15m MIRPHAB project to establish mid-IR photonics device fabrication supply chain

IQE to provide volume source of laser epiwafers

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has joined the new consortium MIRPHAB (Mid InfraRed PHotonics devices FABrication for chemical sensing and spectroscopic applications), which will establish a €15m pilot line to serve the growing needs of European industry in analytical micro-sensors. Funding comes from the both the European Commission's Photonics Public Private Partnership under the Horizon 2020 program (€13m) and the Swiss Government (€2m). IQE's role will be to provide consortium partners and commercial customers with a volume source of mid-infrared laser epitaxial wafers.

MIRPHAB's aim is to establish a European-based production capability for mid-IR photonics devices. By bringing together high-volume epiwafer production facilities at IQE

along with key end-users, the consortium will deliver an end-to-end production supply chain for mid-IR devices for a wide range of infrared sensing applications.

Mid-infrared lasers and detectors are a key enabling technology in applications where the precise and fast detection of chemicals in gases and liquids is required. The rapid growth in demand for mid-IR devices will be exploited by the pilot line in product areas that include:

- measurement and control of environmental pollutants from industrial manufacturing processes and automotive engines;
- stand-off detection of explosives and biological threats;
- non-invasive medical diagnosis; and
- specialized free-space communication systems.

In addition, the initiative will provide open access to the European photonics industry, focusing on innovative SMEs, catering for their requirements to prototype a wide range of mid-IR devices for multiple end-use applications.

"IQE has established a strong track record in the manufacture of compound semiconductor wafers for laser applications, so we are very pleased to participate in MIRPHAB and provide the consortium with a commercial source of mid-infrared epitaxial wafers," says Dr Mark Furlong, VP of IQE's Infrared business unit. "With demand for mid-infrared devices growing rapidly, supporting the pilot line with a high production volume capability for wafers will be essential."

www.mirphab.eu

www.iqep.com

Infrared division wins \$3m in orders for antimonide IR products

In March, IQE received record volume purchase orders worth over \$3m (to be delivered over the next 12 months) for its indium antimonide (InSb) and gallium antimonide (GaSb) substrate materials.

The orders from three long-term customers of IQE's Infrared business unit are for various specifications of InSb and GaSb substrate materials, including large-diameter products that are used to fabricate infrared detector products. InSb and GaSb are key materials for a wide range

of infrared detector technologies in consumer, defence, security, medical and industrial imaging applications.

IQE Infrared reckons it is uniquely positioned as a global supply of antimonide materials to the IR detector industry, with IQE's US (Galaxy Compound Semiconductors) and UK (Wafer Technology) operations providing a secure dual source of 2-5" InSb and GaSb wafers.

IQE claims it has the largest antimonide wafer production capacity in the industry, using multiple

production tools (pullers), volume double-side polishing platforms and state-of-the art product metrology.

The new orders "reflect the high quality of the antimonide substrate products that we supply as well as the confidence that our customers have in Galaxy Compound Semiconductors and Wafer Technology to support their longer-term requirements for a wide range of InSb and GaSb substrate materials up to 5" in diameter," says Dr Mark Furlong, VP of IQE's Infrared unit.

IQE's Infrared division presents invited papers at SPIE DCS

At the SPIE Defense and Commercial Sensing conference (DCS) in Baltimore, MD USA (17-21 April), IQE presented two invited papers on recent key developments and commercialization of advanced infrared materials.

- 'Bulk Growth and Surface Characterization of Epitaxy Ready Cadmium Zinc Telluride substrates

for use in IR imaging applications', covering new product development in the area of cadmium zinc telluride (CZT) IR substrate technology through a partnership between IQE's US substrate manufacturing subsidiary Galaxy Compound Semiconductors and Redlen Technologies of Victoria, BC, Canada, a leader in the manufacture of CZT-based

radiation detectors.

- 'A study of the preparation of epitaxy-ready polished surfaces of (100) Gallium Antimonide substrates demonstrating ultra-low surface defects for MBE growth'

<http://spie.org/conferences-and-exhibitions/defense--commercial-sensing>
www.redlen.com

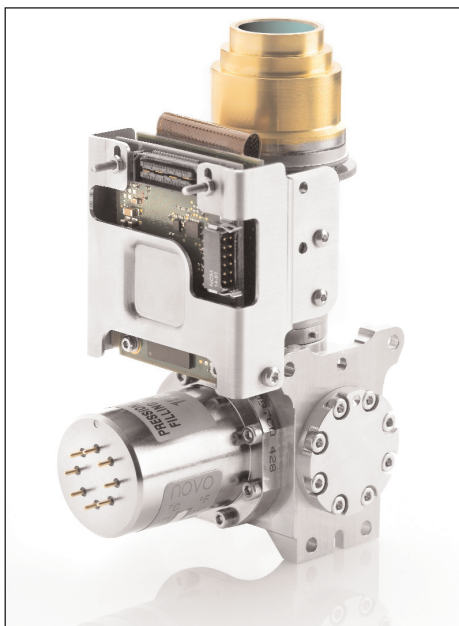
Sofradir starts production of Daphnis 10 μ m-pixel-pitch HD-format midwave IR detector

Sofradir of Palaiseau near Paris, France, a subsidiary of Safran and Thales that makes cooled infrared (IR) detectors for military, space, scientific and industrial applications, says that its new Daphnis HD is entering production.

Sofradir says that the decision to launch production of the 10 μ m pixel-pitch high-definition midwave (MW) IR detector follows the positive feedback and subsequent new orders received from select customers that have been extensively sampling the product.

System-level equipment maker Safran-Sagem has selected the Daphnis HD MW in order to meet end-customer demands for more recognition and identification ranges on optronic products," says Safran-Sagem's R&T director Thierry Dupoux. "High-end optronic equipment is required to carry increasingly more functions in constrained volumes. From this standpoint, the reduction in pixel pitch size of Daphnis FPA enables improved performance across all dimensions of an ISTAR mission — information, surveillance, target acquisition and reconnaissance — without compromising the compactness of the optronic product. This is another strong market request," he adds.

Whereas visible imaging systems



The Daphnis 10 μ m-pitch HD-format midwave IR detector.

(which use shorter wavelengths than IR wavelengths) have been using HD formats for several years now, the transition to the HD format in IR wavelengths (3–5 μ m) has just begun to take place. In that respect, Daphnis' 4.8 μ m spectral cut-off wavelength is a key differentiator that allows unsurpassed signal-over-noise ratio, even in a low-temperature scenario, says Sofradir.

"Thanks to the sharp square-like profile of its mercury cadmium telluride photodiode and enlarged MW

band, Daphnis offers improved recognition range versus any competing 10 μ m-pitch products we have recently seen introduced in the market," claims Sofradir's general manager Laurent Fullana. "This elevates Daphnis to the product of choice for applications like gimbals, high-end vehicles sights and infrared search and track systems," he adds. "Moreover, the ability to obtain an HD image format from a detector whose size fits previous platform generations is a real benefit as it facilitates customer system upgrades."

The Daphnis-HD MW IR detector brings a wider field of view, longer-range capabilities and all-important higher resolution to elite military equipment. Key features include:

- higher resolution (1280 x 720 pixels);
- longer range (achieving up to 55% DRI range improvement on the preceding generation of IR detectors);
- wider field of view (enabling up to twice the field coverage of 15 μ m pixel-pitch MWIR detectors);
- ROIC (read-out integrated circuit) functionalities with digital output for easy integration; and
- full compatibility with HD screen formats and visible or SWIR camera channels.

www.sofradir.com

Sofradir celebrates 30th anniversary at SPIE DCS

At the SPIE Defense + Commercial Sensing (DCS 2016) event in Baltimore, MD, USA (17–21 April), Sofradir marked its 30th anniversary.

At DCS, Sofradir unveiled its extended Daphnis MW portfolio featuring the HD version, which is claimed to be the first high-definition (HD)-format midwave IR detector based on the new 10 μ m pixel-pitch industry standard (which replaces 15 μ m pixel-pitch generation models). With 1280 x

720 pixels packaged to fit previous platform generations, Daphnis-HD MW enables imaging equipment used in airborne, naval and ground vehicles to achieve longer range, wider field of view and better resolution than previously available (significantly improving target detection, recognition and identification ranges).

Sofradir's IR detectors are at the center of multiple military and space programs and applications:

thermal imagers, missile seekers, surveillance systems and targeting systems. Its IR detectors have played a key role in space-borne earth observation, meteorology and environment monitoring such as Sentinel 2, Tropomi, Hayabusa 2 and, more recently, ExoMars space programs (now totaling over 70 flight models to date).

<http://spie.org/conferences-and-exhibitions/defense--commercial-sensing>

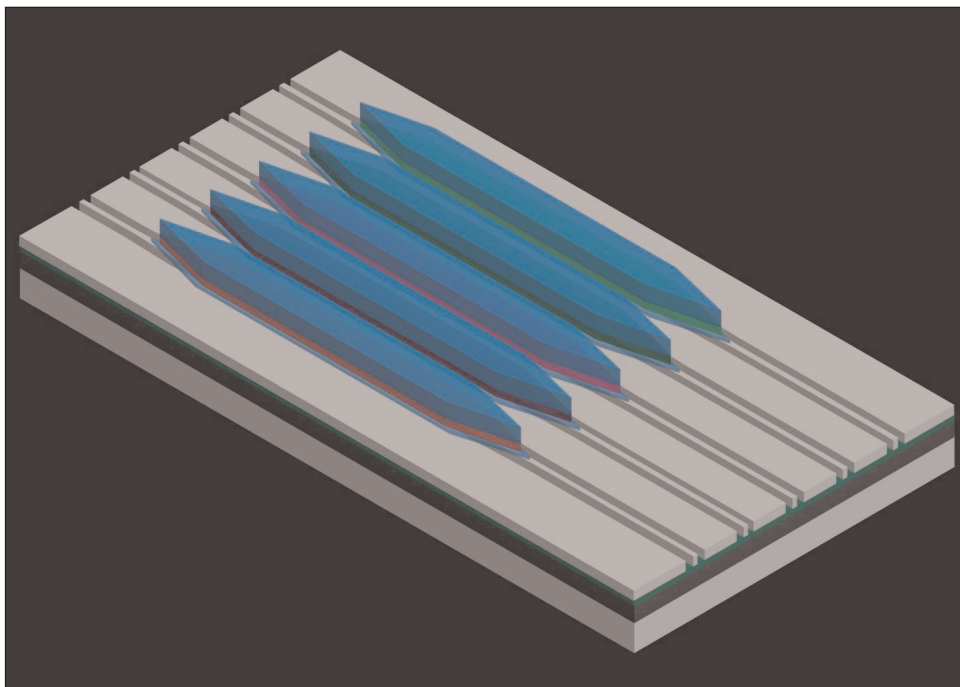
UCSB-led team reports first quantum cascade laser on silicon

Eliminates the need for external light source for mid-IR silicon photonic devices or photonic circuits

A team led by Alexander Spott of University of California, Santa Barbara — in collaboration with the US Naval Research Laboratory (NRL) and the University of Wisconsin, Madison — has fabricated what is said to be the first quantum cascade laser (QCL) on silicon. The advance may have applications that span from chemical bond spectroscopy and gas sensing to astronomy and free-space communications.

Integrating lasers directly on silicon chips is challenging, but it is much more efficient and compact than coupling external laser light to the chips. The indirect bandgap of silicon makes it difficult to fabricate a laser from silicon, compared with diode lasers fabricated from III-V materials such as indium phosphide (InP) or gallium arsenide (GaAs). By directly bonding a III-V layer on top of the silicon wafer and then using the III-V layers to generate gain for the laser, this same research group previously integrated a multiple quantum well (MQW) laser on silicon that operates at $2\mu\text{m}$. However, limitations in diode lasers prevent going to longer wavelengths where there are many more applications, so the group instead turned its attention to using quantum cascade lasers.

Fabricating a quantum cascade laser on silicon was a challenging task made more difficult by the fact that silicon dioxide becomes heavily absorptive at longer wavelengths in the mid-infrared. "Not only did we have to build a different type of laser on silicon, we had to build a different silicon waveguide too," says Spott. "We built a type of waveguide called a SONOI waveguide [silicon-on-nitride-on-insulator], which uses a layer of silicon nitride [SiN] underneath the silicon waveguide, rather than just SiO_2 ," he adds.



3D artistic depiction of multiple quantum cascade lasers integrated above silicon waveguides. Credit: Alexander Spott.

The development could lead to several applications. "Traditionally, silicon photonic devices operate at near-infrared wavelengths, with applications in data transmission and telecommunications," Spott says. "However, there is emerging research interest in building these silicon photonic devices for longer mid-infrared wavelengths, for a range of sensing and detection applications, such as chemical bond spectroscopy, gas sensing, astronomy, oceanographic sensing, thermal imaging, explosive detection, and free-space communications," he adds.

The next step for the team is to improve the heat dissipation to improve the performance of the QCLs and to allow them to make continuous-wave (cw) QCLs on silicon. "We generally hope to improve the design to get higher powers and efficiency," Spott says. "This brings us closer to building fully integrated mid-infrared

devices on a silicon chip, such as spectrometers or gas sensors," he adds. "Silicon is inexpensive, the fabrication can be scaled up to significantly reduce the cost of individual chips, and many small devices can be built on the same silicon chip — for example, multiple different types of sensors operating at different mid-infrared wavelengths."

A paper 'Quantum Cascade Laser on Silicon at $4.8\mu\text{m}$ ' by Alexander Spott, Jon Peters, Michael Davenport, Eric Stanton, Charles Merritt, William Bewley, Igor Vurgaftman, Jerry Meyer, Jeremy Kirch, Luke Mawst, Dan Botez and John Bowers will be presented at the Conference on Lasers and Electro-Optics (CLEO 2016) on 9 June (2–4pm) in the San Jose Convention Center, San Jose, CA, USA.

<https://labs.chem.ucsb.edu/bowers>
www.nrl.navy.mil
www.wisc.edu
www.cleoconference.org

POET demonstrates resonant cavity detector performance exceeding best-in-class

Process transfer to 6" foundry on target for 2016 product launch

POET Technologies Inc of San Jose, CA, USA — which has developed the proprietary planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — has provided updates toward key operational milestones and reaffirmed its confidence to prototype its first detector product by the end of 2016.

POET aims to commercialize its integrated resonant cavity detector as its first product and demonstrate this prototype by the end of 2016. Fabricated recently at the firm's foundry supplier, 6-inch detector wafers based on the POET platform demonstrated superior responsivity parameters relative to best-in-class performance, it is claimed.

The detectors differ from conventional devices in that they are resonant cavity designs, which enable greater sensitivity in detector applications. Benchmark parameters (such as responsivity) far exceed the performance of detectors currently on the market, it is claimed. At a bias voltage of 3.3V, POET detectors have demonstrated a room-

temperature thyristor enhanced saturated responsivity of 13A/W at an input optical power threshold of less than 200mW and at an aperture of 10mm. This is about 20 times higher on a 3 times smaller device relative to typical 850nm PIN diodes. These results from the first set of detector wafers from the production foundry provide critical proof points for POET to introduce a differentiated detector product to the market later this year, the firm says.

Confirming a key milestone in validating POET's process technology transfer, multiple 6-inch wafer lots of vertical-cavity surface-emitting lasers (VCSELs) and transistors were also processed at the high-volume production foundry supplier. Testing and characterization of the devices is underway, and POET expects to require further development cycles through additional wafer processing to fully achieve the true potential for the integrated optoelectronic devices.

"Over the next few months we plan to make additional announcements on our key milestones and device performance as we continue

our aggressive drive towards commercialization of POET's highly differentiated technology," says chief operating officer Dr Subhash Deshmukh.

Chief scientist Dr Geoff Taylor is retiring (effective 30 April), in order to focus on recuperating from multiple surgeries. "Over the past several months I have been dealing with surgeries arising from complications with a knee replacement and therefore been unable to fulfill my duties," says Taylor. "The company is now on the verge of successful growth under its new leadership and I believe is well positioned to produce critical prototypes necessary for POET to be recognized as a leader in the data communications market," he adds.

"We expect to remain on-plan in the execution of our lab-to-fab commercialization initiative to achieve market success for the technology developed and nurtured by Geoff over the past several years," comments CEO Suresh Venkatesan.

www.poet-technologies.com/poet-operations-update

VI Systems demos record 54Gb/s reach of 2.2km MMF using single-mode VCSEL with OOK modulation

New 850nm VCSEL design features narrow optical spectrum at high optical output power

VI Systems GmbH of Berlin, Germany (a fabless spin-off of the Technical University of Berlin and the A. F. Ioffe Physico-Technical Institute in St Petersburg, Russia) has demonstrated a record transmission distance of 2.2km of multimode OM4 fiber at a data rate of 54Gb/s. The standard graded index fiber is specified with 50/125µm.

Developed with the help of advanced computer simulation

software (implemented to advance the performance of the firm's laser products), the new 850nm vertical-cavity surface-emitting laser (VCSEL) design features a narrow optical spectrum at a high optical output power.

The transmission experiment is based on a conventional non-return-to-zero (NRZ) modulation format. This on-off keying (OOK) modulation scheme favors low

latency performance in communication networks compared with more complex higher-order modulation.

Details of the achievement were published on 14 April (G Stepniak et al, '54 Gbps OOK transmission using single-mode VCSEL up to 2.2 km MMF', Electronics Letters vol52 (2016) no8, p633).

<http://digital-library.theiet.org/content/journals/10.1049/el.2015.4264>
www.v-i-systems.com

GigOptix's Q1 sales up 25% year-on-year to record \$11.4m Firm renamed GigPeak after acquiring Magnum Semiconductor

Financial results have been announced for GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks) for first-quarter 2016 to 27 March (not including any contribution from Magnum Semiconductor Inc, acquired subsequently on 5 April, after which GigOptix was renamed GigPeak Inc, focusing on ICs and software solutions for high-speed connectivity and high-quality video compression over the network and cloud).

Revenue rose for the eighth consecutive quarter to a record \$11.4m, up 3% on \$11.1m last quarter and up 25% on \$9.1m a year ago.

"First-quarter 2016 was an exceptional quarter to conclude our exactly 9 year history of GigOptix going back to our inception in 2007," says founder, chairman & CEO Dr Avi Katz.

Gross margin has risen further, from 62% a year ago and 67% last quarter to a record 69%.

Excluding \$0.8m of expenses incurred from due diligence and negotiation of the Magnum Semiconductor acquisition, net income has risen from \$0.7m (\$0.02 per diluted share) a year ago and \$2.2m (\$0.05 per diluted share) last quarter to \$2.4m (\$0.05 per diluted share). Likewise, adjusted EBITDA has risen from \$1.4m a year ago and \$2.9m last quarter to \$3m.

Free cash flow generation was a record \$2.8m, compared with \$20,000 last quarter and outflow of -\$0.7m a year ago (and about 3.5 times higher than the \$0.8m generated in full-year 2015).

During the quarter, the firm invested \$1.2m in Anagog Inc in January, but also raised \$4.7m from a direct investment by Shanghai Pudong Science and Technology Investment Co Ltd (PDSTI) in March.

Hence, during the quarter, total cash and cash equivalents rose from \$30.2m to \$36.8m.

"We delivered yet again another quarter of historic record revenue, highest ever gross margin, enhanced profitability, and generated exceptional record free cash flow," notes Katz. "These results demonstrate the continued strength of our business model and core business execution in all our served markets," he adds.

"With a strong foundation in place, the recent acquisition of Magnum Semiconductor significantly enlarges our financial profile," says Katz.

Following the acquisition, the firm expects to deliver a 50% increase in full-year revenue over 2015, with further improvements to gross margin, improved profitability, and higher than initially guided non-GAAP earnings per share.

"Supporting our better financial outlook is the fact that the acquisition gives us a much broader product portfolio with the

Driven by the acquisition ... it is expected that the targeted available markets have risen from \$1bn to about \$5bn.

We will likely move later this year to line up the company along two business lines: enterprise networking (which will include telecom, datacom and broadcasting, and which will be named the GigOptix product line) and consumer and cloud connectivity (which will be named the GigCloud line)

addition of software-based solutions to deliver best-in-class video and data-streaming capabilities to the world's leading broadcasting, IoT [Internet of Things] and consumer customers," says Katz. "With the exponential growth in video traffic putting more pressure on the network, we expect a growing demand for the entire GigPeak product portfolio and solutions that deliver real-time, high-speed and high-quality information streaming and video compression in the cable, satellite, telco/IPTV and mobile/over the top markets," he adds.

Driven by the acquisition and the opportunities to expand the firm's focus from the enterprise, telecom and datacom networking markets into the cloud connectivity, broadcasting head-end, IoT, and consumer markets, it is expected that the targeted available markets have risen from \$1bn to about \$5bn. "As we will reorganize GigPeak to address these markets, we will report our financial results beginning 1 January 2016 without the historical classification of High-Speed Communications and Industrial ASICs, as we did in the previous years," notes Katz.

"We will likely move later this year to line up the company along two business lines: enterprise networking (which will include telecom, datacom and broadcasting, and which will be named the GigOptix product line) and consumer and cloud connectivity (which will be named the GigCloud line). When we complete this realignment in the future, we will then start to report according to those two business lines."

The initial revenue outlook for second-quarter 2016 (which will include about 10 weeks of sales from Magnum Semiconductor products) is expected to be \$15-15.3m, up 33% on Q1/2016 and up 55% year-on-year.

www.gigoptix.com

GigOptix launches complete 28G/100G chipset portfolio for short- and long-reach Ethernet product datacenter applications

GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks) has launched a complete chipset portfolio for 28Gbps- and 100Gbps-based solutions for short-reach (SR) and long-reach (LR) Ethernet applications for inter- and intra-datacenter connectivity.

“With an already dominating market share in the current generation of 40Gbps active optical cables (AOCs) and transceivers for data-center connectivity, GigOptix is pleased to announce that it started shipping complete production chipsets for 100Gbps short-reach (SR) and long-reach (LR) Ethernet applications for inter- and intra-datacenter connectivity,” says Tom Kapucija, director of datacom marketing. The chipsets comprise: 1x and 4x short-reach trans-impedance amplifier (TIA) receiver (HXR8201 and HXR8204), vertical-cavity surface-emitting laser (VCSEL) driver (HXT8201 and HXT8204), 1x and 4x long-reach directly modulated laser (DML) driver (HXT42100 and HXT42400), complemented by the proven clock & data recovery (CDR) technology represented by the 2x and 4x CDR/re-timer chips (HXC42200 and HXC42400).

GigOptix short- and long-reach configurations

In addition to the quad-channel devices, GigOptix is releasing production samples of its single-channel products for SFP28+ modules and its 12-channel products for super-computer applications.

For SR10 applications

In addition, the 12-channel solutions for super-computer applications consist of the following configuration:

- HXT8201 — single-channel, 28Gbps VCSEL driver;

- HXR8201 — single-channel, 28Gbps TIA+PA (power amplifier) receiver; and

- HXC42400 — quad-channel, 28Gbps CDR/re-timer.

Short-reach solutions

The single- and 12-channel TIA+PA receivers are developed around the HXR8204 four-channel receiver architecture with integrated TIA provides 60_APP input sensitivity at 28Gbps with 10^{-12} bit error rate (BER), AGC and ATC, and a limiting post-amplifier stage. Linear per-channel RSSI outputs are provided to enable active alignment during manufacturing in order to provide optimum performance and manufacturability. The 1MHz I²C interface enables full control of additional functionality such as signal detect and squelch, pre-emphasis, maskable interrupt generation, internal temperature monitor selection, channel polarity inversion, and output voltage swing with enable.

The single- and 12-channel VCSEL drivers are developed upon the HXT8204 four-channel VCSEL driver architecture which supports modulation and average VCSEL currents up to 10mA with a dedicated BurnIn capability up to 15mA average current. The 1MHz I²C interface enables full control of all driver functions including input equalization, output peaking and peaking duration, signal detect and squelch, channel polarity inversion, diagnostics such as average current and temperature monitoring as well as user-maskable interrupts and VCSEL voltage supervisory functions.

Long-reach solutions

The HXT42100 and HXT42400 DML drivers share the same architecture with a high level of integration, low power dissipation, and small form factor. The HXT42100 single-channel driver footprint is

sufficiently small to use within a TOSA (TO-can) solution. Both DML driver solutions support low voltage supply operation as low as 2.5V with modulation and bias currents of 50mA and 50mA respectively, enabling the next generation of low-power modules, and can be driven with supply voltages up to 3.3V if higher modulation and bias currents are required. A single-channel operating at 2.5V will dissipate less than 200mW of chip power. Neither of the two devices require any external digital analog convertors (DAC) for operations.

A high level of integration is provided with both the HXT42100 and HXT42400 by incorporating the modulation, bias and pulse-shaping DAC into the devices with an integrated I²C interface for control, monitoring, fault and status detection. The 1MHz I²C interface enables full control of additional functionality such as signal detect and squelch, bandwidth adjust, maskable fault and interrupt generation, internal temperature monitor selection, channel polarity inversion, and programmable CTLE input equalization.

“Our patented, low-power digital CDR architecture complements our leading datacom transimpedance amplifier (TIA) and laser driver (LD) portfolio to support both short- and long-reach applications,” says Tom Kapucija. “GigOptix will continue to leverage its innovative products and architectures for the current generation and future generations of datacenter connectivity solutions.”

GigOptix gave SFP28+ and QSFP28 product demonstrations at the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March).

www.gigoptix.com

www.ofcconference.org

Mellanox announces first 200Gb/s silicon photonics devices, doubling performance in QSFP form factor

At the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March), Mellanox Technologies Ltd of Sunnyvale, CA, USA and Yokneam, Israel (a supplier of end-to-end InfiniBand and Ethernet interconnect solutions and services for servers, storage and hyper-converged infrastructure) demonstrated 50Gb/s silicon photonics optical modulators and detectors. Since the devices are the key component in 200Gb/s and 400Gb/s LinkX cables and transceivers, the demonstration is an important milestone toward providing end-to-end solutions for HDR 200Gb/s InfiniBand and Ethernet interconnect infrastructure, according to the firm.

“Silicon photonics is the enabling

technology for 200Gb/s InfiniBand and Ethernet networks,” says Amir Prescher, executive VP of business development & interconnect products. “The QSFP56 doubles the front-panel density for next-generation switches; enables 200G copper DACs and 50G breakout cables for adapters and inside-the-rack applications; and silicon photonics transceivers supports all data center reaches to 2km,” he adds.

Mellanox plans to offer 50Gb/s and 200Gb/s direct-attach copper cables (DACs); copper splitter cables (QSFP56 to 4x SFP56); silicon photonics-based active optical cables (AOCs) for reaches to 200m; and silicon photonics transceivers for reaches to 2km. Mellanox’s 200Gb/s cables and transceivers will seam-

lessly support previous generations of 40 and 100Gb/s networks.

“The transition from 40G to 100G networks inside the data center has begun in earnest,” comments Dale Murray, principal analyst at Light-Counting Market Research. “This announcement comes just as the cloud and hyperscalers are planning their migration to 200G and 400G.”

Mellanox’s LinkX interconnect product family includes 10, 40, 25, 50 and 100Gb/s copper cables, active optical cables and transceivers for both single-mode fiber and multi-mode fiber applications. The newest LinkX additions, introduced at OFC, are 25Gb/s transceivers and active optical cables, and use the SFP28 form factor.

www.mellanox.com

Mellanox and InnoLight announce availability and interoperability of 100Gb/s PSM4 transceivers at 1310 and 1550nm wavelengths

At OFC, Mellanox, network test firm Ixia of Calabasas, CA, USA and InnoLight Technology Corp of Suzhou, China (which designs and makes optical transceivers for cloud computing) announced the advent of interoperable parallel single-mode (PSM4) transceivers that allow cloud and Web 2.0 companies to mix and match transceivers in their data centers. Representing an industry first, the Ethernet demonstration at OFC with Ixia’s QSFP28 Xcellon-Multis Load module and Mellanox’s Spectrum switch confirms 50Gb/s and 100Gb/s interoperability between Mellanox’s 1550nm PSM4 transceivers and InnoLight’s 1310nm PSM4 transceivers.

“Interoperability is an important consideration for Web 2.0, cloud and telecom customers,” says InnoLight’s chief marketing officer Osa Mok. “We are delighted to participate with Mellanox and Ixia to showcase the expanded capability of our wavelength-agnostic transceivers.”

“We selected PSM4 transceivers because they are currently the best option for scaling networks from 10 and 40G Ethernet to 25, 50 and 100G Ethernet,” comments Yuval Bachar, principal engineer, global infrastructure architecture & strategy at LinkedIn. “With PSM4, the transceivers are readily available at high volumes and we can have networks with a mix of 50G links and 100G links by splitting the PSM4 to two 50G ports,” he adds.

“Interoperability provides more options and better solutions for our customers,” says Amir Prescher, senior VP & general manager of Mellanox’s LinkX Interconnect business unit. “We are demonstrating end-to-end networking using our extensive LinkX interconnect product family including 25, 50 and 100Gb/s copper cables, active optical cables and transceivers for both single-mode and multi-mode fiber applications,” he adds. “The end-to-end demos with 32 100Gb/s ports, ConnectX-4 adapters with

25, 50 and 100Gb/s ports, and the newest LinkX products: 25Gb/s transceivers and active optical cables in the popular SFP28 form factor.”

To ensure that all LinkX cables and transceivers work the first time every time, Mellanox subjects its products to a full system test in a stressed environment. So, network engineers don’t waste time debugging a new installation with inadequately tested products. LinkX products deliver higher quality and signal integrity, allowing installers to bring up new clusters rapidly due to fewer interconnect problems.

To maximize overall data-center performance, all commercial versions of Mellanox’s LinkX interconnect products endure full system testing to a bit error rate (BER) of 10^{-15} (which provides 1000x fewer transmission errors than many competing products, it is claimed). Fewer transmission errors translate to fewer re-tries, higher system performance, and more revenue-generating traffic, says Mellanox.

Kaiam demonstrates first complete 100Gb/s CWDM4 silicon photonics transceiver

At the Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22–24 March), Kaiam Corp of Newark, CA, USA — a private company founded in 2010 commercializing hybrid photonic integrated circuit (PIC) technology — demonstrated what it claims is the first silicon photonics-based 100Gb/s CWDM4 transceiver.

To showcase the capability of the QSFP28 transceiver, Kaiam gave a live demonstration with the module connected to a standard directly modulated laser (DML) version of its CWDM4 transceiver through 10km of single-mode fiber. The silicon photonics module combines all the high-speed electronics — modulator driver, transimpedance amplifier (TIA) and clock & data recovery (CDRs) — together with high-performance silicon modulators and detectors in a

single 3D chip stack. The wavelength multiplexing and demultiplexing is realized in the firm's glass-based planar lightwave circuits (PLCs), while the continuous-wave (CW) light is generated by indium phosphide lasers, coupled to the PLCs using Kaiam's proprietary MEMS-based alignment technology. Standard grating couplers connect the glass PLCs to the silicon photonics IC.

"Data-center operators are continually looking for performance and cost improvements as many of them transition to WDM interfaces," says VP of engineering Dr Ron Kaneshiro. "This silicon photonics transceiver highlights that Kaiam has the tools available to deliver products in volume [via its large-scale manufacturing in Livingston, Scotland, UK] to meet and exceed our customers' demands," he adds.

"Each material system has its own strengths and weaknesses. Our technology allows us to combine the best materials for each function in a simple low-cost integrated module," notes CEO Dr Bardia Pezeshki. "For example, implementing wavelength multiplexing and demultiplexing in silicon photonics has traditionally been difficult in uncooled applications. By combining Kaiam's temperature-insensitive and low-cost PLC technology with silicon photonics ICs, we can bring benefits of electronic integration to applications requiring WDM interfaces," he adds. "Our demonstration further shows that Kaiam's MEMS approach is well suited for hybrid integration of a range of optical technologies from DMLs to silicon photonics."

www.kaiam.com

Imec enhances silicon photonics for 50G NRZ lane rates

At the Optical Fiber Communication Conference & Exhibition (OFC 2016) imec presented improvements in performance of various key building blocks of its wafer-scale integrated silicon photonics platform (iSiPP). The new results expand imec's iSiPP device portfolio to support 50Gb/s non-return-to-zero (NRZ) optical lane rates, and represent a milestone for the realization of high-data-rate silicon integrated optical interconnects targeting high-density, high-bandwidth, low-power telecom and datacom transceivers, as well as for low-cost large-volume applications such as sensors or LiDAR, says imec.

Through process and design optimization, imec has improved the operating speed of the silicon-based traveling-wave Mach-Zehnder modulators and ring modulators to reach 50Gb/s NRZ lane rates. Also, a C-band GeSi (germanium-silicon alloy) electro-absorption modulator was developed with an electro-

optical bandwidth beyond 50GHz, enabling NRZ modulation at 56Gb/s and beyond. All modulator types can be driven with competitive drive voltages of 2Vpp or below, enabling compatibility with power-efficient CMOS driver circuits.

The responsivity of the high-speed germanium (Ge) photodetectors has been improved to 1A/W, enabling highly sensitive 50Gb/s NRZ receivers both in the C-band and the O-band. Also, edge coupling structures were developed for broadband optical coupling to high-NA (numerical aperture) and lensed fiber with less than 3dB insertion loss in the C-band. Moreover, designers can exploit the patterning fidelity provided by 193nm lithography, enabling robust active and passive waveguide devices.

The 50Gb/s components are included in imec's 200mm silicon photonics multi-project wafer (MPW) foundry offer, and are supported by a process design kit (PDK). The MPW service is available via the

Europractice IC service and MOSIS, a provider of low-cost prototyping and small-volume production services for custom ICs. Imec's active iSiPP50G run is now open for registration (with a deadline of 28 June) for first wafers out on 9 January 2017.

Imec also provides technology customization options with dedicated wafer fabrication services supported by a PDK. This service enables the use of full-size reticles, delivery of full wafers, and access to specialty modules enabling high-efficiency integrated heaters, MOSCAP devices and flip-chip assembly etc.

The PDKs have been validated with silicon data, based on a minimum of two process runs for most of the components, and describe the process and device performance statistics. They are supported in various electronic design automation (EDA) environments and include DRC (design rule checking), supporting first-time right designs.

www.imec.be

Semtech announces initial production release of quad 25G chipset for 100G SR4 optical modules and AOCs

Semtech Corp of Camarillo, CA, USA, which supplies analog and mixed-signal semiconductors for high-end consumer, enterprise computing, communications and industrial equipment, has announced the production release of its GN2108 and GN2109 chipset for quad-channel 100G-SR4 optical interconnects operating at 25.78Gb/s.

The GN2108 is a quad-channel clock & data recovery (CDR) chip with integrated vertical-cavity surface-emitting laser (VCSEL) drivers, and the GN2109 is a quad-channel CDR with integrated transimpedance amplifiers (TIAs). A full suite of on-chip features minimizes external components and helps users to speed up their hardware and firmware development. The GN2108 and GN2109 chipset offers users developing optical modules, active optical cables and optical interconnects what is claimed to be best-in-class link performance, high flexibility and a low

overall solution cost.

The GN2108 VCSEL driver was architected to compensate for optical distortion introduced by VCSELs. This enables several benefits, including extended reach well beyond the 100G-SR4 standard to greater than 300m over OM4 multi-mode fiber (and greater than 150m over OM3 multi-mode fiber), operation with lower-bandwidth and lower-cost VCSELs, and operation with lower VCSEL bias settings for lower power and higher VCSEL reliability. The GN2108 and GN2109 chipset's comprehensive digital circuitry, together with a set of analog-to-digital (ADC) and digital-to-analog converters (DAC), implements a complete set of alarms monitoring and test features, which enables the use of cost-effective micro-controller units (MCUs) and simplifies module-level firmware design (speeding time-to-market) as well as aiding module debugging and production testing. In addition, the GN2109's receiver

input sensitivity and crosstalk performance makes it suitable for both SR4 multi-mode as well as PSM4 single-mode optical interconnects.

"The GN2108 and GN2109 chipset has strong traction with our customers," says Dr Timothy Vang, senior director of datacom marketing for Semtech's Signal Integrity Product Group. "The performance and feature set of the GN2108 and GN2109 is enabling our customers to quickly bring to market winning solutions for 100Gbps QSFP28 and active optical cables (AOCs) for datacenters and a wide range of other applications," he adds.

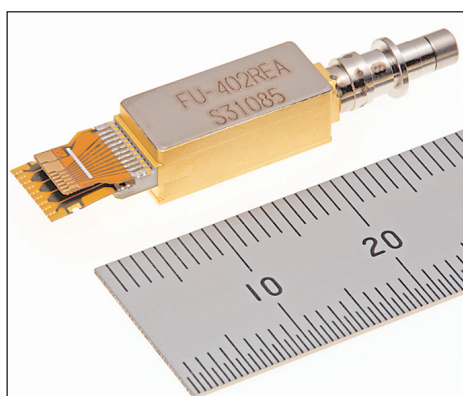
Semtech demonstrated the GN2108 and GN2109 by appointment in booth 1383 at the Optical Fiber Communication Conference (OFC 2016) in Anaheim, CA, USA (22–24 March). The GN2108 and GN2109 are in initial production now. Semtech offers comprehensive design assistance, including field- and factory-based support.

www.semtech.com

Mitsubishi Electric shrinks integrated 100Gbps 40km EML-TOSA to 30% size of predecessor

Tokyo-based Mitsubishi Electric Corp says that on 1 July it will start shipping a laser-diode transmitter optical subassembly (TOSA) capable of supporting 100Gbps optical transmissions. The new FU-402REA was displayed at the Optical Fiber Communication conference & exhibition 2016 (OFC) in Anaheim, CA, USA (20–24 March).

The new TOSA, which comprises four 1.3 μ m-wavelength electro-absorption modulator lasers (EMLs) integrated with an optical multiplexer, offers what is claimed to be one of most compact EML-TOSA solutions available for IEEE 100GBASE-ER4 applications. Modulated by a small driving voltage, operating power consumption is



Mitsubishi Electric's new FU-402REA 100Gbps EML-TOSA.

low (2W maximum) with a high extinction ratio (9dB typical) for an output power of -2dBm to +2dBm.

Mitsubishi Electric says that, in response to the growing need to

install communication equipment in increasingly confined spaces, its new laser-diode TOSA offers long-distance 40km transmission capability (e.g. between data centers) in one of the industry's smallest footprints. Optical multiplexer and other components have been optimized to reduce the package size to 6.5mm x 25.0mm x 5.4mm (just 30% that of its predecessor FU-401REA), compliant with common specifications for CFP4 optical transceivers. This combination is expected to help downsize 100Gbps communication facilities and expand high-speed 100Gbps optical transmission networks.

www.mitsubishielectric.com/semiconductors/products/opt

II-VI Inc showcases new optical amplifiers, pump lasers, optical monitors and transceiver-embedded components

At the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March), engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA showcased a portfolio of optical communication products, including the following:

Intelligent subsystems & line-cards:

II-VI designs and makes line-cards for next-generation systems using a broad portfolio of small components and intelligent modules produced in-house. The line-cards feature mature, stable and reliable software controls as well as differentiated optical monitoring methods.

Embedded optical monitoring:

II-VI's channel monitors are claimed to be the world's smallest and capable of monitoring super-channels on a flexible grid. The firm's new optical channel monitor (OCM) features a dwell mode to enable advanced signal analysis on a selected channel. II-VI's new OTDR+ (optical time-domain reflectometry) platform, designed with patent-pending technologies, performs sensitive fault location measurements using very low optical power.

Vertically integrated optical amplifiers:

II-VI designs and manufactures optical amplifiers including the pump laser chips and micro-optics, packaged with other optical functions into hybrids, arrays or hybrid-arrays, in order to minimize cost and size.

This results in custom-designed optical amplifiers that are small, efficient and cost effective, says II-VI.

980nm pump lasers:

II-VI continues to evolve its 980nm pump laser portfolio, either boosting the launched optical power to higher levels or shrinking the package size. The new 1W pump laser can replace pairs of lower-power modules, enabling cost-effective, more thermally efficient and environmentally conscious designs.

The cooled dual-chip pump laser delivers 2 x 810mW of optical power to meet demanding arrayed or multi-stage amplifier designs.

Transceiver-embedded amplifiers & components:

II-VI offers a complete portfolio of small, hybrid and tunable optical components designed to meet the compact physical requirements of high-density transceivers. The new

8-pin uncooled 980nm pump lasers feature 80µm-diameter tight-bend low-loss fiber pigtails designed to fit in tight spaces.

Tunable receivers & burst-mode amplifiers for NG-PON2:

For upstream time wavelength division multiplexing (TWDM) passive optical network (PON) links, II-VI recently announced a prototype-stage burst-mode gain-controlled optical amplifier. For downstream transmission, II-VI has demonstrated a miniaturized tunable receiver that can be integrated in standard bi-directional optical subassemblies (BOSAs).

Products for optical switching & wavelength routing:

II-VI says that its optical switches and flat-top tunable filters for 50GHz channel spacing are compact and cost-effective solutions for wavelength routing and optical path-protection switching at the edge of the network. The high-port-count MEMS optical switch is especially suited to applications requiring frequent switching, such as when monitoring multiple points in the network, says the firm.

www.ii-vi-photonics.com

II-VI introduces burst-mode gain-controlled optical amplifier for NG-PON2 broadband access networks

II-VI has announced prototype-stage availability of a burst-mode gain-controlled optical amplifier designed for upstream transmission in NG-PON2 broadband access networks.

The Full Service Access Network (FSAN) industry interest group has selected TWDM (time and wavelength division multiplexed) PON technology as the NG-PON2 standard for the next-generation passive optical network architecture. This architecture supports the convergence of the communication infrastructure for services such as residential broadband, enterprise access and wireless backhaul. II-VI

has developed an optical amplifier for TWDM PON upstream links using patent-pending technology.

"This new technology showcases our ability to leverage our core expertise and deliver application-specific optical amplifier solutions," says Dr Sanjai Parthasarathi, VP, product marketing & strategy, Optical Communications Group. "We designed an optical amplifier to match the requirements of TWDM PON upstream transmission and enable service providers to increase bandwidth to their subscribers over their existing passive optical network infrastructure."

Passive optical networks are eco-

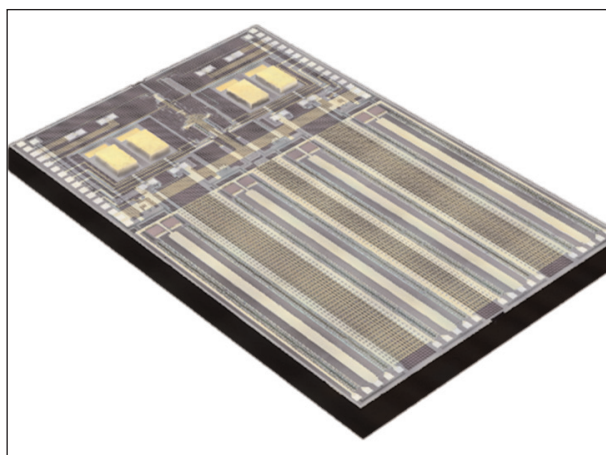
nomical due to their broadcast architecture. II-VI says that its new optical amplifier implements a novel gain-control technique that adapts instantaneously to rapid changes in optical signal levels received, as subscribers take turns communicating upstream from various distances. This fast adaptability enables service providers to scale up the bandwidth on their existing distribution infrastructure, while the time-shared functionality minimizes capital expenditures.

II-VI's burst-mode gain-controlled optical amplifiers have completed customer laboratory trials. Prototype units are available for evaluation.

MACOM launches first CWDM₄ L-PIC for 100G data-center applications

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched the MAOP-L284CN, a 4-channel, 28Gbps silicon photonic integrated circuit (PIC) integrated with lasers (L-PIC) to provide a driverless 100G transmit solution for CWDM₄ and CLR₄ applications.

To meet the explosive growth of data traffic driven by video and mobile, major Internet content providers (such as Amazon, Microsoft, Google and Facebook) are building hyper-scale data-centers, which require high-speed interconnect solutions that are power efficient, compact and cost optimized. MACOM says that its Etched Facet Technology (EFT) continuous-wave (cw) lasers are attached to the silicon PIC using its proprietary self-alignment process (SAEFT) with high coupling efficiency, offering a power efficient solution at reduced manufacturing cost.



MACOM's new L284CN 4-channel, 28Gbps L-PIC.

The MAOP-L284CN features four high-bandwidth Mach-Zehnder modulators integrated with four lasers (emitting at wavelengths of 1270, 1290, 1310 and 1330nm) and a CWDM multiplexer, with each channel operating at up to 28Gb/s. The L-PIC operates on a standard single-mode optical fiber, and includes integrated tap detectors for fiber alignment, system initialization and closed-loop control. A single fiber aligned to the output edge coupler of this 4.1mm x 6.5mm

die is the only optical requirement for implementing this device into QSFP28 transceiver applications. MACOM is also offering the MASC-37053A modulator driver integrated with CDR, matched with this L-PIC for optimized performance and power dissipation.

"MACOM's L-PIC solves the key challenge of aligning lasers to the silicon PIC with high yield and high coupling efficiency, making the adoption of

silicon PICs a reality for high-speed optical interconnects within the datacenter," states Vivek Rajgarhia, VP of strategy, High-Speed Networking, for MACOM.

The new L-PIC was on display at the Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22-24 March).

www.macom.com/products/product-detail/MAOP-L284CN
www.macom.com/opto
www.ofcconference.org

MACOM launches first 64Gbaud linear modulator driver for 400G and beyond

At the Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22-24 March), M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched what is claimed to be the industry's first 64 Gbaud quad-channel linear Mach-Zehnder modulator driver. The MAOM-006428 will support data rates of 400Gbps and beyond on a single wavelength for long-haul communications using coherent technology.

By increasing the data rate on a single wavelength, operators can

increase capacity and reduce the overall cost-per-bit of transmission. Metro networks can use higher-order modulation formats at 32Gbaud to achieve this, but these higher-order modulation formats such as 32 and 64 QAM have very limited reach due to signal-to-noise requirements. Long-haul networks therefore require the use of higher baud rates up to 64G to achieve data rates of 400G on a single wavelength.

The MAOM-006428 modulator driver features surface-mount inputs and G3PO outputs to mate with the next-generation high-bandwidth modulator which is currently being standardized by the

Optical Internetworking Forum (OIF). The device has linear performance to support higher-order modulation formats with low power consumption and a compact form factor taking up <275mm² of PCB real estate.

"The MAOM-006428, in addition to being the industry's first 64 Gbaud linear modulator driver, provides customers with a revolutionary package design that delivers the high performance required by 64Gbaud in a cost-effective form factor," believes Ray Moroney, direct of product marketing for High-Performance Analog at MACOM.

www.macom.com/opto-1

MACOM launches first optical subassemblies since FiBest acquisition

At the Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22–24 March), MACOM launched its first OSA products since the acquisition of Japan-based FiBest Ltd (a merchant-market component supplier of optical subassemblies) in December. Optimized for 100G LR4 applications and targeted at the QSFP28, CFP4, CFP2 and CFP form factors, the FBT4821AG transmitter optical subassembly (TOSA) and the FBR4102PB receiver optical subassembly (ROSA) were on display in private demonstrations at OFC.

High density and low power consumption are critical enablers for addressing demand for higher-bandwidth long-reach connectivity,

which underpins the communication of aggregated cloud, data-center and mobile traffic, says MACOM. The FBT4821AG and FBR4102PB offer a 100G LR4 solution for integration in high-density form factors such as QSFP28, while exceeding link budget requirements for communication over 10km of single-mode fiber. MACOM says that its TOSA and ROSA solutions, along with the firm's de-facto standard clock & data recovery (CDR) integrated circuits, provide an optimized solution for implementing 100G LR4 optical modules.

The FBT4821AG provides optimal low power consumption by integrating the directly modulated laser (DML) driver function within the TOSA.

This enables the TOSA to interface directly with MACOM's low-power M37049 CDR and match to the internal laser without requiring power-hungry back termination. Integration of the DML driver also enables a simpler module implementation and excellent mask margin, the firm claims.

As well as low power consumption, the FBR4102PB ROSA offers what is claimed to be industry-leading sensitivity and overload and is designed to interface with MACOM's M37046 CDR. The ROSA features operation up to 28Gb/s and per-channel receive signal strength indication.

www.macom.com/products/optoelectronics

MACOM launches dual 28Gbps clock & data recovery devices with integrated laser driver for SFP28 modules

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched the MASC-37028 and MASC-37029, dual 28Gbps clock & data recovery (CDR) devices with integrated laser driver, suitable for SFP28 short-reach (SR) or long-reach (LR) module applications with flexibility in module design.

The dual reference-free CDR devices feature multi-rate re-timing, with the MASC-37028 re-timing from 24Gbps to 26.5Gbps and the MASC-37029 re-timing from 25.5Gbps to 28.1Gbps. The flexible output drive options with programmable output swing and eye-shaping feature support vertical-cavity surface-emitting laser (VCSEL), directly modulated laser (DML) and externally modulated laser (EML) applications. The MASC-37029 also incorporates dedicated RS0/RS1 functionality to enable use with Fibre Channel

speed negotiation.

These devices offer high input jitter tolerance and low output jitter with low-power and low-latency performance. The devices provide an integrated temperature sensor, supply voltage monitor, Tx power monitor and receive power indicator. Additionally, both the MASC-37028 and MASC-37029 offer adaptive input equalization, programmable LOS threshold and slice level adjust and integrated PRBS generator, checker and bi-directional loop back.

"MACOM's MASC-37028 and MASC-37029 are highly integrated, low-power 28G solutions designed to be flexible for both SR and LR SFP28 applications," says Angus Lai, MACOM's director of product marketing, High-Performance Analog. "These devices interface seamlessly with MACOM's M03002, a low-power single-channel 28G TIA [transimpedance amplifier], for a complete SFP28 SR application solution. They are also compatible with MAOM-

002301, a low-power single-channel 28G DML driver, for a complete SFP28 long-reach application solution," he adds.

"MACOM's new innovative dual 28G CDR with integrated laser driver provides the rich feature set and superior performance ideal for ease of use in SFP28 module design," comments Frank Wang, project manager at Accelink Technologies Co Ltd. "This SFP28 chipset solution will enable us to deliver cost-effective, flexible solutions for both SFP28 SR and LR modules to our customers, further accelerating the deployment of 24G wireless, 25G Ethernet and 32G Fiber Channel applications."

The MASC-37028 and MASC-37029 were featured in a private demonstration at the Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22–24 March).

www.macom.com/products/product-detail/MASC-37028
www.macom.com/products/product-detail/MASC-37029

NeoPhotonics launches high-power InP DFB lasers for 100G silicon photonics intra-datacenter applications

NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and maker of hybrid photonic integrated optoelectronic modules and subsystems for high-speed communications networks) has launched 1310nm and 1550nm high-power distributed feedback (DFB) lasers and laser arrays for 100G silicon photonics-based QSFP28 modules for intra-datacenter applications.

With the ever-growing demand for more bandwidth, data-center operators and service providers are actively deploying low-cost, scalable, silicon photonics based 100G modules defined in industry-standard multi-source agreements (MSAs) such as CWDM4, CLR4 and PSM-4. Each of these is designed around a specific implementation of silicon high-speed analog and digital electronic devices and related photonic components. All rely on

indium phosphide (InP) DFB lasers as an efficient, high-power light source.

In support of the emerging silicon photonics ecosystem, NeoPhotonics has introduced a range of high-power, uncooled lasers and laser array sources for both the 1310nm and 1550nm wavelength bands. These lasers support power of 40–60mW over a wide temperature range.

One specific 100G data-center application uses silicon photonics parallel single-mode architecture (PSM4) in a high-power laser diode array product. NeoPhotonics has partnered with Mellanox Technologies Ltd of Sunnyvale, CA, USA and Yokneam, Israel (a supplier of end-to-end InfiniBand and Ethernet interconnect solutions and services for data-center servers and storage systems) to develop laser arrays that can be passively flip-chip bonded onto Mellanox's optical engine, producing a high-volume,

low-cost, electronics-style assembly for a 100G PSM-4 module.

"NeoPhotonics has opened its unique high-power, high-yield laser technology to the ecosystem," says Mehdi Asghari, Mellanox's VP of silicon photonics. "Several key laser integration and performance features have enabled us to support our customers with a solid and growing portfolio of high-performance LinkX 100G modules and cables," he adds.

"NeoPhotonics was a pioneer in the development and volume production of InP PIC [photonic integrated circuit]-based DFB lasers and particularly in the extension of this technology to arrays," says NeoPhotonics' chairman & CEO Tim Jenks. "Among other applications, we have shipped several hundred thousand of these lasers over the last decade into demanding DWDM applications."

www.mellanox.com

www.neophotonics.com

NeoPhotonics extends high-speed pluggable transceiver platform to 400G with CFP8 PAM4 development

NeoPhotonics has announced its 400G transceiver development for network interconnections in data-center, cloud and other telecom applications.

"The drive for higher performance and higher density in optics is increasing as transmission speeds move toward 400G," says chairman & CEO Tim Jenks. "We are extending our high-speed product family in a manner which leverages both proven, high-performance and high-volume capabilities, while providing an efficient path to high density and higher speed," he adds.

NeoPhotonics' 400G PAM4 (4-level Pulse Amplitude Modulation) CFP8 form-factor module development leverages the firm's high-speed component technologies including:

- a 28Gbaud high-performance EML (electro-absorption modulated laser);

- high-speed opto-electronics packaging techniques; and
- high-performance and low-loss multiplexers.

The 400G CFP8 transceiver will be compliant with the IEEE 802.3bs 400GBASE-LR8/FR8 specifications for links up to 10km.

NeoPhotonics' high-speed module technologies from its QSFP28 and CFP2 dual-rate 100G LR4 products are leveraged in this new 400G CFP8 LR8/FR8 PAM4 development. This also leverages the firm's demonstrated 100G dual-lambda PAM4 transmission, introduced at the European Conference on Optical Communications (ECOC 2015) and complying with the 400GBASE-LR8 standard.

"A number of market factors are driving the need for smaller and faster 400G client-side transceivers, as the move to 400G can-

not be reasonably achieved by using the same 100G modules," says Jenks. "Our 400G PAM4 CFP8 solution will fulfill key market needs by leveraging the superior link performance of our high-performance EML lasers, while reducing power consumption through integration of technology-leading CMOS PAM4 chipsets," he believes.

Also, at the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March) NeoPhotonics gave a live demonstration of its single-wavelength 112Gbps link enabled by the firm's new 56Gbaud EML with an integrated driver, which creates the path to delivering 100G and 400G transceivers in compact modules for data-center applications.

www.neophotonics.com/pam4-the-solution-for-400g-client-side-links

NeoPhotonics conducts demos enabled by new products for 100–400G telecom and datacenter networks

At the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March), NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and maker of hybrid photonic integrated optoelectronic modules and subsystems for high-speed communications networks) conducted demonstrations of 100G to 400G transmission, enabled by new products for 100–400G telecom and datacenter networks, including a CFP2-ACO Class 3 pluggable module, a 45Gbaud integrated coherent receiver (ICR) and a 56Gbaud electro-absorption modulated laser (EML).

First, the operation and optical signal-to-noise ratio (OSNR) performance of NeoPhotonics' ClearLight CFP2-ACO Class 3 pluggable coherent module was illustrated in a loop-back DP-QPSK 100G configuration. The module incorporates the firm's ultra-narrow-linewidth power-efficient tunable laser and high-responsivity coherent receiver and is also suitable for 200G DP-16QAM operation.

Second, the new 45Gbaud micro coherent receiver was used with the firm's ultra-narrow-linewidth tunable laser to show the bit-error rate (BER) and OSNR performance of a single-wavelength 400G datacenter interconnect link utilizing a 45Gbaud DP-32QAM configuration. This demonstration also included NeoPhotonics' off-line digital signal processing (DSP) algorithms. This configuration can also be used for 200G transmission over long-haul reaches with 45Gbaud DP-8QAM, and 300G transmission over metro reaches with 45Gbaud DP-16QAM.

Finally, a single-wavelength 112Gbps link enabled by the new 56Gbaud EML with integrated driver in a PAM4 configuration was shown for intra-datacenter connections of up to 2km. This configuration can also be utilized to make a four-wavelength 400G intra-datacenter transceiver module.

"The drive for higher-density optics has not reduced the requirements for high performance, particularly as transmission speeds move toward

400G, making it imperative to select the best technology for each function," says chairman & CEO Tim Jenks. "These demonstrations combine several elements of our advanced hybrid photonic integration technology, including our hybrid silica/InP ICR [integrated coherent receiver], our ultra-narrow-linewidth tunable laser, as well as our integrated high-speed EML and driver, and illustrate how high performance can be achieved by closely combining different technologies for different functions in a compact form factor."

Also at OFC, NeoPhotonics exhibited its suite of standard and small-form-factor photonic integrated circuit (PIC)-based components for 100–400G coherent line-side applications, along with its 100G client-side and datacenter CFP2 and QSFP28 transceivers, its multi-cast switches for 'contentionless' reconfigurable optical add/drop multiplexers (ROADMs) and its next-generation transceivers for access.

www.neophotonics.com
www.ofcconference.org

Infinera launches Infinite Capacity Engine

Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical transport networking systems incorporating its own indium phosphide-based photonic integrated circuits (PICs), has launched the Infinite Capacity Engine, a multi-terabit optical subsystem for wave division multiplexing (WDM) that is claimed to be the first to offer the combined benefits of delivering optical super-channel capacity up to 2.4Tb/s and reach up to 12,000km in a single small package.

Powered by Infinera's FlexCoherent Processor and its fourth-generation PIC, the Infinite Capacity Engine will be integrated into Infinera Intelligent Transport Network platforms customized for long-haul terrestrial, subsea, metro and data-

center interconnect networks to provide a comprehensive set of solutions.

Driven by the rapid growth in cloud-based services, increasing broadband access speeds, 5G mobile data, the Internet of Things and on-line video, the exponential growth in demand for transport network bandwidth requires innovation to be made, says Infinera.

Defining a new approach to deliver multi-terabit capacity in optical networks, the Infinite Capacity Engine enables the pre-deployment of bandwidth that is service-ready and can be provisioned on-demand in 100Gb/s increments with simple software activation that leverages Infinera Instant Bandwidth (which enables new capacity to be deployed in less than 1 hour). Infinera's

standard license offerings have been expanded to include Time-based Instant Bandwidth, providing 100G temporary licenses enabling capacity to be deployed for a specific duration of time. This, combined with up to 2.4Tb/s of pre-deployed capacity, can be SDN-controlled in 100G increments, with each slice configurable for color, modulation and direction, which provides network operators with a way to reduce operational rigidity and forecasting complexity. The Infinite Capacity Engine allows network operators to instantly deploy massive increments of line-side bandwidth when and where they need it (rather than weeks or months to deploy bandwidth with a competing solution).

www.infinera.com/go/engine

Oclaro showcases products to help data-center operators and service providers accelerate transition to 100–400Gb/s single-mode fiber networks

Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has announced its line-up of fiber-optic transceivers designed to drive the data-center transition from 40Gb/s to 100Gb/s and multi-mode fiber to single-mode fiber networks, displayed at the Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22–24 March).

Featuring small form factors, high density and low power dissipation, the products will enable users to quickly and cost-effectively upgrade to higher-speed networks that can meet the demand for higher bandwidth, says Oclaro.

“Delivering the higher bandwidth that data-center operators and telecom service providers are demanding requires critical advancements in core optics technology, which is where Oclaro remains focused,” says chief commercial officer Adam Carter. “Oclaro has leveraged its decades of experience and world-class manufacturing strength to deliver the breakthroughs in fiber-optic transceivers and components needed to transition to higher speeds while still maintaining competitive cost structures,” he adds.

100Gb/s and 400Gb/s high-speed optics demonstrations

At OFC, Oclaro demonstrated its 100Gb/s LR4 full product line-up showcasing interoperability between its second-generation CFP, CFP2, CFP4 and the newly introduced QSFP28 module. Details of the demo include:

- 100GbE/OTU4 dual-rate capability based on Oclaro’s in-house lasers; and
- higher front-panel density and meeting bandwidth requirements with new smaller form factors (CFP4 & QSFP28) while keeping full backward compatibility with older-generation form factors (CFP/CFP2)

for core routing and data-center applications.

Oclaro also showcased its 400Gb/s CFP8 for next-generation core and data-center applications. Details of the demo include:

- support for reaches of 2km and 10km, based on the optical 50Gb/s PAM4 modulation scheme according to IEEE 802.3bs 400GBASE-FR8/LR8 specifications under discussion at IEEE;
- use of Oclaro’s in-house laser diode and photodiode devices based on mature 100Gb/s technology used in LR4 CFPx/QSFP28 products; and
- eight times front-panel bandwidth density compared with 100Gb/s CFP.

First single-carrier 400Gb/s end-to-end live demonstration

Together with partners Teledyne LeCroy, Coherent Solutions and Anritsu, Oclaro demonstrated that its industry-first high electro-optic bandwidth lithium niobate (LiNbO₃) external modulator is suitable to run data rates of 400Gb/s on a single carrier (wavelength). This demo showcased a symbol rate of 56Gbaud and 16-QAM as modulation format.

The combination of this symbol rate and modulation format allows users to run a true 400Gb/s data rate on a single carrier.

Oclaro says that the live demo was the second milestone that

demonstrates the capability of its LiNbO₃ to run data rates higher than 400Gb/s (the first milestone was at ECOC 2015, when Oclaro ran a live demo using 56Gbaud and QPSK modulation format) making it suitable for many different applications, from data-center interconnect to metro and long-haul networks.

SFP28-LR/LR Lite I-Temp demo

Oclaro demonstrated what is said to be the first SFP28-LR Lite I-temp and SFP28-ER interoperating with QSFP28 CWDM4. The SFP28/LR/LR Lite is designed for enterprise switches, next-generation 5G mobile front-haul networks, data-center switches and access applications where data rates are increasing from 10Gb/s to 25Gb/s and 40Gb/s to 100Gb/s.

To develop the SFP28 LR/LR Lite I-temp transceiver, Oclaro leveraged its 1310nm 28Gb/s DML laser chip and its experience as the highest volume manufacturer of 100Gb/s client-side transceivers. The firm also developed a 28Gb/s TO-CAN transmitter optical subassembly (TOSA) for this product using its existing 10G TOSA packaging technology. Oclaro claims to be the first supplier to offer an SFP28 LR/LR Lite solution that achieves 1.2W (maximum) at commercial operating temperatures. Prototype samples of the SFP28 I-temp are available now, and Oclaro expects to begin volume production of the SFP28 LR in second-quarter 2016.

Oclaro 400Gb/s external modulator

Oclaro’s 400Gb/s lithium niobate external modulator is designed to enable 400Gb/s-and-beyond speeds on a single wavelength or carrier. The modulator is a high electro-optic bandwidth polarization multiplexed quad parallel Mach-Zehnder (PM-QMZ) device that integrates into a hermetic package an input beam

Oclaro demonstrated the first SFP28-LR Lite I-temp and SFP28-ER inter-operating with QSFP28 CWDM4... designed for enterprise switches, next-generation 5G mobile front-haul networks, data-center switches and access

► splitter, four parallel Mach–Zehnder modulators configured for I–Q modulation, a polarization combiner, and a monitor photodiodes for power and bias control.

Key features of the 400Gb/s lithium niobate external modulator include the following:

- a 3dB electro-optic bandwidth exceeding 35GHz;
- very smooth optical response up to 50GHz, enabling a symbol rate of up to 64Gbaud;
- an extinction ratio above 25dB to enable complex modulation formats; and
- insertion loss below 13dB for high efficiency.

Non-hermetic 25Gb/s DFB laser diodes

Also at OFC, Oclaro announced internal qualification of its non-hermetic 25Gb/s 1.3 μ m distributed feedback (DFB) laser diodes suitable for use in 100Gb/s transceivers. Featuring low operating current at high temperatures, the 25Gb/s DFB is a key component for enabling data-center operators to

transition faster to highly meshed 100Gb/s connections over single-mode fiber.

Oclaro representatives participate on panels at OFC

At OFC, Oclaro had representatives participating on the following panels:

- Workshop: ‘Silicon Photonic Transceivers: Competition or Coexistence?’ by senior vice president R&D Beck Mason (co-organizer of the workshop).
- OSA Executive Forum Presentation: ‘Optics Inside the Datacenter — Is COBO the Next Big Thing or Just Another Thing?’ by chief commercial officer Adam Carter.
- Market Watch Presentation: ‘The Promising Market of 100Gbit/s and Beyond Pluggable Devices — Talk with Experts’ by Yves LeMaitre, president of Oclaro’s Optical Connectivity Business;
- Panel Presentation: ‘Next Generation Data Center Optics’ by Beck Mason, Oclaro’s senior VP, R&D;

Poster Presentation: ‘Integrated Nonlinear-optical Signal Processing’ by Mike Wale, Oclaro;

- Poster Presentation: ‘Quasi Single-Sideband (SSB) IM/DD Nyquist PAM Signaling for High-Spectral Efficiency DWDM Transmission’ by Takayoshi Fukui, Oclaro Japan;

Partner presentations:

Oclaro partners also participated on several technical presentations, including:

- ‘Industry first End-to-End 400G Test Equipment Platform’ at the Teledyne LeCroy booth;
- Dr Katarzyna Lawniczuk of the Technical University Eindhoven, The Netherlands, spoke in a workshop on Photonics Foundries ‘Open-Access InP Foundry Services for Photonic ICs’;
- Oclaro sponsored a photonic integrated circuits workshop ‘Everything You Need to Know in Order to Design a PIC and to Use Key Service Providers to Do This Faster and Cheaper’.

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Non-hermetic 25Gb/s 1.3 μ m DFB lasers for 100Gb/s transceivers

Oclaro has announced qualification of its non-hermetic 25Gb/s 1.3 μ m distributed feedback (DFB) laser diodes for 100Gb/s transceivers. Featuring low operating current at high temperatures, the 25Gb/s DFB is a key component for enabling data-center operators to transition faster to highly meshed 100Gb/s connections over single-mode fiber.

“The 25Gb/s DFB laser diode is a critical component at the core of a new generation of 100Gb/s transceivers optimized for data-center switching applications such as QSFP28 CWDM4/CLR4,” says Yves LeMaitre, president, Optical Connectivity Business at Oclaro. “By making our lasers suitable for use in non-hermetic packages, we are enabling a faster adoption of proven telecom-grade laser technologies into data-center environments,” he adds. “Oclaro is strongly focused on the market

transition to distributed cloud networking and will continue to leverage its optical expertise to deliver cost-optimized, reliable and high-performance 100Gb/s solutions.”

The 25Gb/s DFB laser diode is designed for 100Gb/s and 25Gb/s optical transceivers used in transmission client interface, high-end spine switch/core router interfaces and large-scale data-center meshed networks.

Leveraging the firm’s experience in high-speed laser design, the 25Gb/s DFB laser diode features higher bandwidth and lower power con-

By making our lasers suitable for use in non-hermetic packages, we are enabling a faster adoption of proven telecom-grade laser technologies into data-center environments

sumption, allowing transceiver module designers to migrate to non-hermetic designs to further reduce costs and footprint.

Additional features of the 25Gb/s laser diode include the following:

- eye mask performance with more than 5dB extinction ratio at 60mA driving current at 70°C of transceiver module level;
- leveraging Oclaro’s design and mass-production technology of InAlGaAs-MQW (multi-quantum well) and ridge waveguide (RWG) structure to deliver optimum optical performance; and
- completing the non-hermetic test compliant with the Telcordia GR-468-CORE issue 2 including non-hermetic damp heat/damp heat for powered non-hermetic devices.

The 25Gb/s DFB laser diode is now fully qualified and available for production.

Finisar launches 25G Ethernet optics for high-speed data centers; drives definition of PAM4 optics technology

At the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA announced several new optics products and technology demonstrations.

Specifically, the firm showcased two new products for 25 Gigabit Ethernet (25GbE) data-center applications, including an SFP28 eSR transceiver enabling 300m links over existing OM3 MMF (multi-mode fiber) as well as 25G SFPwire, an active optical cable (AOC) with embedded technology that provides real-time troubleshooting and link performance monitoring. Finisar also demonstrated optics technology supporting the PAM4 modulation format for Ethernet interfaces at a data transmission rate of 50Gb/s per lane.

25GbE SFP28 eSR transceivers for data centers

During OFC, Finisar featured its SFP28 eSR (extended short reach) transceiver in a demonstration targeting 25G Ethernet data-center applications. The new optical module extends links from 70m to 300m over existing OM3 MMF and enables a seamless upgrade from installed 10GbE fiber plant to 25GbE. The transceiver leverages in-house vertically integrated optics and ICs and interoperates with existing 25GbE SFP28 SR and QSFP28 SR4 modules.

The demonstration showed the SFP28 eSR module transmitting over 300m of OM3 MMF, in compliance with the same specification as the 25GbE SR module, per the IEEE standard. With this product, users are able to utilize existing deployed fiber infrastructure, while increasing network bandwidth by 2.5x over existing 10GbE networks, saving significant capital expense, the firm says.

25G SFPwire AOC with Connectivity Diagnostics

The 25G SFPwire AOC is a solution for intra- and inter-rack high-speed data-center interconnections. Designed for ease-of-use, the 25G SFPwire AOCs are lighter, more flexible and lower in power consumption than comparable direct attached copper cables (DACs). Finisar says that its vertical-cavity surface-emitting laser (VCSEL) and IC technology deliver high signal integrity and reliable performance for error-free 25G connectivity. This allows users the option to by-pass the host FEC, for non-standard, low-latency connections, which is not possible with comparable DACs.

Embedded Connectivity Diagnostics technology provides data centers with real-time performance monitoring of the 25G SFPwire AOCs, through both a host-software interface and physical indicators on the AOC pull-tabs. Claimed to be the only technology of its kind in the industry, Connectivity Diagnostics provides critical information used for troubleshooting, link performance monitoring and port-connectivity mapping.

The booth demonstration showed multiple 25G SFPwire AOCs operating between two switches. Connectivity Diagnostics features are demonstrated without affecting data traffic.

Driving the definition of PAM4 optics technology

PAM4 is a modulation format that has been adopted by the Ethernet Standards for 50Gb/s per lane signaling, and will become the building block for future 50GbE, 100GbE, 200GbE and 400GbE interconnects.

Finisar says that PAM4 presents a significant and challenging transition for the optical interconnect industry, driving an industry-wide re-assessment of link budgets, optical components and transceivers in order to implement PAM4 optical technology in an open, standards-driven way.

The firm says that it is leading the definition and development of PAM4 optical technology for both shortwave (SW, multimode) and longwave (LW, single mode) applications. The PAM4 Optical Technology demonstration, located in both Finisar and Ethernet Alliance booths, showcased Finisar directly modulated laser (DML) technology transmitting two channels of 50Gb/s PAM4 on the CWDM grid over 10km of single-mode fiber (SMF). Hosted within Juniper and Spirent systems in the Ethernet Alliance booth, it is the first interoperability demonstration using DML technology to transmit Nx50Gb/s PAM4. Finisar reckons that its DML technology, in both SW and LW implementations, will be critical for the success of PAM4 modulation, especially in higher loss-budget implementations such as large data-center interconnects with multiple patch-panels.

Test instrument portfolio

Finisar also demonstrated new capabilities of the WaveShaper and WaveAnalyzer test equipment portfolio in combination with the UltraSpan broadband source. The WaveShaper 16000S demonstrates broadcasting to 16 ports, each with individual amplitude and phase filtering. The WaveAnalyzer demonstrates triggered spectral measurements as they are required, for example, in a recirculating loop setup. The demonstrations are supported by Finisar's new UltraSpan broadband source, which provides a powerful and flat ASE signal across the C-band.

www.finisar.com

Source Photonics demos 2x50G-PAM4 QSFP28 module

At Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22–24 March), optical communication product maker Source Photonics Inc of West Hills, CA, USA demonstrated a 2x50G-PAM4 QSFP28 100G module, adding to its portfolio of small-form-factor 100G products. The PAM4 demonstration follows the launch of the firm's 100G QSFP28 LR4 platform of products. Source Photonics announced industry-first samples of LR4 and LR4 Lite modules in March 2014 and mass production in March 2015. This January it announced shipment of its 10,000th QSFP28 module.

For 100G-and-higher products, Source Photonics has developed a common platform using externally modulated laser (EMLs) for both 2km and 10km CWDM4, LR4 Lite and LR4 products operating with typical power consumption of less than 3.5W. The unique design reduces component count and complexity versus directly modu-

lated laser (DML) solutions and enables the firm to leverage the same design blocks and manufacturing footprint to support all three products and future products like 50G-PAM4 and 100G-PAM4.

Source Photonics has now taken the next step by reducing the complexity and component count of 100G transceivers by a factor of two using 50G-PAM4 modulation.

The 2x50G-PAM4 QSFP28 will operate at a worst-case power consumption of 3.5W at 70°C case temperature and support KR4 FEC in the host IC. The firm is also in development to support a KP4 FEC imple-

Source Photonics has now taken the next step by reducing the complexity and component count of 100G transceivers by a factor of two using 50G-PAM4 modulation

mentation similar to the FR8 requirements for 8-channel 400G standards.

Source Photonics — which has now released 100G QSFP28 LR4, QSFP28 LR4 Lite, CFP4 LR4 and CFP4 OTU4 to mass production, and will be in production on the QSFP28 CWDM4 by the end of second-quarter 2016 — continues to grow its portfolio of 100G+ product offerings.

"Cloud-scale and Web 2.0 data-centers are demanding increased volume and lower-cost 100G small-form-factor products, and reducing component count is a critical long-term solution," says chief scientist Sheng Zhang. "We are demonstrating a major step towards the productization of PAM4 technology that will be instrumental in the cost reduction of 100G QSFP28 products and the release of initial 400G products," he adds.

www.sourcephotonics.com
www.ofcconference.org

MACOM showcases PAM-4 technology, targeted at 28Gbaud PAM-4 applications enabling 200G & 400G optical connectivity

At the Optical Fiber Communication Conference & Exposition (OFC 2016) in Anaheim, CA, USA (22–24 March), M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) gave a private technology demonstration featuring a complete electronics chip-set utilizing PAM-4 technology and enabling a 56Gbps per lane data rate. The featured IP demonstrates MACOM's chipset solution for 200G and 400G optical connectivity in both parallel single-mode fiber (PSM) and wavelength-division multiplexing (WDM) applications.

MACOM claims that its technology

demonstration achieves industry-leading transimpedance amplifier (TIA) sensitivity and low power, which enables the development of 200G QSFP and 400G MSA optical modules.

On the transmit side, the demonstration features a 28Gbaud linear driver and clock & data recovery (CDR). The signal is transmitted over single-mode fiber, and recovered on the receiver side using MACOM's 28Gbaud TIA and re-timed with the firm's receiver CDR.

"MACOM has achieved excellent performance in silicon through its 28Gbaud PAM-4 chipset IP. This technology, along with recently announced L-PIC silicon photonics and our CW lasers, will enable

next-generation 200Gbps and 400Gbps solutions for small-form-factor optics," says Preet Virk, senior VP & general manager, Networks, at MACOM. "We anticipate that our complete chipset and laser solutions for PAM-4 technology will build on our success at 100Gbps and enable the next generation of 200G and 400G optical connectivity for enterprise and data-center applications," he adds. "Based on this technology, MACOM is now engaged with customers on the development of commercial products with projected industry-leading performance to sample later this year."

www.macom.com/products/optoelectronics
www.ofcconference.org

Emcore launches Medallion 6100 series DOCSIS 3.1 1550nm externally modulated CATV transmitter with DOCSIS 3.1-compatible frequency extension to 1.2GHz

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 Medallion 6100 series DOCSIS 3.1 1550nm externally modulated CATV transmitter, which was displayed at the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March) and also at the China Content Broadcasting Network show (CCBN 2016) in Beijing (24–26 March).

The Medallion 6100 series represents the next level of evolution of the widely deployed Medallion 6000 series. The use of Emcore's low-noise, high-optical-output-power and narrow-optical-linewidth laser results in what is claimed to be unmatched fiber-optic transmission link performance. The transmitter supports the DOCSIS 3.1 standard of 1.2GHz in the CATV domain, and optionally up to 3.5GHz in the SAT-IF band to support new international satellite deployments. Gain tilt control is now available for both the CATV and SAT-IF band. In par-

allel, the Medallion 6100 offers a number of platform upgrades including the addition of a USB port for local communication, a 1000BaseT Ethernet port with an on board 4-port Ethernet switch, support for IPv4/IPv6, and SNMPv3 for advanced services.

The Medallion 6100 transmitters leverage proprietary pre-distortion circuitry to provide superior CSO (composite second order) and CTB (composite triple beat) performance allowing links up to 150km, making it suitable for extending traditional hybrid fiber coaxial CATV systems. Additionally, SBS (stimulated Brillouin scattering) suppression levels greater than 21dBm through 40km of fiber makes the Medallion 6100 series suitable for RFoG (radio frequency over glass) and RF overlay in FTTx networks in countries around the world.

"Our Medallion series of rack-mount CATV transmission equipment is ideal for network systems providers that

demand the highest-quality, economical delivery of high- and ultra-high-definition video and audio, along with the highest bandwidth data transmission," says Gyo Shinozaki, VP of marketing. "The Medallion 6100 transmitters extends bandwidth for DOCSIS 3.1 compatibility, while adding advanced platform features to support cable operators as they migrate their networks to the latest technology," he adds.

At OFC and CCBN, Emcore also showcased its chip-level devices portfolio for telecom, GPON FTTx, datacom and wireless applications including 1310, 1490 and 1550nm laser diode chips, 10G Fabry-Perot laser chips, and 2.5G and 10G APD photodetectors. In addition, Emcore featured its full line of distributed feedback (DFB) butterfly lasers, DOCSIS 3.1 lasers, TO-56 lasers, low-noise optical receivers, broadband photodiodes and components for wireless and distributed antenna system (DAS) applications.

www.ofcconference.org
www.ccbntv
www.emcore.com

Gain tilt control is now available for both the CATV and SAT-IF band

Emcore launches Medallion 7110 series of CATV 1RU high-power erbium ytterbium fiber amplifiers

Emcore has launched the Medallion 7110 series of CATV fiber amplifiers, as displayed at the Optical Fiber Communication Conference & Exhibition (OFC 2016) in Anaheim, CA, USA (22–24 March) and also at the China Content Broadcasting Network (CCBN) show at the in Beijing (24–26 March).

As the latest addition to the 7000 series of optical amplifiers, the new Medallion 7110 series offers high power and low noise figures demanded by CATV applications. It is packaged in a compact 1 RU

housing, compatible with industry-standard 19" and 23" rack systems, while offering up to 31.5dBm of pre-splitter output power, and up to 16 SC/APC output ports. Various output power and port count configurations are available with optional integrated WDM filters for RFoG (radio frequency over glass) or RF overlay in FTTx which further preserves rack space and reduces cost by eliminating a separate network element.

"The Medallion 7110 fiber amplifier is an ideal companion product to

our Medallion series of rack-mount CATV transmission equipment that further pushes the boundaries of high-density, high-optical-power launch and split architectures deployed in RFoG and RF overlay for FTTH networks," says Gyo Shinozaki, VP of marketing. "The Medallion series is designed for network systems providers that demand the highest-quality, economical delivery of high- and ultra-high-definition video and audio, along with the highest-bandwidth data transmission," he adds.

Arbitration tribunal rejects Sumitomo Electric's claims, awarding legal fees of \$2.5m to Emcore

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 — says that it has received a favorable ruling from the International Court of Arbitration tribunal relating to its ongoing dispute with Tokyo-based Sumitomo Electric Industries Ltd (SEI).

In September 2014, SEI filed for arbitration against Emcore in connection with certain disputes

arising from Emcore's sale of its vertical-cavity surface-emitting laser (VCSEL)-based product lines — including VCSEL and photodiode components, parallel-optical transceiver modules, and active optical cables (AOCs) — to Sumitomo Electric in May 2012. Sumitomo Electric was seeking \$47.5m from Emcore relating to numerous claims.

On 12 April, a three-member arbitration panel rejected Sumitomo Electric's claims. The panel ruled

that Emcore owes none of the amounts that Sumitomo Electric sought in the arbitration and that Emcore is entitled to collect the \$1.9m it is holding in escrow. Emcore is also entitled to recover more than \$2.5m in fees and costs. As of 31 December 2015, Emcore had accrued \$3.4m of liabilities relating to potential claims, in addition to the \$1.9m it held in escrow for these claims.

www.emcore.com

<http://global-sei.com>

ClariPhy introducing multi-sourced CFP2-ACO coherent optical ecosystem partners including Finisar, Fujitsu Optical Components and Oclaro

ClariPhy Communications Inc of Irvine, CA, USA, which develops high-speed mixed-signal digital signal processing (MXSP) systems-on-chip (SoC) for coherent optical networks, has introduced its multi-source CFP2-ACO coherent optical ecosystem partners including Finisar, Fujitsu Optical Components (FOC) and Oclaro. At the Optical Fiber Communications conference (OFC 2016) in Anaheim, CA, USA (22–24 March), ClariPhy jointly showcased its CL20010 LightSpeed-II Coherent DSP (digital signal processor), based on its integrated CFP2 analog coherent optical (ACO) reference platform. ClariPhy notes that CFP2-ACO is rapidly gaining momentum and being adopted because of its cost, scalability and interchangeability across optical networks.

"Coherent metro and data-center inter-connect (DCI) network deployment is ramping now. This is a more cost-sensitive market; CFP2-ACO and merchant DSPs are key technologies that will enable deployment in these new metro and DCI applications," says Andrew Schmitt, lead analyst at Cignal AI.

"ClariPhy's LightSpeed-II 200G Coherent DSP along with its CFP2-ACO module partners are demonstrating solutions today that designers can use now," he adds.

"ClariPhy continues to build on its CFP2-ACO coherent reference platform by creating a field-proven, multi-sourced coherent optics ecosystem ready for mainstream volume deployment," says ClariPhy's chief technology officer & co-founder Norm Swenson. "By delivering an easy-to-design turnkey CFP2-ACO platform, we are accelerating cost-effective metro and data-center optical networks."

The integrated 100G/200G CFP2-ACO reference platform is a turnkey solution, solving the challenges of the linear interface between coherent DSPs and plug-gable optical modules while also providing the necessary proven schematics, layout files, GUI/Software, and other development documentation to speed time to market while reducing risk, says ClariPhy. The platform optimizes performance in full support of the Optical Internetworking Forum's (OIF's) CFP2-ACO Implementation Agree-

ment, combining two boards into a single PCB reference platform that simplifies line-card design while streamlining manufacturing by enabling CFP2-ACO skew control, pre-emphasis and calibration.

ClariPhy claims its LightSpeed-II CL20010 28nm multimode SoC offers unprecedented levels of integration, performance and software-defined networking (SDN) capabilities. Solutions based on the LightSpeed-II SoC enable support for 100G/200G 16QAM modulation on a single wavelength. The SoC hence enables single-carrier 200G or dual-carrier 400G super channels. The advanced equalization and forward error correction (FEC) algorithms enable systems to overcome the impairments of the optical link, including chromatic dispersion, polarization mode dispersion and bandwidth limitations of optoelectronic components.

At OFC, ClariPhy also gave a live demonstration of the CFP2-ACO platform at the OIF PLL Interoperability Demo.

www.clariphy.com/products/cl20010.php

www.ofcconference.org

Tampere granted €2.5m to develop III-V solar cells with up to eight junctions

The European Commission's European Research Council (ERC) has granted €2.5m to professor Mircea Guina of the Optoelectronics Research Centre (ORC) at Tampere University of Technology (TUT) to apply new technology in solar cell development as part of the five-year project 'Advanced III-V Materials and Processes Enabling Ultrahigh-efficiency (50%) Photovoltaics' (scheduled to begin at the end of 2016 and run through 2021).

Currently, the best performing solar panels can convert 30–40% of the sun's energy, while the new cells could improve this to over 50%. "Percentage-wise, this may not sound like a major improvement, but when you consider the fact that increased cell efficiency could reduce the energy costs by at least 20%, we are talking about billions of euros worldwide," says project leader Guina.

The ERC funding is the result of long-term research strategy at TUT.

Guina's group began its research on high-efficiency solar cells supported by funding from the Finnish Funding Agency for Technology and Innovation (TEKES) in 2009. At the time, material was developed that enabled several cell structures to be stacked, one atop the other, for better harvesting of the solar spectrum. A follow-up project funded by the European Space Agency (ESA) involved the development of three-junction solar cells using the same material. The new ERC project will build on the previous research and aim to develop solar cells with up to eight junctions.

ERC funding enables Guina's group to focus on its work for the next five years. "The funding could not have been granted at a better time: this is a testimony that TUT currently holds world-leading expertise in this area of research," says Guina.

In addition to creating new technology, Guina's group also aims to

deploy the technology over a quick schedule, with the aim of making Finland one of the world's foremost countries in terms of next-generation solar energy solutions and also in the field of renewable energy as a whole, it is reckoned. "A whole soccer field full of current silicon cells could be replaced with just a few square meters worth of new cells made of the III-V materials and produce same energy," Guina explains.

This new technology could also prove useful in space. Light weight is a substantial benefit for telecommunications satellites, for example. Higher efficiency solar cells are also needed for deeper space travel. "I hope to be able to incorporate these III-V cells in satellites in approximately ten years' time, but for terrestrial purposes, the technology can be deployed a lot sooner," concludes Guina.

<https://erc.europa.eu>
www.tut.fi/orc/semicon

Sol Voltaics achieves alignment and orientation of GaAs nanowires in thin film

Sol Voltaics AB of Lund, Sweden, which provides nanomaterial technology for enhancing solar panels and other products, has confirmed the successful alignment and orientation of nanowires in a thin film. The firm reckons this is the most significant technology milestone in solar nanowire manufacturing to date, paving the way for photovoltaic module efficiencies of 27% or more — a 50% boost in energy conversion efficiencies for existing solar modules.

While showing highly promising characteristics in solar energy generation, nanowires are notoriously difficult to align due to their high aspect ratios and material characteristics. By controlling nanowire orientation and alignment at the centimeter scale on standard-sized wafers, Sol Voltaics reckons that it

has taken a major step toward the commercial production of solar films for tandem solar PV modules.

"Gallium arsenide nanowires have recently come to the forefront as holding great promise for boosting solar module efficiencies well beyond current levels," says CEO Erik Smith. "By aligning nanowires within a membrane, we've taken our greatest stride yet toward manufacturing solar nanowire films at the commercial scale. This will enable solar panel manufacturers to greatly enhance the energy-generating capability of their products."

This follows Germany's Fraunhofer Institute for Solar Energy Systems (ISE) in March 2015 confirming a record 1-sun PV efficiency of 15.3% for the firm's epitaxially grown GaAs nanowire solar cells. The cells were

recently re-tested by Fraunhofer and showed little or no degradation nearly 18 months after the initial tests, affirming the technology's performance reliability.

Also, Sol Voltaics has progressed through several generations of development of its Aerotaxy production technology. The patented process allows cost-effective III-V nanowire solar cell production via a continuous gas-phase process.

"We have a few remaining hurdles to get over in order to get into commercialization but we're very confident we can deliver a truly transformative energy solution, the kind of solution called for by the Breakthrough Energy Coalition, COP 21 summit," says Smith.

www.breakthroughenergycoalition.com
www.solvoltaics.com

First Solar to provide 230MW more modules to Silicon Ranch in new supply agreement building on strategic partnership

First Solar Inc of Tempe, AZ, USA — which makes thin-film photovoltaic modules based on cadmium telluride as well as providing engineering, procurement & construction (EPC) services — have entered into a framework agreement for 231.6MW_{DC} of its modules to be used by a subsidiary of Nashville-based full-service renewable energy provider Silicon Ranch Corp in projects to be constructed in 2017 and early 2018.

The new agreement builds on previous agreements for more than 180MW_{DC} of modules used in Silicon Ranch projects entering commercial operations in 2015 and 2016, located in Colorado, Georgia, Mississippi, Arkansas and Tennessee. The southeastern US region is rapidly emerging as a growing market for PV solar development, where Silicon Ranch has played a leading role as a developer, owner and operator.

First Solar says that its thin-film PV technology has demonstrated clear advantages over conventional multi-crystalline silicon (mc-Si) solar products in all regions of the world, most significantly in the hot, humid climates that make up a large part of Silicon Ranch's project footprint. Taking into account conversion efficiency, temperature coefficient, spectral response and shadow tolerance, First Solar reckons that its technology provides an energy density of more than 10% over mc-Si products in this region. So, given the same land area with an equivalent module ground cover ratio, its modules can produce more annual energy from the same land area than mc-Si.

"There is deep value in aligning with a trusted, major solar developer, and our previous endeavors with Silicon Ranch have allowed us to jointly benefit from working in a

region with exciting growth opportunities," says Roger Bredder, First Solar's VP of US business development.

"First Solar is a US manufacturer with superior products and a strong balance sheet, all of which were important factors in our selection," says Silicon Ranch's chief technology officer Pete Candelaria. "Furthermore, their technical and logistics units are the best in the business."

Similar to a portion of the 2015/2016 Silicon Ranch projects, some of the 2017 projects may also employ First Solar's balance of system solutions, including the firm's single-axis tracker. Silicon Ranch plans to begin to take delivery of the first modules under this agreement in first-quarter 2017 and will continue to supply its projects until first-quarter 2018.

www.siliconranchcorp.com
www.firstsolar.com

First Solar publishes its first Corporate Sustainability Report

Cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA has published its first Corporate Sustainability Report which, the firm says, showcases its commitment to drive down the cost of solar electricity by providing eco-efficient photovoltaic (PV) solutions through implementation of sustainable business practices and its PV module manufacturing, recycling and responsible PV power plant construction.

First Solar's utility-scale PV power plants have consistently led the way in driving down the cost and improving the reliability of solar electricity, cementing PV as a valued component of the global generation portfolio. The report provides a look at how First Solar fulfills its mission on delivering the

'triple bottom line' of people, planet and profit. Highlights include:

- How the firm is delivering the leading eco-efficient PV technology with a superior energy yield, competitive cost and smallest environmental impacts on a life cycle basis;
- How PV module manufacturing facilities in the USA and Malaysia and its PV power plants (which generate clean electricity for 25+ years) create local jobs and can contribute to biodiversity protection;
- How globally available PV recycling services (that recover over 90% of the semiconductor material for reuse in new modules and 90% of the glass for reuse in new glass products) are the new industry standard;

- Why minimizing the firm's environmental impact (through increased module and manufacturing throughput efficiency, conservation projects and on-site PV installations) is important and achievable;
 - Examples of how First Solar support local communities and work with non-governmental organizations (NGOs) through the firm's Global Charitable Giving Program.
- "By continuously driving down the cost of solar electricity and providing a solution that addresses energy security and water scarcity, we are delivering on our commitment to build a more sustainable energy future," says First Solar's Alex Heard, VP of global technical services.

www.firstsolar.com/en/About-Us/Corporate-Responsibility.aspx

Solar Frontier modules chosen by Staten for 16 projects in California's agricultural segment

Tokyo-based Solar Frontier — the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — says that its CIS modules will be installed by California-based engineering, procurement & construction (EPC) firm Staten Solar at 16 solar project sites (ranging in size up to 522kW) on farms producing almonds, pistachios and table grapes in Tulare and Kern Counties of California's Central Valley.

Each project has unique characteristics requiring innovative construction techniques and designs including a mix of ground-mounted and Staten Solar's proprietary levee-mounted racking systems. Solar Frontier says that the PV systems integrate cost effectively with the customer's existing facilities, environmental/land requirements and business models. The modules were selected by Staten Solar for



Solar Frontier's CIS modules installed in the Ag-solar installation in Delano, California. (Photo courtesy of Staten Solar.)

their performance in real-world conditions, including high yields in hot temperatures and under partial shading. Three of the 16 projects are currently operational, with the balance expected to be completed by the end of 2016.

"Staten Solar understands the challenges the agricultural communities face and utilizes their solar

expertise in aggregated net metering, rate optimization, demand response, peak day pricing, and financing to deliver valuable energy solutions that help farmers reduce their monthly operating costs," comments Charles Pimentel, chief operating officer of Solar Frontier Americas.

"Staten Solar has been impressed with the quality, performance and customer service provided by Solar Frontier," comments Staten

Solar's chairman & managing director Sandipan Bhanot. "Our customers expect us to recommend the best product for their needs and for the hot Central Valley — Solar Frontier panels are an excellent choice in terms of superior production and high performance in the field."

www.StatenSolar.com

www.solar-frontier.com

XsunX completes commercial solar carport project

XsunX Inc of Aliso Viejo, CA, USA, which is developing hybrid copper indium gallium (di)selenide thin-film (CIGS) photovoltaic (TFPV) cell technologies and 'CIGSolar' manufacturing processes, has concluded the construction of another large commercial solar power system, a 157kW Solar Carport Installation in Anaheim, CA, capable of delivering over \$1m in projected energy savings in its first 25-years of operation.

Installed in Anaheim to service a multi-tenant commercial office space, the project should reduce the facility's operating costs by nearly \$30,000 in the first year alone. Annual savings will continue to rise to nearly \$40,000 by the tenth year.

"The robust solar carport application will provide our client with many years of clean energy and pay for itself in just over four years," says CEO Tom Djokovich. "Solar carports are one of the better



The 157kW Solar Carport Installation.

investments [that] commercial property owners can make," he adds. "With our ability to offer solar carports at nearly the same costs as roof-top solar, we help turn parking areas into profitable assets, allowing our clients to never look at their parking areas the same way again."

XsunX says that its turn-key solar

carport solutions, in addition to improving parking area aesthetics, enable the conversion of parking areas into valuable solar power plants capable of reducing facility operating costs and increasing net operating margins and property values while delivering thousands in Federal tax credits.

XsunX notes that it is in a growing sector of the renewable energy market

that provides solutions unhindered by common logistical challenges associated with traditional roof-top applications. The firm continues to develop its strategy to market to a broad range of customers, including school, government and commercial organizations.

www.xsunx.com

ZSW raises its CIGS PV cell efficiency from 21.7% to European record of 22%

By optimizing various manufacturing processes, ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung) in Stuttgart, Germany has raised the European record for copper indium gallium diselenide (CIGS) thin-film photovoltaic solar cell efficiency to 22% — just 0.3 percentage points behind the world record — as confirmed by Fraunhofer Institute for Solar Energy Systems ISE. In September 2014, ZSW had raised its cell efficiency to 21.7% (which was, at that time, a world record for thin-film PV).

ZSW's latest cell has a surface area of 0.5cm² (standard for test cells) and was produced in a laboratory coating machine by co-evaporation. "The technological potential is far from tapped out at 22% efficiency," says professor Michael Powalla, ZSW board member and head of

the Photovoltaics division. "It will be possible to achieve up to 25% in the next few years," he believes.

A race between solar power technologies

CIGS technology overtook market-dominating multi-crystalline silicon technology in cell efficiency some time ago, extending its lead to a full percentage point. However, in module efficiency, silicon PV is still ahead (about 17% for commercially available modules, versus about 14% for CIGS modules).

Manufacturing costs amount to just 40 cents per watt even in small CIGS factories, and they can be slashed by expanding production capacity. Given an annual output of 0.5–1GW, CIGS PV plants can achieve 18% or greater module efficiency and costs as low as 25 cents per watt. So, costs can be

brought down to a competitive level even at a relatively low output, it is reckoned, and it follows that CIGS PV manufacturing requires less upfront investment than silicon PV production.

Thin-film PV market on the rise

ZSW notes that thin-film PV modules deliver higher yields under low light conditions and are more shade-tolerant. Also, it takes less energy to manufacture CIGS modules than silicon PV modules. Flexible versions featuring high-efficiency CIGS are also in the works.

The efficiency rates achieved in the southwest of Germany are also of interest to industry, ZSW adds. Industry partner Manz AG of Reutlingen, Germany recently decided to continue its commitment to CIGS and is developing the technology further in a joint effort with ZSW.

Mistra funds Midsummer to develop modules for EVs

Midsummer AB of Järfälla, near Stockholm, Sweden, a provider of turnkey production lines for manufacturing flexible, lightweight copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) solar cells, has received funding from the Swedish Foundation for Strategic Environmental Research (Mistra) to develop lightweight solar modules for integration into body panels in the composite roof of a Clean Motion Zbee ultra-light electric vehicle.

Mistra is funding Midsummer's development of lightweight solar modules on vehicles. The project aims to research and evaluate the integration of thin-film solar panels for urban transport using ultra-light vehicles.

Clean Motion has developed the ultra-light electric vehicle Zbee, aiming to create a vehicle using little resources (both at production and usage) without compromising safety or design. Solar panels would enable



A Clean Motion Zbee ultra-light EV.

the use of solar energy to recharge the vehicle's battery, increasing the driving range before needing conventional battery charging.

"Using solar panels is the only way towards making a vehicle energy autonomic," says Midsummer's CEO Sven Lindström. "Midsummer solar panels are flexible both by being bendable and possible to manufacture in different size and voltage configurations," he adds. "Also, the CIGS cells on thin stainless-steel substrates, together with the plastic material layers, give resistant light-

weight modules".

Solar energy boosts range by 10%

Clean Motion and Midsummer have worked together to provide ZBee with solar cells that charge the battery. Standard 6" solar cells in a panel shaped like a 'W' allowed mounting onto the double-curved roof. Tests conducted in Sweden showed that solar energy increased the mileage by 5km per day (a 10% increase). In southern latitudes and with optimized PV area and electronics, mileage would rise further, and some users may hence not even need conventional battery charging.

Development will continue to improve integration and performance, since the initial Zbee project demonstrates that solar cells have the potential to replace conventional battery charging and that Midsummer solar panels are suited to being customized for different applications.

www.midsummer.se

<http://cleanmotion.se/zbee>

www.mistra.org/en/mistra.html

Noise and aluminium indium arsenide antimonide avalanche photodiodes

Researchers implement staircase structure from 1980s proposal.

The universities of Virginia and of Texas in the USA have been developing avalanche photodiodes (APDs) based on aluminium indium arsenide antimonide (AlInAsSb) alloys. Two papers from the group detail the implementation of a staircase structure [Min Ren et al, Appl. Phys. Lett., vol108, p081101, 2016] and low-noise performance [Madison E. Woodson et al, Appl. Phys. Lett., vol108, p081102, 2016].

Staircase APDs were proposed in the early 1980s, but suitable semiconductor materials were not available at that time for the required bandgap engineering. The idea of the staircase steps is to reduce excess noise coming from electron multiplication in a way similar to dynode structures in photomultiplier tubes.

The structure of Ren et al (Figure 1) was grown by molecular beam epitaxy (MBE) on n-type gallium antimonide (n-GaSb) (001) substrates at 480°C. The alloying was achieved with a digital technique where the sources were shuttered in sequences that produced stable binaries of AlSb, AlAs, AlSb, InSb, InAs and Sb.

The multiplication was achieved at the narrow-bandgap InAsSb ($\sim 0.25\text{eV}$) step. The AlInAsSb injector region

had a much wider bandgap ($\sim 1.16\text{eV}$). The conduction band discontinuity was around 0.6eV .

The researchers comment that the threshold for impact ionization in narrow-bandgap materials is typically around $1.5\times$ the bandgap. Since the conduction band drops 0.6eV from the injector, the electrons entering the step have more than $2\times$ the bandgap energy of 0.25eV .

"This is sufficient to provide a high probability of impact ionization at the bandgap discontinuity," the researchers point out.

The step was sandwiched between digitally graded material that was designed to flatten the band edges in the graded layers to form a staircase-condition band structure at high bias.

The APDs were fabricated with circular mesas, SU-8 photoresist passivation, and titanium/gold contacts.

The multiplication gain for 543nm wavelengths was found to be around 1.8 in the reverse-bias range $1\text{--}4\text{V}$ (Figure 2). The measured gain is close to the $2\times$ achieved in theory and Monte Carlo simulations.

The gain remains constant in the temperature range $80\text{--}300\text{K}$. Without composition grading between the

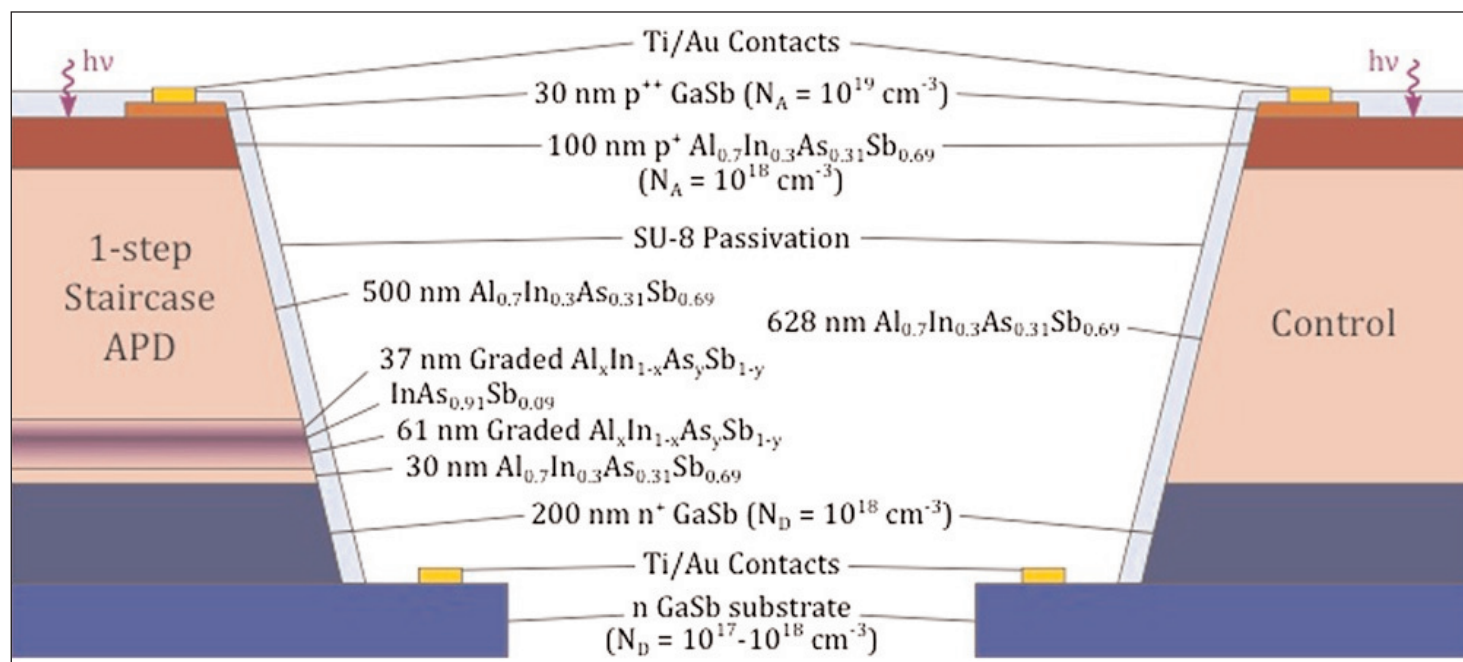


Figure 1. Schematic cross-sections of the 1-step AlInAsSb staircase APD (left) and control (right).

InAsSb and AlInAsSb layers, the gain was reduced to about 1.6. The researchers suggest that the reduction could be due to the electrons losing energy at the abrupt interface. Varying the input wavelength up to around 950nm did not change the gain, although the response increased due to absorption in the InAsSb. The constancy rules out enhanced absorption, and confirms impact ionization as the source of the observed gain, according to the researchers.

Generally, noise scales as the square of the gain, suggesting an increase of $\sim 3.2\times$ for the graded APD. The measured noise was 2–2.2x. “While fortuitous, this unexpectedly low noise will be the subject of future study,” the researchers comment. They point out that similar noise suppression has been seen before in impact-ionization engineered heterojunction APDs.

The researchers believe their research could lead to separate absorption, charge and multiplication (SACM) AlInAsSb staircase APDs with cutoff wavelengths ranging throughout the short-wave and mid-wave infrared bands. Potential applications include night vision, thermal imaging, and free-space telecommunications. Multi-step devices should lead to higher gain.

Woodson et al used solid-source MBE on tellurium-doped n-GaSb to produce the structure for low-noise AlInAsSb APDs using digital alloying with 3nm period and an AlSb, AlAs, AlSb, InSb, InAs, Sb shutter sequence (Figure 3). Circular mesa APDs with SU-8 passivation were produced.

The resulting APDs had low excess noise performance (Figure 4), indicating extremely low k-factors — the ratio of hole to electron ionization probabilities. The behavior was consistent with a k-factor for the 30 μm -diameter device of 0.015, comparable with silicon (~ 0.04). The excess noise factor from increasing gain was thus comparable to silicon devices. Indium phosphide (InP) APDs usually have k-factors in the range 0.45–0.52. The peak quantum efficiency of the AlInAsSb APD was 68% at 735nm.

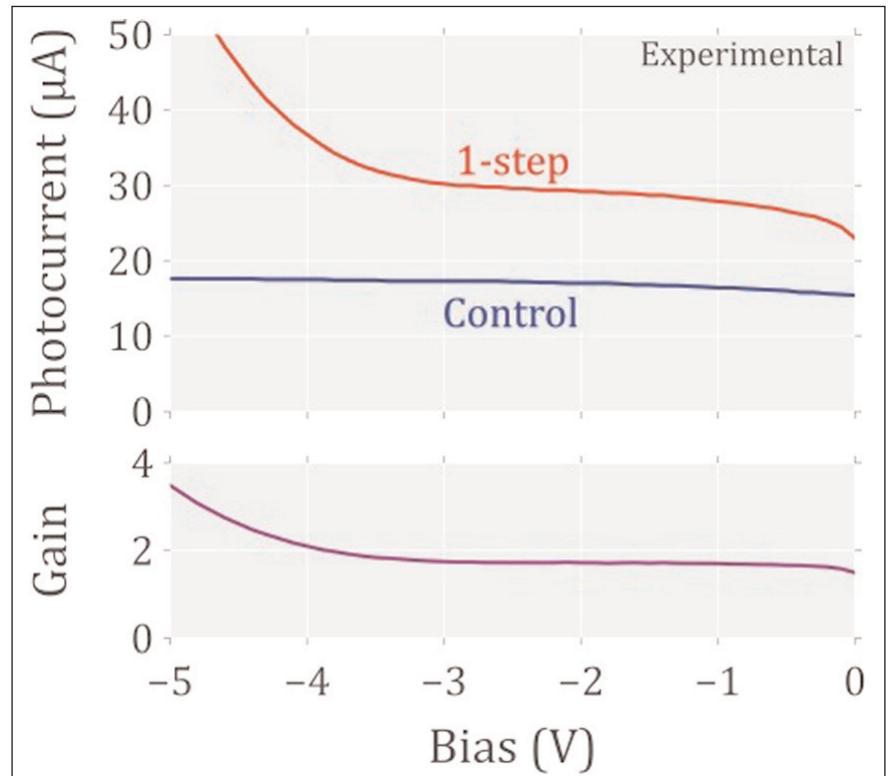


Figure 2. Enhancement of photocurrent from 50 μm -diameter 1-step staircase APD over control at reverse biases up to 5V under 543nm wavelength.

Unlike silicon, AlInAsSb has a direct bandgap, which suggests that APDs based on the technology could achieve high bandwidths due to a shorter absorption length. Also, changing the composition of the material could lead to devices sensitive across the visible and

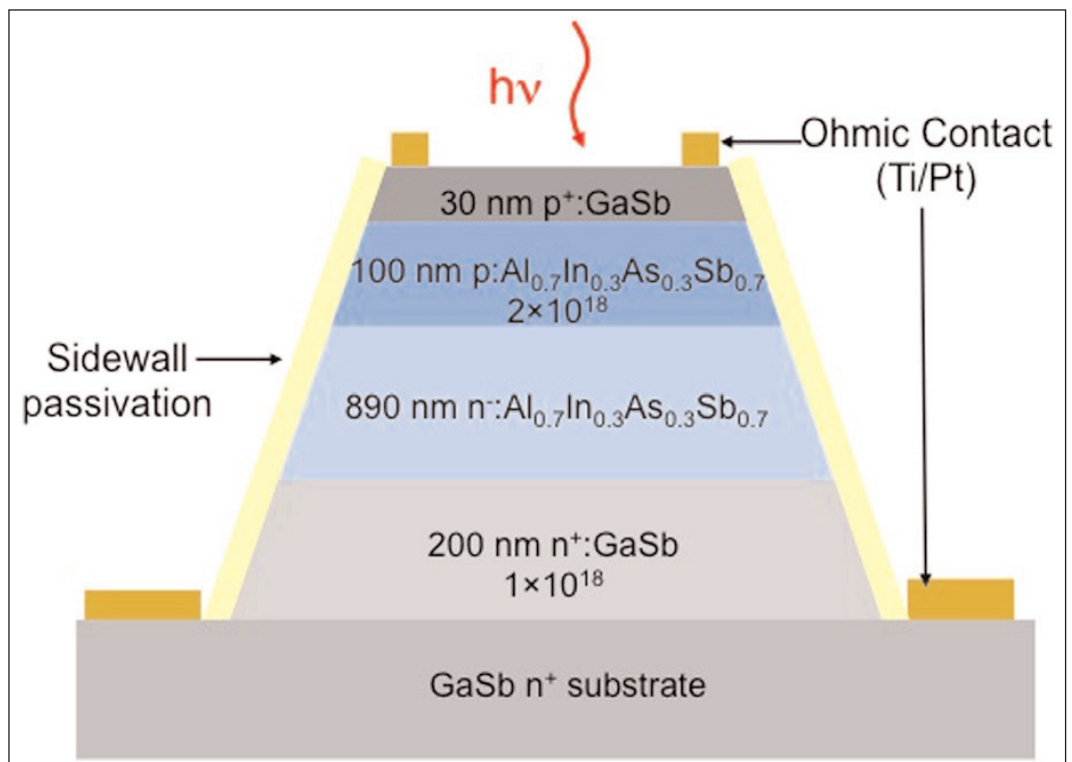


Figure 3. Cross-sectional schematic of low-noise APD.

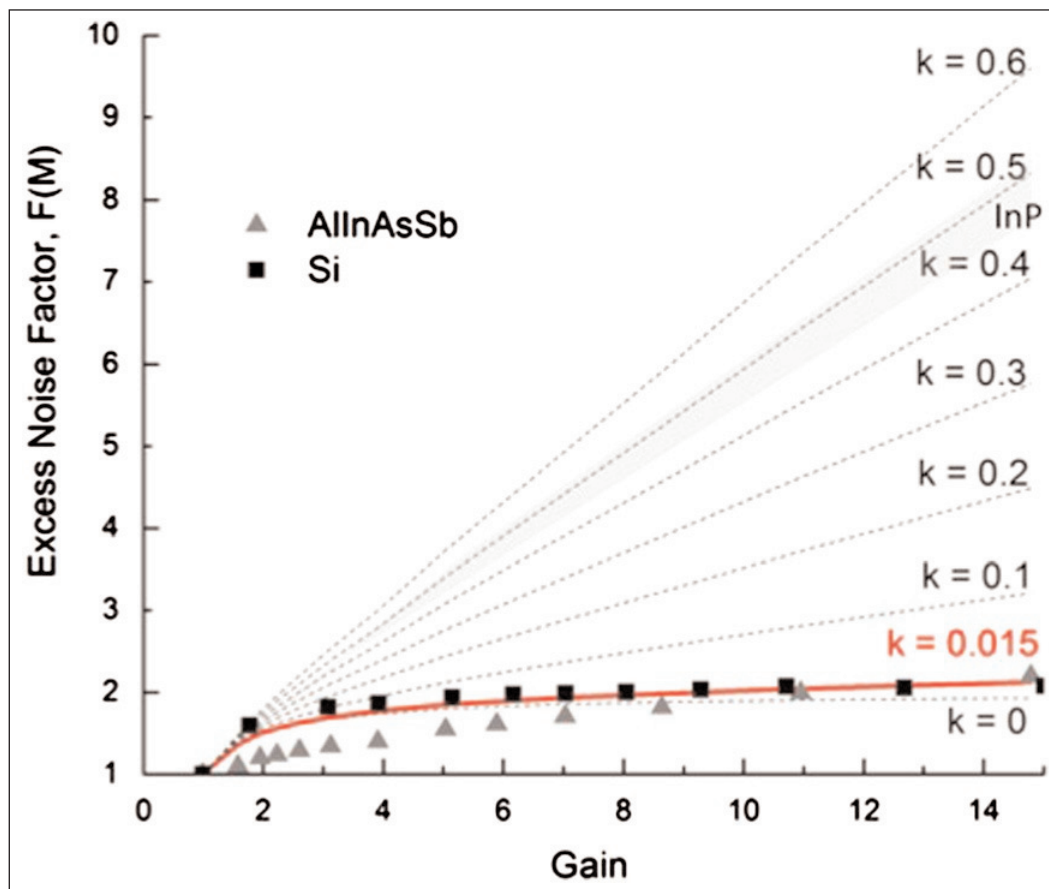


Figure 4. Excess noise factor versus gain for AlInAsSb and Si APDs. Solid lines are plots of excess noise factor using local field model for k values from 0 to 0.5. Lightly shaded region with k of more than 0.45 indicates typical InP APD performance.

near-infrared wavelength ranges. In particular, the $1\mu\text{m}$ to $12\mu\text{m}$ wavelength cut-off range is mentioned in the paper. A $1\mu\text{m}$ cut-off device would be sensitive to sub-micron wavelengths, such as visible light. Possible applications include optical communications, imaging, and single-photon detection. ■ <http://dx.doi.org/10.1063/1.4942370>
<http://dx.doi.org/10.1063/1.4942372>
 Author: Mike Cooke

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NREL theory overcomes barrier to using 2D semiconductors in electronic and opto devices

2D metal electrode binds with 2D semiconductor via van der Waals interaction to tune out Schottky barrier.

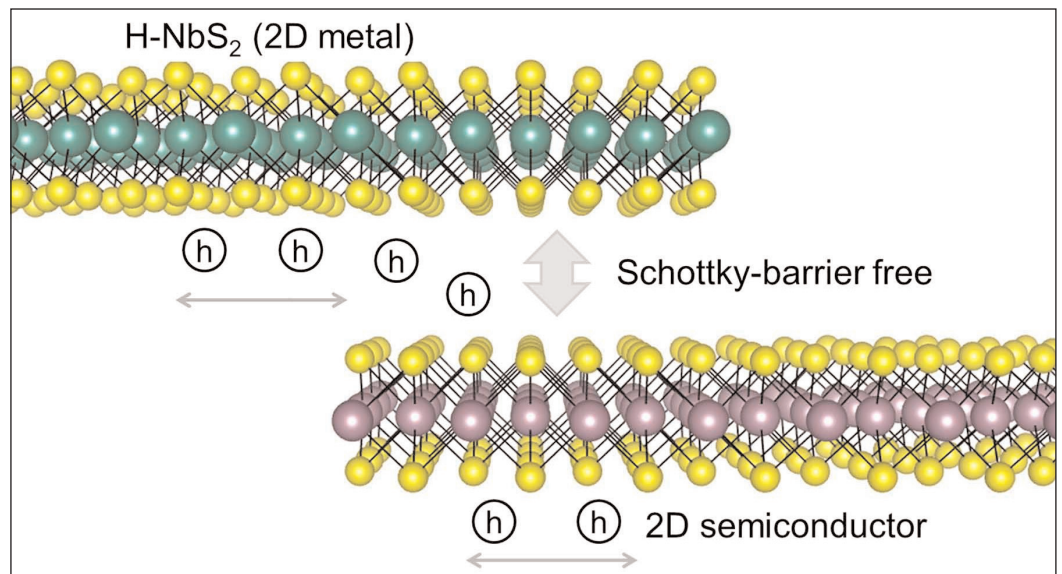
The US Department of Energy's National Renewable Energy Laboratory (NREL) says that it has uncovered a way to overcome a principal obstacle in using two-dimensional (2D) semiconductors in electronic and optoelectronic devices (Yuanyue Liu, Paul Stradins and Su-Huai Wei, 'Van der Waals metal-semiconductor junction: weak Fermi level pinning enables effective tuning of Schottky barrier', *Science Advances*, vol.2, no.4, e1600069).

2D semiconductors such as molybdenum disulfide are only a few layers thick and are considered promising candidates for next-generation devices.

Researchers must first overcome limitations imposed by a large and tunable Schottky barrier between the semiconductor and a metal contact. The barrier, at the metal/semiconductor junction, creates an obstacle for the flow of electrons or holes through the semiconductor.

The NREL team discovered that the height of the Schottky barrier can be adjusted — or even made to vanish — by using certain 2D metals as electrodes. Such adjustments are not possible with conventional three-dimensional metals because of a strong Fermi-level pinning (FLP) effect occurring at the junction of the metal and the semiconductor, due to electronic states in the semiconductor bandgap that are induced by the metal. Increasing the flow of electrons or holes through a semiconductor reduces power losses and improves the device performance.

The NREL theorists considered a family of 2D metals that could bind with the 2D semiconductors through van der Waals (vdW) interaction. Because this interaction is relatively weak, the metal-induced gap states are suppressed and the FLP effect is negligible, so the Schottky barrier becomes highly tunable. By selecting



Using 2D metal as contact for 2D semiconductor allows Schottky barrier to be tuned, due to the weak Fermi level pinning at the junction caused by the suppression of metal-induced gap states. Schematic illustrates that 2D H-NbS₂ can form a Schottky-barrier-free contact with 2D semiconductor for hole transport.

an appropriate 2D metal/2D semiconductor pair (such as H-NbS₂/WSe₂ for hole conduction), one can reduce the barrier to almost zero.

The researchers noted that using a 2D metal as an electrode would also prove useful for integrating into transparent and flexible electronics because the 2D metal is also transparent and flexible. They also noted that the junction of 2D metal and 2D semiconductor is atomically flat and can have fewer defects, which would reduce carrier scattering and recombination.

The NREL research predicts that the hexagonal phase of niobium disulfide (NbS₂) is the most promising for hole injection into a 2D semiconductor, and heavily nitrogen-doped graphene can enable efficient electron injection.

The research was funded by the Department of Energy's Office of Energy Efficiency and Renewable Energy. The work used computational resources at NREL and the National Energy Research Scientific Computing Center. ■

<http://advances.sciencemag.org/content/2/4/e1600069>
www.nrel.gov

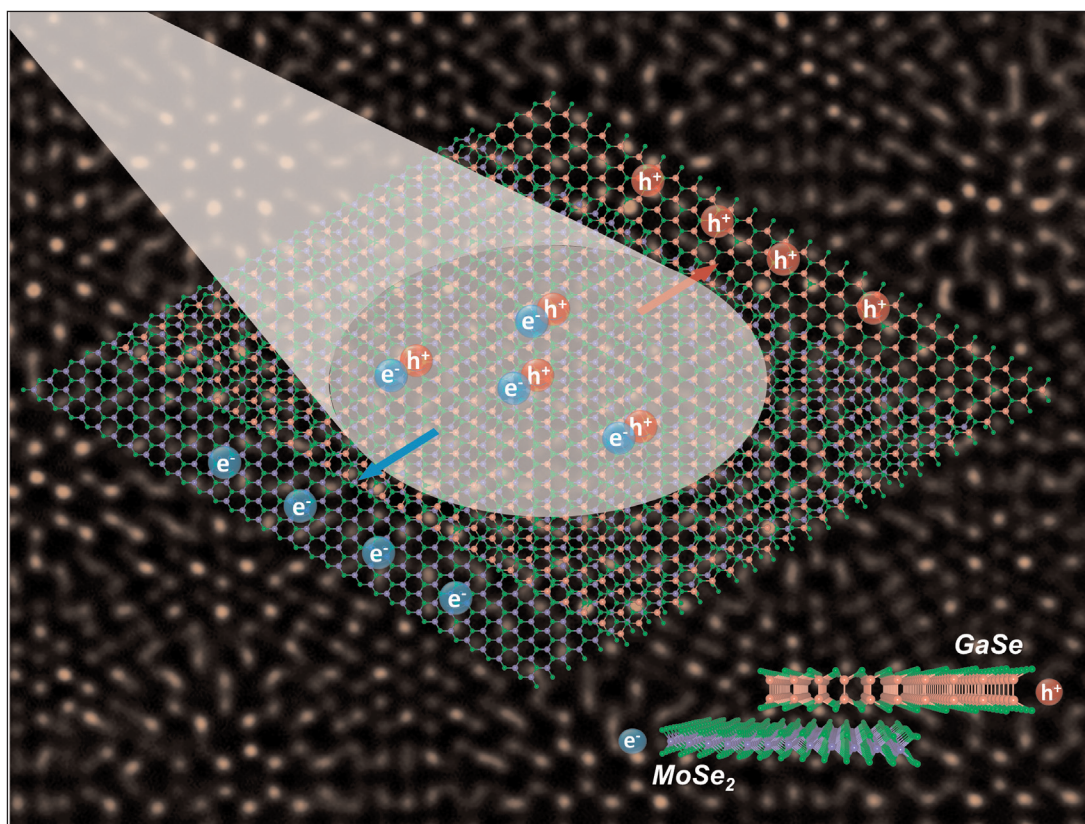
ORNL-led group grows aligned monolayers of lattice-mismatched semiconductors

van der Waals epitaxy of 2D GaSe/MoSe₂ misfit bilayer heterojunction yields building block for energy-efficient optoelectronics.

Led by the Department of Energy's Oak Ridge National Laboratory (ORNL), a group of researchers has synthesized a stack of atomically thin monolayers of two lattice-mismatched semiconductors (Xufan Li et al, 'Two-dimensional GaSe/MoSe₂ misfit bilayer heterojunctions by van der Waals epitaxy', *Science Advances*, Vol. 2, no. 4, e1501882). ORNL's Functional Hybrid Nanomaterials group, led by David Geohegan, conducted the study with partners at Vanderbilt University, the University of Utah, and Beijing Computational Science Research Center.

Stacking different materials on top of each other usually only works when the individual materials have very similar crystal lattices with a good lattice match. In contrast, the researchers have grown high-quality layers of very different two-dimensional (2D) materials, broadening the number of materials that can be combined and thus creating a wider range of potential atomically thin electronic devices.

In the research, the interface between the two layers of p-type semiconductor gallium selenide (rich in hole charge carriers) and n-type semiconductor molybdenum diselenide (rich in electron charge carriers) formed an atomically sharp p-n junction heterostructure which generated a photovoltaic response by separating electron-hole pairs generated by light. "Because the two layers had such a large lattice mismatch between



Light drives the migration of charge carriers at the junction between semiconductors with mismatched crystal lattices. The schematic's background is a scanning transmission electron microscope image showing the bilayer in atomic-scale resolution. Credit: Oak Ridge National Laboratory, US Dept. of Energy. Image by Xufan Li and Chris Rouleau.

them, it's very unexpected that they would grow on each other in an orderly way," says ORNL's Xufan Li, lead author of the study. "But it worked." This atomically thin solar cell shows the promise of synthesizing mismatched layers to enable new families of functional 2D materials, say the researchers.

In particular, the group is first to show that monolayers of two different types of metal chalcogenides (binary compounds of sulfur, selenium or tellurium with a more electropositive element or radical) having such different lattice constants can be grown together to form a perfectly aligned stacking bilayer. "It's a new,

potential building block for energy-efficient optoelectronics," Li said.

Li first grew a monolayer of molybdenum diselenide, and then grew a layer of gallium selenide on top. This technique of 'van der Waals epitaxy' is named for the weak attractive forces that hold dissimilar layers together. "With van der Waals epitaxy, despite big lattice mismatches, you can still grow another layer on the first," Li says. Using scanning transmission electron microscopy, the team characterized the atomic structure of the materials and revealed the formation of Moiré patterns.

Upon characterizing their new bilayer building block, the researchers found that the two mismatched layers had self-assembled into a repeating long-range atomic order that could be directly visualized by the Moiré patterns they showed in the electron microscope. "We were surprised that these patterns aligned perfectly," Li says.

"These new 2D mismatched layered heterostructures open the door to novel building blocks for optoelectronic applications," says senior author Kai Xiao of ORNL.

"They can allow us to study new physics properties which cannot be discovered with other 2D heterostructures with matched lattices," he adds. "They offer potential for a wide range of physical phenomena ranging from interfacial magnetism, superconductivity and Hofstadter's butterfly effect."

The researchers plan future studies to explore how the material aligns during the growth process and how material composition influences properties beyond the photovoltaic response. The research advances efforts to incorporate 2D materials into devices. "We've opened the door to exploring all types of mismatched heterostructures," says Li.

The research, including materials synthesis, was supported by the DOE Office of Science. Materials characterization was conducted in part at the Center for Nanophase Materials Sciences (a DOE Office of Science User Facility at ORNL). ORNL Laboratory Directed Research and Development funds supported some device measurements in the study. ■ <http://advances.sciencemag.org/content/2/4/e1501882>
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Exciton control in molybdenum disulfide

Researchers hope that work will lead to room-temperature Bose–Einstein condensation and efficient light-emitting structures.

University of California at San Diego (UCSD) in the USA and the University of Manchester in the UK have been developing methods to control excitons in molybdenum disulfide (MoS_2) [E. V. Calman et al, Appl. Phys. Lett., vol108, p101901, 2016].

The researchers hope that states such as Bose–Einstein condensates found in low-temperature gallium arsenide (GaAs) exciton structures could be realized at room temperature, giving access to resistance-free superfluid flow. Also, better control of excitons is considered to be a path to more efficient light emission.

The use of MoS_2 should allow exciton states to be studied at room temperature and above. Gallium arsenide excitons have much smaller binding energies, and thus cannot survive temperatures above 100K.

MoS_2 is a transition metal dichalcogenide (TMD) — a group of materials that can be separated into atomic-scale layers. Much present research is being carried out into the properties of MoS_2 and other materials in this class, such as molybdenum diselenide, tungsten disulfide, and tungsten diselenide.

In addition, there are other materials that can be separated along weak van der Waals-type bonds such as graphene, black phosphorus, and hexagonal boron nitride.

It is hoped in future to develop electronic devices and mass-production methods that could lead to small low-cost technology based on atomic-scale layers of materials.

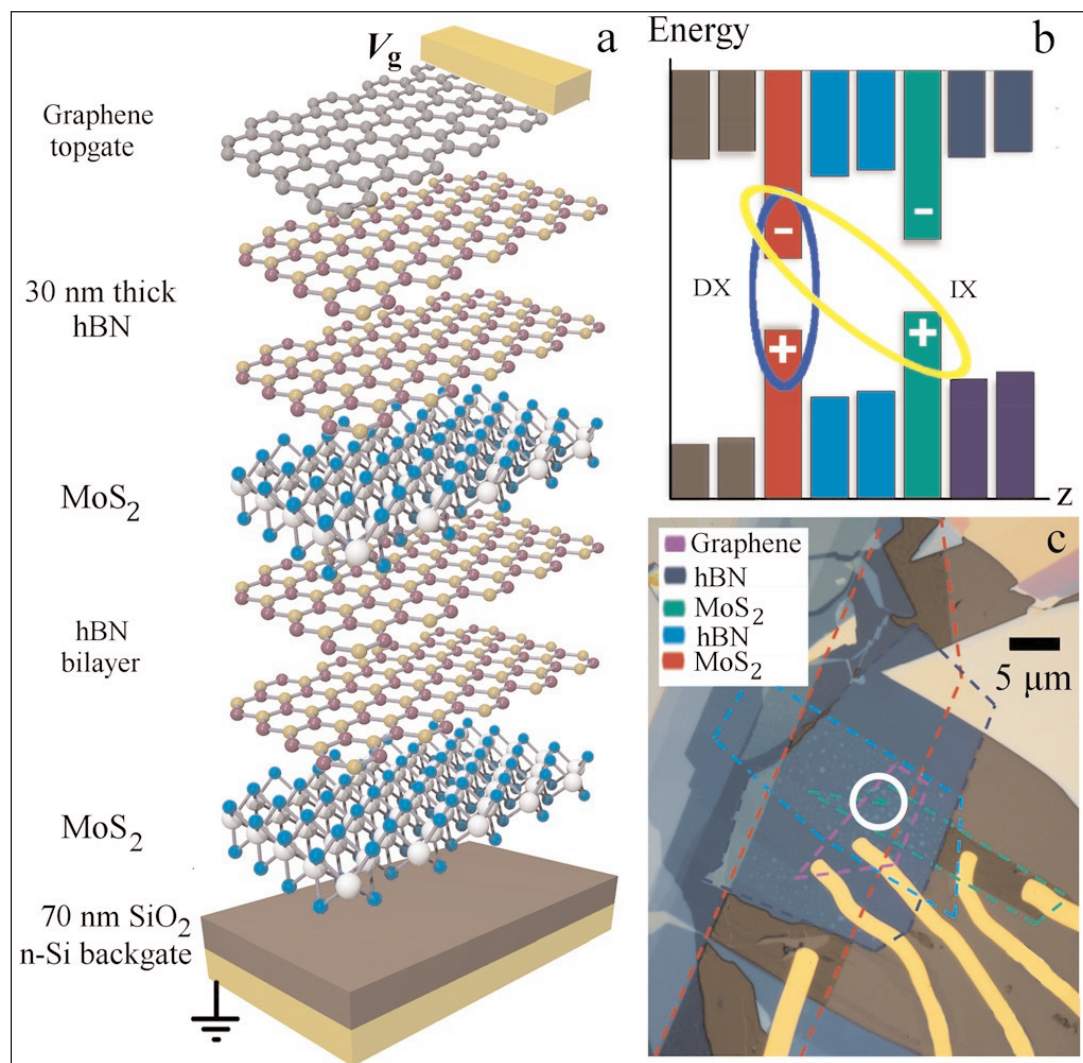


Figure 1. Coupled quantum well van der Waals heterostructure. Layer (a) and energy-band (b) diagrams. Ovals indicate direct (DX) and indirect (IX) excitons composed of electron and hole. (c) Microscope image showing layer pattern of device. Laser excitation target is indicated by circle.

The San Diego/Manchester test structure (Figure 1) was assembled from Scotch-tape mechanically exfoliated layers on a silicon dioxide layer on n-type silicon (n-Si) substrate. The Scotch-tape technique was developed at Manchester by one of the paper's authors, Andre Geim, in his Nobel-prize-winning research into graphene.

Coupled quantum wells of MoS_2 monolayers were separated by a bilayer of hexagonal boron nitride (hBN). About 30nm of hBN was also used to give a dielectric cladding for the top graphene electrode. A 'gate' voltage

(V_g) could be applied between the top electrode and n-Si substrate.

Photoluminescence was measured under various conditions using continuous wave (cw) laser excitation at three energies: 3.1eV, 2.3eV and 1.9eV.

Spectra were gathered at temperatures between 1.6K and 286K at 3.1eV excitation with 0.8mW power. Also, the laser power of a 2.3eV laser was varied between 0.5mW and 800mW. Circularly polarized light was used to probe spin relaxation. Pulsed excitation at 3.1eV was used for time-resolved spectra. The voltage across the structure was also varied between -20V and +40V.

The spectra showed three main peaks: two high-energy emissions separated by about 20meV, and a broader lower-energy state. The analysis arising from the various set ups suggested that the states were direct excitons — i.e. carrier bound states within the wells — rather than indirect states coupling carriers in different wells.

The high-energy peaks were considered to be from electron-hole bound states — A excitons, the 'A' referring the type of hole determined by spin-orbit coupling effects in the valence band. The binding energies of the two MoS₂ A excitons were about 0.5eV, split by about 25meV. The splitting between A and B excitons in MoS₂ is about 0.2eV.

The 0.5eV binding is much greater than the typical scale of fluctuations from thermal effects at room temperature of 26meV. Excitons in the usual compound semiconductors have binding energies of at most tens of milli-electron-volts (e.g. ~60meV in zinc oxide). Gallium arsenide has exciton binding energies of about 4.2meV.

The researchers suggest that the ~25meV splitting could be associated with the spin-dependence of the electron mass in the conduction band. The team writes: "The calculated 10% difference in the masses, 0.44 versus 0.49 m_0 , of the conduction band spin states results in a 5% difference in the reduced electron-hole masses and, in turn, exciton binding energies. This

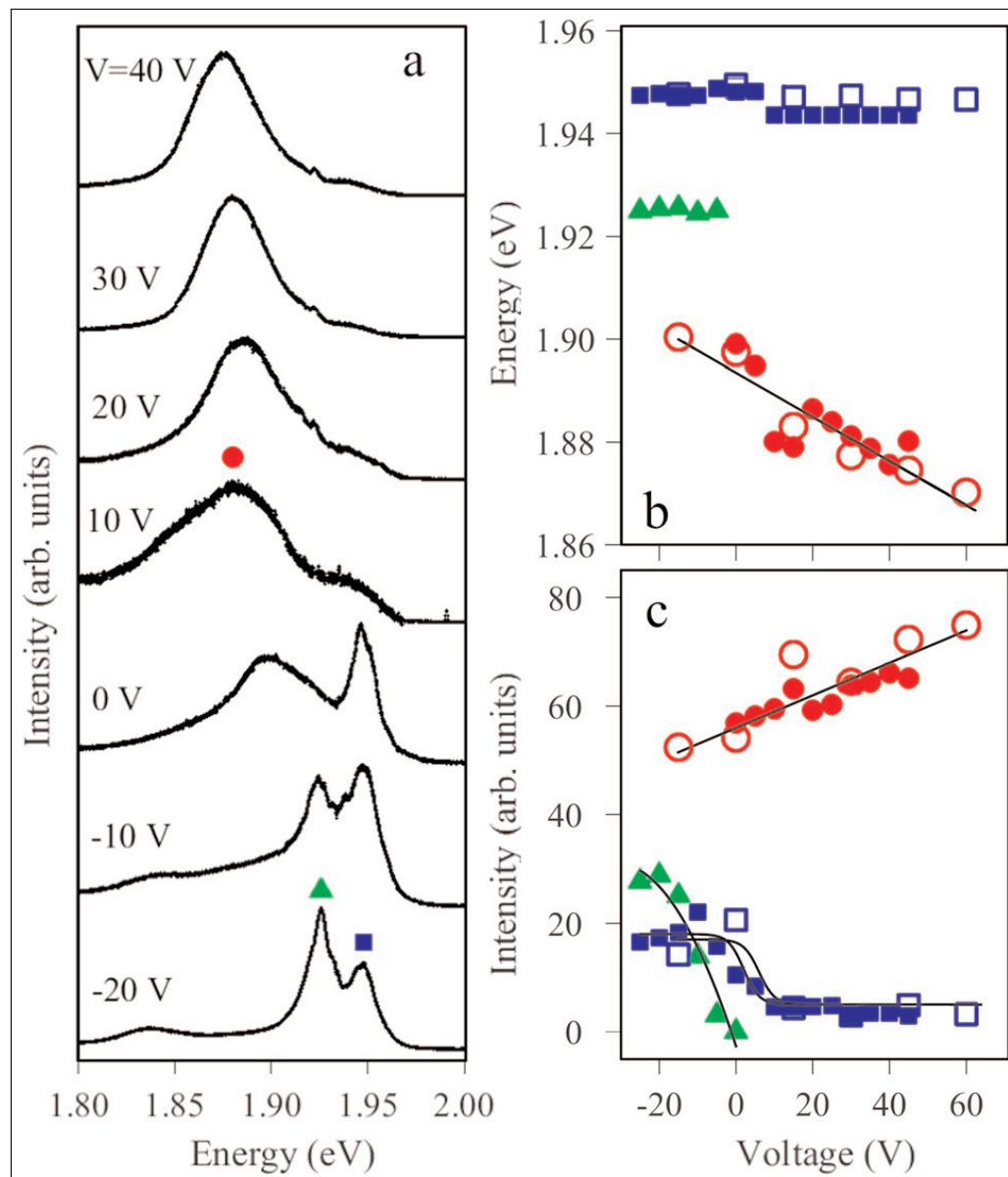


Figure 2. Gate voltage dependence. (a) Emission spectra at different V_g . Energy (b) and relative intensity (c) of emission lines marked in (a) versus V_g . Curves are guides to eye. Solid (open) symbols correspond to excitation energy 3.1eV (2.3eV) at 0:8mW power and 2K temperature.

leads to the energy splitting 25meV consistent with the experiment."

The researchers associated the broad lower-energy state with charged excitons — trions — consisting of three carriers. The application of voltage across the structure enabled disentangling of the nature of the trions (Figure 2).

The researchers comment: "The main effect of the gate voltage in the direct regime is the control of the exciton and trion PL intensities: the high-energy exciton emission increased at the negative V_g , while the low-energy trion emission increased at the positive V_g . This behavior is attributed by the voltage-dependent electron concentration n_e in the MoS₂ layers." ■

<http://dx.doi.org/10.1063/1.4943204>

Author: Mike Cooke

Tantalum barrier reduces gallium phosphide contact resistance

Out-diffusion is blocked in gold-beryllium alloy contacts, reducing Schottky barrier height in LEDs.

Korea University has been working to improve metal contacts on aluminium gallium indium phosphide (AlGaInP) light-emitting diodes (LEDs) [Dae-Hyun Kim et al, Jpn. J. Appl. Phys., vol55, p032102, 2016]. In particular, the research team added a tantalum diffusion barrier to lock in beryllium-alloy atoms in gold-based contacts on p-type GaP.

AlGaInP LEDs emit in the wavelength range from red down to green-yellow, used in traffic light lamps, automobile tail lamps, biotherapy, outdoor displays, and solid-state lighting.

The improved metal contacts are designed to overcome current crowding, which is a particular problem in p-type AlGaInP due to low hole concentrations. Platinum and palladium diffusion barriers have previously been shown to reduce specific contact resistivity to less than $10^{-6}\Omega\text{-cm}^2$ for gold-beryllium alloy contacts on p-type gallium arsenide (GaAs), annealed at 390°C for 30 minutes.

The heterostructures were grown by metal-organic chemical vapor deposition (MOCVD) on (111) GaAs substrates (Figure 1). The p-contact metal contact consisted of 130nm gold-beryllium alloy (1% weight Be), 20nm tantalum diffusion barrier, and 100nm gold. Devices without the tantalum barrier were produced for reference.

Thermal annealing reduced the resistance of the tantalum barrier contacts, but degraded the performance of the reference samples without tantalum (Figure 2). The specific contact resistivity

Figure 2. (Color online) (a) Current–voltage characteristics of gold-beryllium/gold (reference) and gold-beryllium/tantalum/gold contacts on p-GaP as deposited, and annealed at 300°C and 500°C. (b) Characteristics of contacts annealed at 450°C for 10 minutes.

Contact	carbon-doped p-GaP	200nm
Contact	magnesium-doped p-GaP	3 μm
Multiple quantum well (MQW)	30x((Al _{0.7} Ga _{0.3}) _{0.5} In _{0.5} P/ (Al _{0.1} Ga _{0.9}) _{0.5} In _{0.5} P))	
Contact	silicon-doped n-Al _{0.5} In _{0.5} P	2 μm
Buffer	n-GaAs	300 μm
Substrate	GaAs (111)	

Figure 1. LED heterostructure.

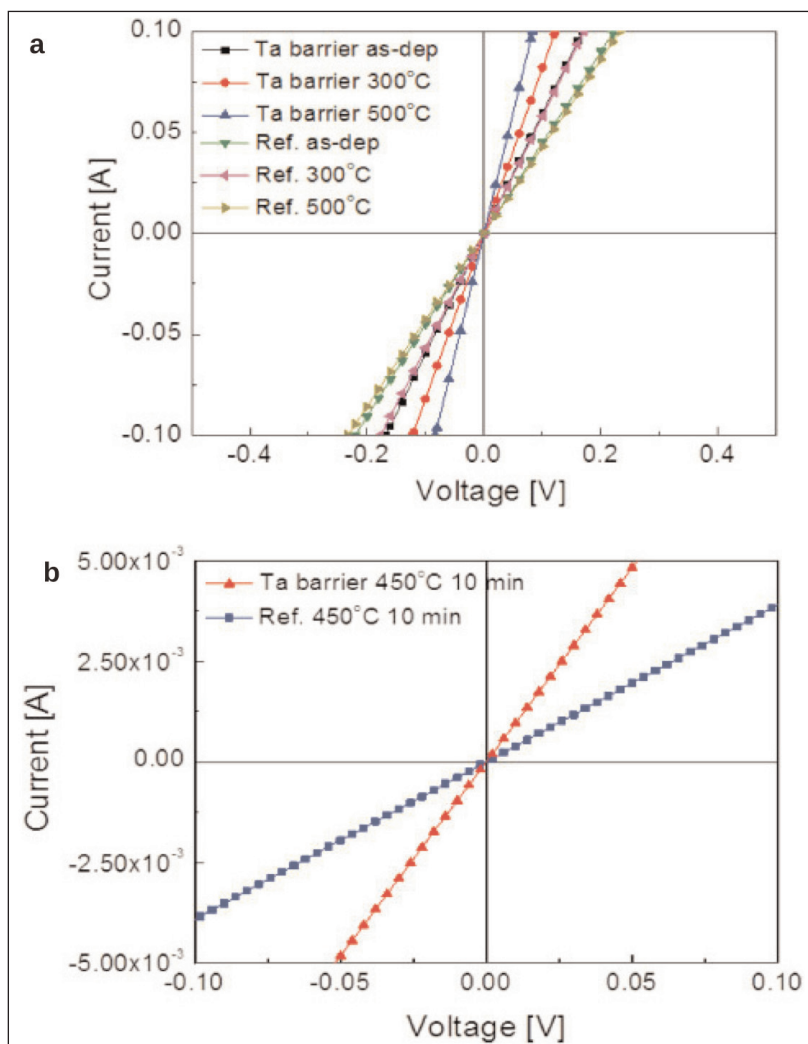
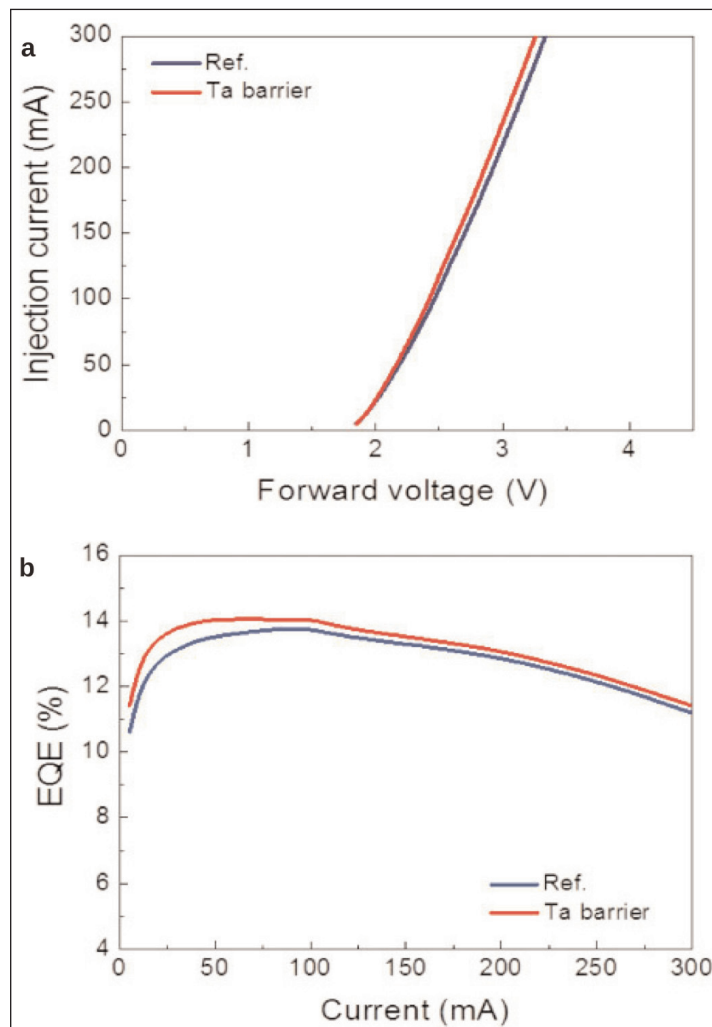


Figure 3. (a) Current–voltage characteristics and (b) external quantum efficiency (EQE) as a function of current of AlGaInP-based MQW LEDs fabricated with gold-beryllium/gold (reference) and gold-beryllium/tantalum/gold contacts annealed at 450°C for 10 minutes.

without annealing was $8.2 \times 10^{-5} \Omega\text{-cm}^2$ and $3.4 \times 10^{-5} \Omega\text{-cm}^2$ for the reference and tantalum-barrier contacts, respectively. After 500°C annealing, the tantalum-barrier resistivity improved by an order of magnitude — $2.8 \times 10^{-6} \Omega\text{-cm}^2$, compared with degradation to $1.0 \times 10^{-4} \Omega\text{-cm}^2$ for the reference sample.

The LEDs with tantalum-barrier contacts that were annealed at 450°C for 10 minutes had a peak external quantum efficiency (EQE) of 14.0%, compared with 13.5% for annealed devices without a tantalum barrier (Figure 3). The researchers attribute the improvement to a lower forward voltage and higher reflectance in the 550–900nm wavelength range of the tantalum-barrier contact. The reflectance at 617nm was 92.8% for the tantalum-barrier contact, compared with 87.7% for the reference.

X-ray photo-electron spectroscopy (XPS) analysis suggested that the tantalum diffusion barrier reduced downward band bending, reducing the Schottky barrier height. Auger electron spectroscopy (AES) showed that the effect of the tantalum barrier was to block out-diffusion of the beryllium and encourage in-diffusion into the underlying GaP layer. Beryllium acts as an acceptor in GaP, increasing hole concentrations and reducing band bending near the surface. ■



<http://doi.org/10.7567/JJAP.55.032102>

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Indium gallium nitride barriers enhance LED power and efficiency

Researchers find that the optimum indium content in the multi-quantum-well barriers is 1.2%, rather than conventional pure GaN barriers.

South China University of Technology has shown improved power and efficiency performance for indium gallium nitride (InGaN) light-emitting diodes (LEDs) with 1.2% indium-content multiple-quantum-well (MQW) barriers [Zhiting Lin et al, *J. Phys. D: Appl. Phys.*, vol49, p115112, 2016].

The purpose of the research was to study the effect of indium in MQW barriers. Most commercial MQW designs use pure GaN barriers (i.e. 0% indium).

The epitaxial heterostructures were grown by metal-organic chemical vapor deposition (MOCVD) on 2-inch (0001) patterned sapphire (Figure 1). The undoped buffer layer was 4 μm . The n-GaN contact was 3 μm . The electron-blocking layer (EBL) and p-contact were 20nm and 150nm, respectively.

The MQW region consisted of seven 3nm wells separated by 14nm barriers. The wells had 20% indium content. The variation in indium content in the barriers was achieved through changing the trimethyl-indium precursor flux. The indium content was evaluated using x-ray diffraction analysis.

Standard InGaN LED chips were fabricated with 250nm indium tin oxide (ITO) transparent conductor, and chromium/platinum/gold n- and p-electrodes. The chip dimensions were 750 μm x220 μm .

The highest light output power above 20mA injection current was achieved with 1.2%-In barriers (Figure 2) — at 70mA the increase in output power over pure GaN barriers was 15.4%. The light output decreased significantly when the indium content exceeded 2%.

Although the 2.0%-In barrier gave the highest peak external quantum efficiency (EQE), the 1.2%-In barrier was better at reducing the droop effect at higher injection current. At 70mA, the 2.0%- and 1.2%-In barriers gave EQE values 3.3% and 10.3% better than for pure GaN barriers.

The researchers therefore consider 1.2% indium to be the optimal content for InGaN barriers. X-ray analysis

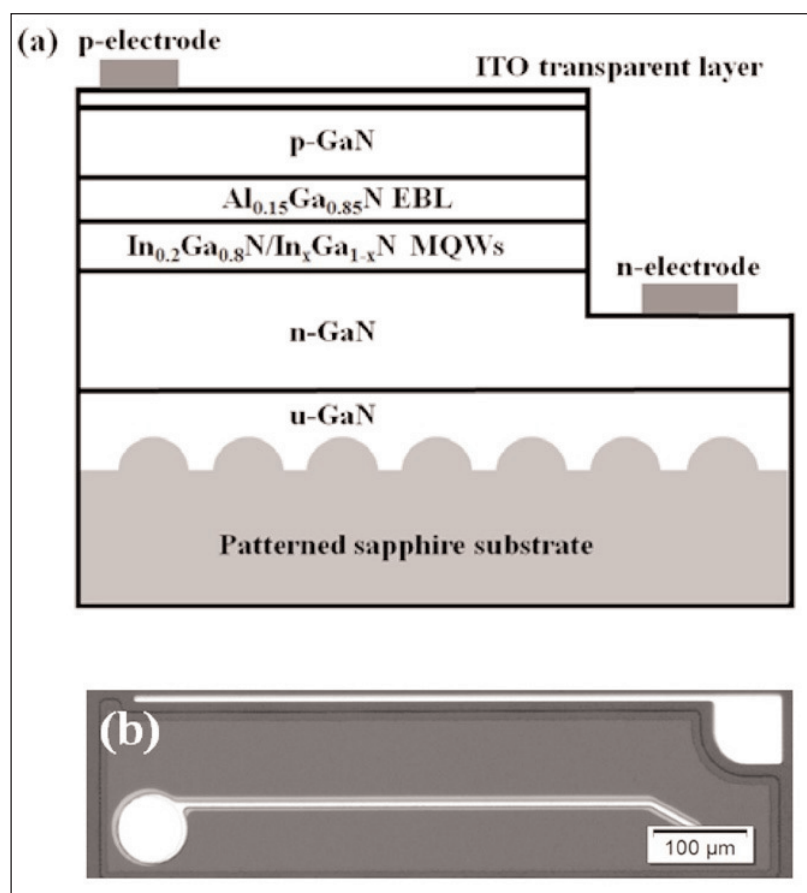


Figure 1. (a) Epitaxial structure of as-grown LEDs; (b) optical micrograph of chip.

suggested that problems with increased indium content included increasing roughness of the well/barrier interface and degraded crystal quality.

One cause of such problems could be the increased lattice mismatch between the barrier and the underlying GaN lattice constant. The thinner wells should be less affected by crystal quality degradation, despite the higher indium content. However, the reduced crystal quality of the barriers and the interface roughness do have their effect on the quality of subsequent well growth, inducing the creation of non-radiative recombination centers.

Photoluminescence analysis showed a slight reduction in intensity for 1.2%-In barriers, compared with pure

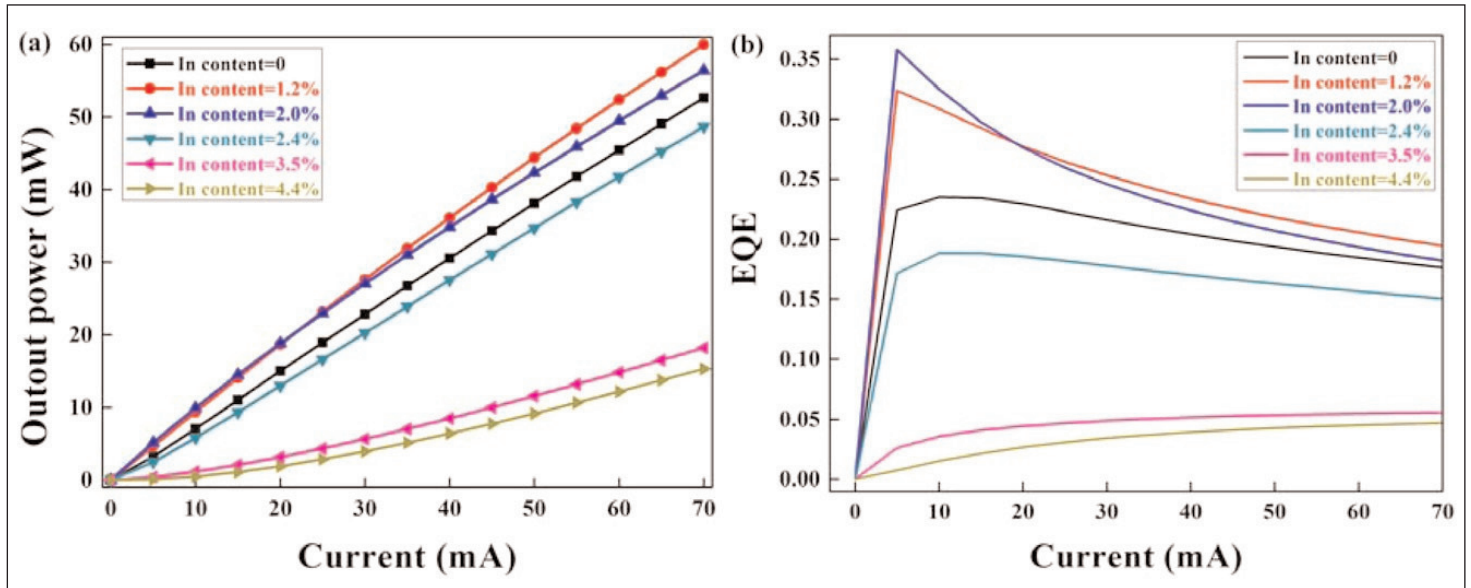


Figure 2. (a) Light output power versus current and (b) EQE versus current.

GaN. As the indium content was increased beyond 1.2%, the photoluminescence decreased sharply.

The researchers used simulations to suggest that a positive effect of increasing indium content in the barriers was to increase carrier concentrations in the MQW structure. "We propose that the gain on carrier concentration and the crystalline quality degradation

are a pair of opposite influential factors as the indium content of InGaN barriers increases," they write.

The calculations also suggest that the increase in indium increases the potential barrier for electrons while reducing that for holes. ■

<http://dx.doi.org/10.1088/0022-3727/49/11/115112>

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Thermal droop in indium gallium nitride light-emitting diodes

Researchers have developed a model of thermal droop in InGaN LEDs through both experiment and simulations.

Researchers based in Europe and India have been developing models of thermal droop in indium gallium nitride (InGaN) light-emitting diodes (LEDs) through experiment and simulations [C. De Santi et al, J. Appl. Phys., vol119, p094501, 2016].

Thermal droop is important in commercial devices since the temperature increases with continuous operation through Joule heating. Some commercial LEDs are rated for operating up to 175°C. Higher operating temperatures can lower device costs through reduced thermal management requirements. However, devices running at 150°C can lose up to 25% of optical power, compared with room-temperature operation.

Generally, InGaN LEDs become less efficient at high temperature. Thermal droop is separate from the more intensively studied efficiency droop at high current. Indeed, efficiency experiments are usually carried out under pulsed operation to avoid Joule self-heating.

University of Padova in Italy, Osram Opto Semiconductors GmbH in Germany, Politecnico di Torino in Italy, and Anna University in India tested a range of c-plane devices on silicon with different point defect densities. The defect levels were estimated using capacitance deep-level transient spectroscopy (C-DLTS).

The device materials were grown using metal-organic vapor phase epitaxy (MOVPE) with the following layer sequence:

- an aluminium nitride buffer layer;
- a 5µm aluminium gallium nitride/gallium nitride

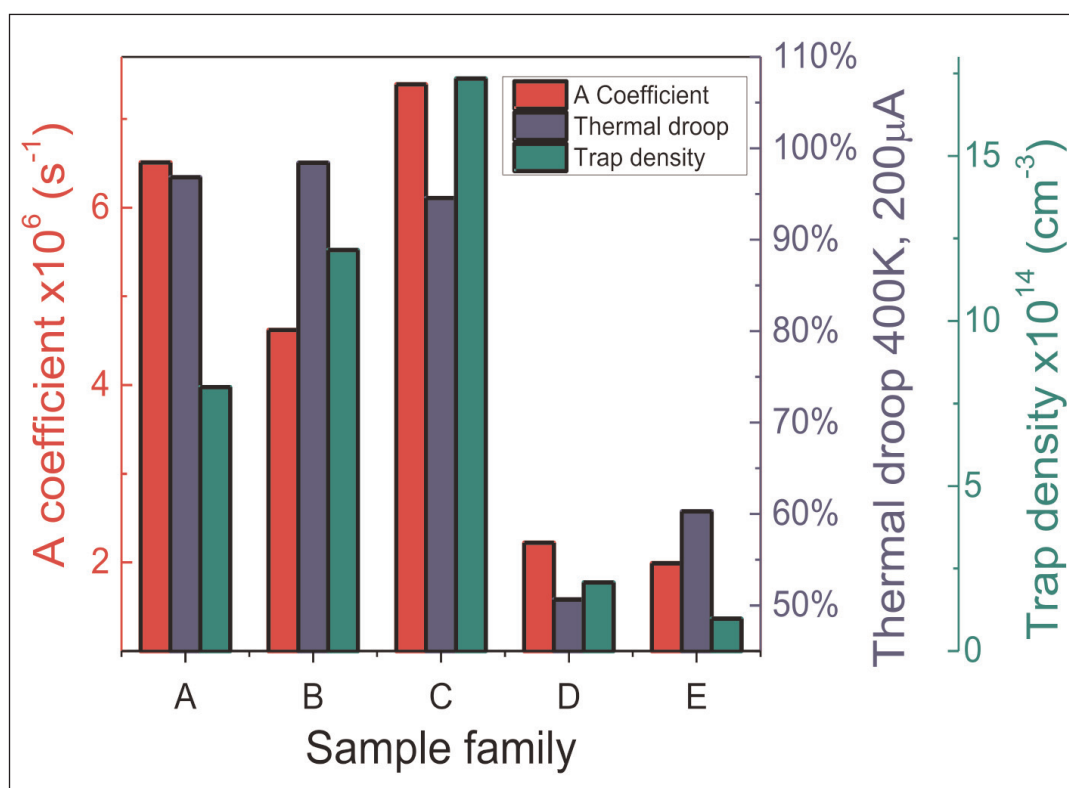


Figure 1. Correlation between SRH A coefficient, obtained by differential lifetime measurements, trap density evaluated by C-DLTS, and amount of thermal droop.

buffer layer;

- a silicon-doped n-type gallium nitride current-spreading layer;
- a 3nm single quantum well;
- a p-type aluminium gallium nitride electron-blocking layer; and
- a p-type gallium nitride contact layer.

The thermal droop was greatest in devices with high defect density, losing more than 99% of output power when the temperature increased from 83K to 475K.

The team relates this behavior to non-radiative Shockley-Read-Hall (SRH) recombination through defect energy levels in the bandgap. The researchers add, however: "thermal droop cannot be explained by simply taking into account the increase in SRH recombination at high temperature levels."

Figure 2. (a) Sketch of proposed escape model, (b) agreement between experimental data and model, and (c) breakdown of overall curve into the two components.

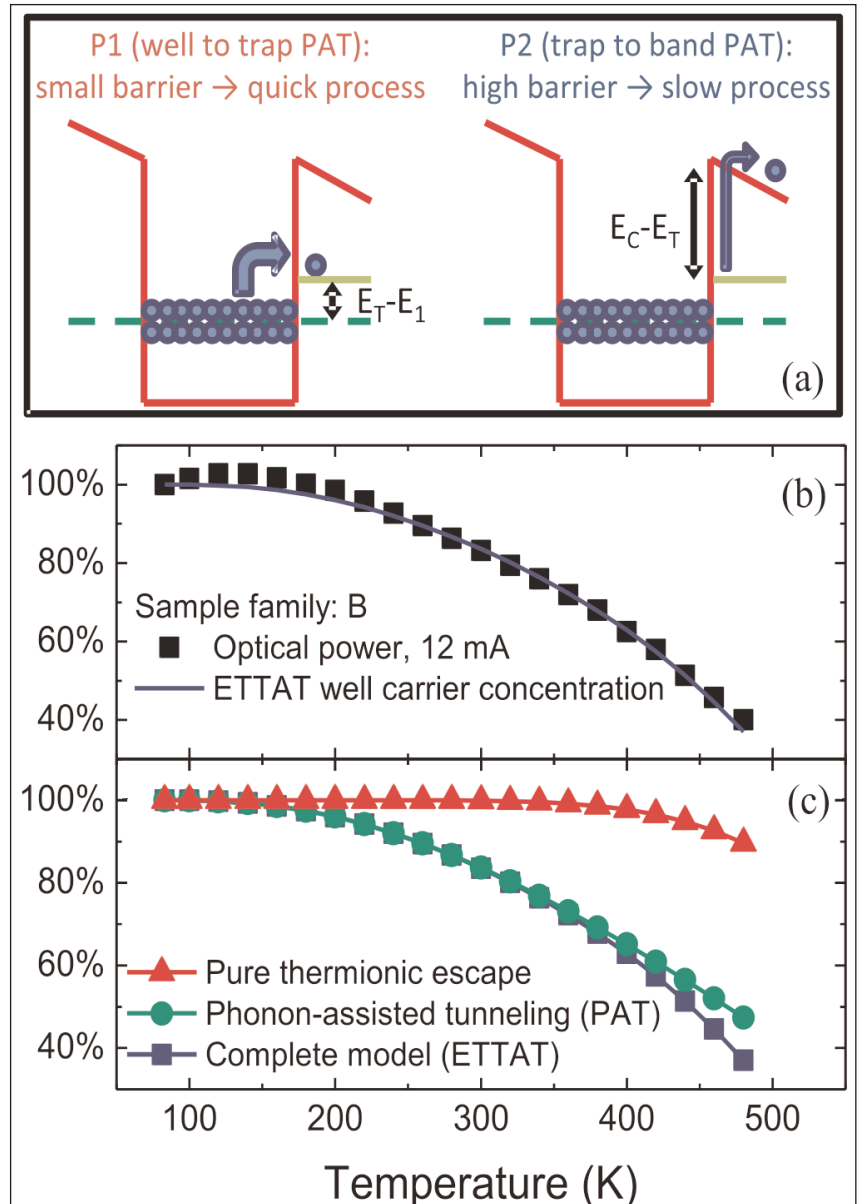
These conclusions were reached through simulation and increasing the defect densities in the devices by applying 100mA stress at 75°C, causing performance degradation. Although non-radiative SRH recombination increased, and photoluminescence decreased, under stress, the magnitude of the thermal droop remained constant, modulo experimental variations.

The quality of the electron-blocking layer has been found to affect thermal droop performance. "This suggests that another possible mechanism for explaining thermal droop is the escape of carriers from the quantum wells," the researchers write.

The researchers considered and found wanting three possible models for such escape: thermionic, phonon-assisted tunneling, and thermionic trap-assisted tunneling. The team therefore developed an "extended thermionic trap-assisted tunneling" process, which consisted of two phonon-assisted tunneling steps. The first step raised the carrier to a trap state, while the second step took the carrier to the external conduction band (Figure 2). The trap acts as a reservoir of electrons for the second step. ■

<http://dx.doi.org/10.1063/1.4942438>

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GaN RF device market to grow at 14% CAGR, rising by 2.5x by end-2022

Market to double from \$300m over next five years, says Yole.

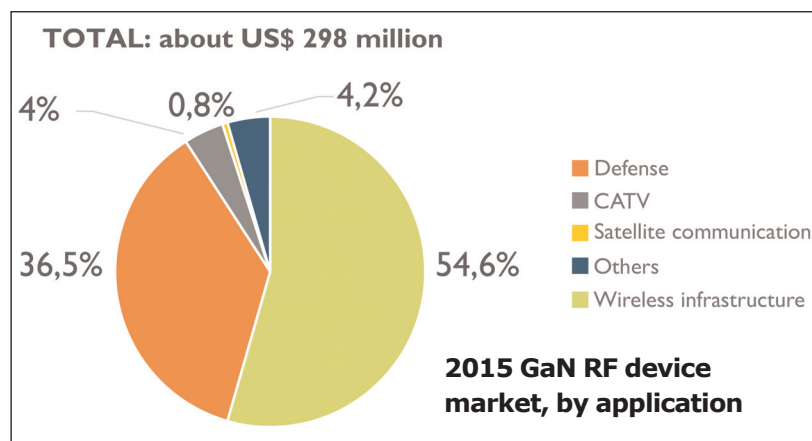
Led by adoption across various market segments, the gallium nitride (GaN) RF device market will double over the next five years, reckons Yole Développement in its new report 'GaN RF Devices Market: Applications, Players, Technology, and Substrates 2016–2022', which spans wireless infrastructure, defense & aerospace, satellite communication, wired broadband (CATV and FTTH), and other industrial, scientific & medical (ISM)-band applications.

Indeed, 2015 was a significant year for the GaN RF industry: In particular, a dramatic increase in wireless infrastructure market sales is being driven by the massive adoption of LTE networks in China. By the end of 2015, the total RF GaN market was close to \$300m.

Sales will likely not soar as high over the next two years, but growth will continue, driven mainly by increased adoption of GaN technology in the wireless infrastructure and defense markets. However, a significant boost will occur around 2019–2020, led by the implementation of 5G networks. "Market size will be multiplied by 2.5 by the end of 2022, posting a CAGR [compound annual growth rate] of 14% from 2016–2022," says technology & market analyst Dr Hong Lin.

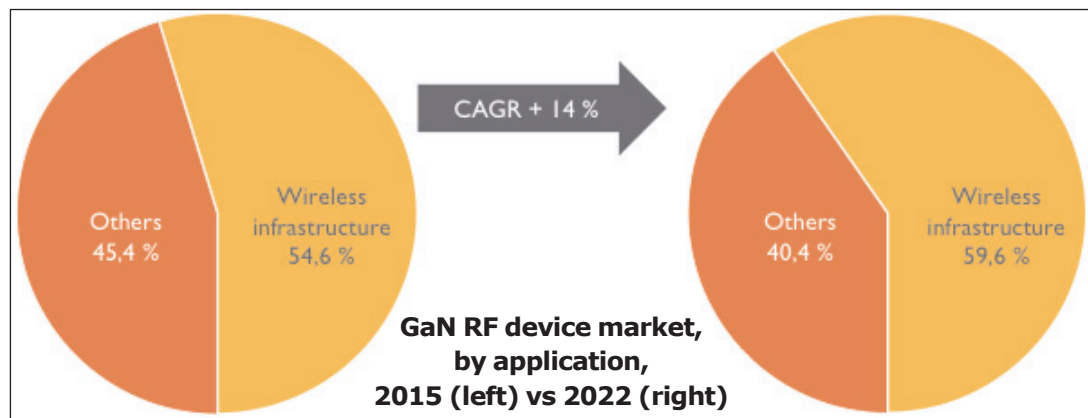
The reason for this success is the wireless infrastructure and defense markets, which both offer great opportunities for GaN technology, says Yole. Wireless infrastructure, having surpassed defense, now represents more than half of the total GaN device market. According to Yole, this segment will continue growing fast, at an expected CAGR of 16% over 2016–2022.

"Though GaN was originally developed to support governmental military and space projects, mainstream commercial markets should fully embraced this novel technology as well," comments technology & market analyst Zhen Zong.

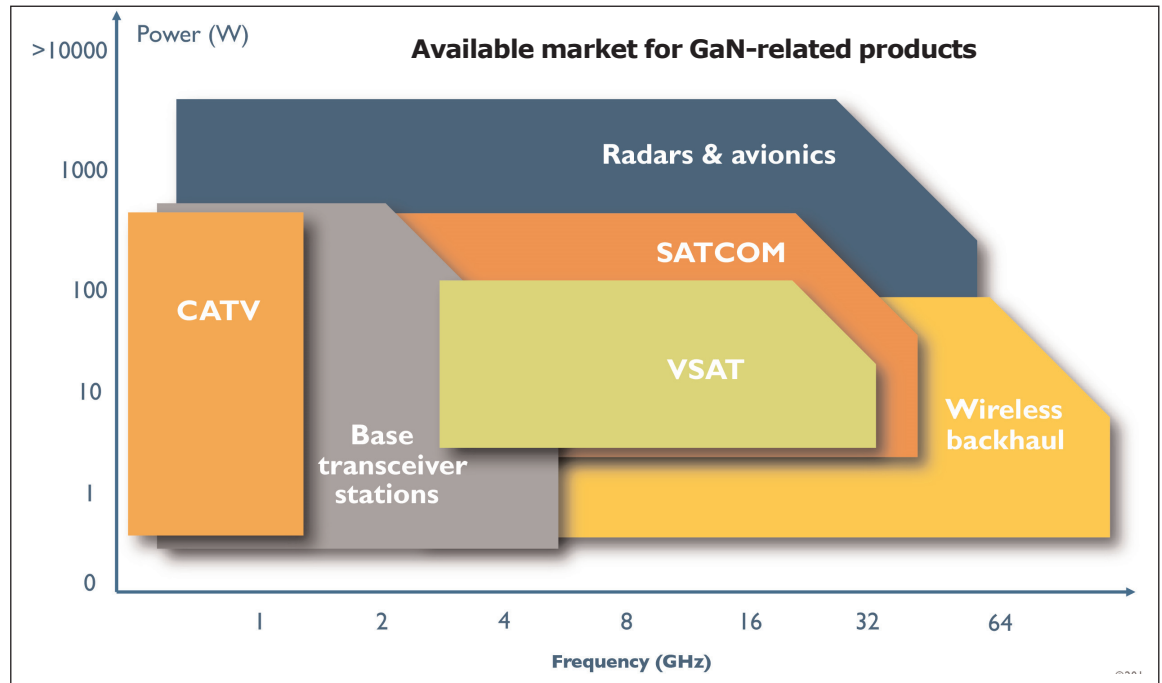


GaN's increased implementation in base stations and wireless backhaul stems from the growing demand for data traffic and higher operating frequencies and bandwidths. In future network designs, new technologies like carrier aggregation and massive MIMO will actually put GaN in a superior position compared with existing LDMOS, says Yole. GaN products have not yet covered the wireless infrastructure market's full spectrum, so more opportunities will arise in the higher-frequency range.

Most GaN device makers offer similar products for base-station applications ranging over 800MHz–3.5GHz (the report covers players such as Sumitomo Electric, Wolfspeed, Qorvo, MACOM, Microsemi, UMS, NXP, Ampleon, RFHIC, Mitsubishi Electric, Northrop Grumman and Anadigics). The competition will no doubt grow fiercer, reckons Yole, and the cake — even if it's a fast-growing one — will not be divided equally between everyone. In 2016, new entrants like Infineon and possibly another LDMOS player will bring more uncertainty, Yole adds.



In the meantime, defense remains another important market for GaN, and more new products and designs are benefiting from GaN's superior performance and design simplification. Yole predicts steadily growing penetration for GaN into defense market applications such as IED (improvised explosive device) jammers, military communications, radar, and electronic warfare (EW).



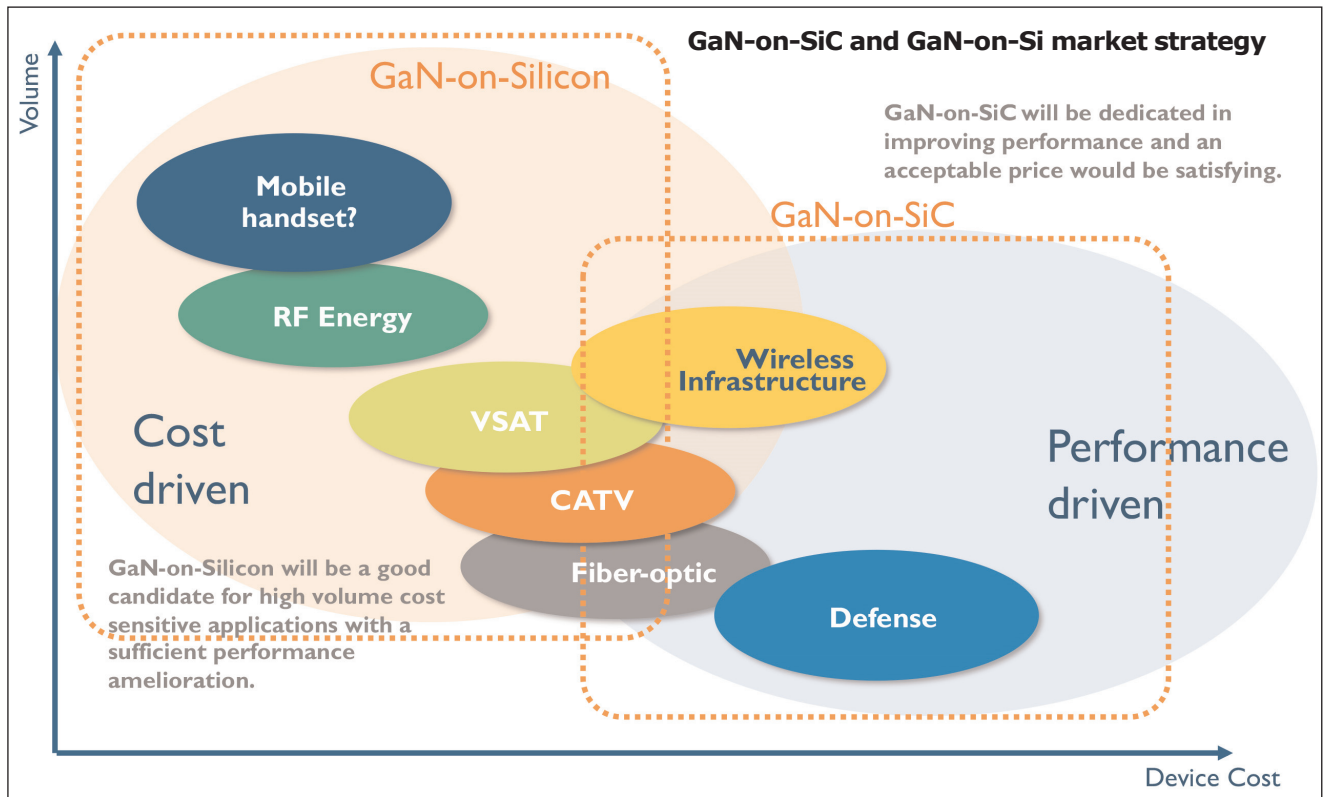
GaN-on-Si opportunity in LTE, SatCom, CATV & RF energy; GaN-on-SiC to remain dominant in GaN RF

Gallium nitride on silicon carbide substrates (GaN-on-SiC) is present in more than 95% of total commercial devices using GaN. GaN-on-SiC's maturity has led it to dominate over GaN-on-silicon, and most GaN RF implementations are currently realized using GaN-on-SiC devices, notes Yole.

GaN-on-SiC is an appealing choice for markets that require higher performance and are less cost-sensitive, and many companies choose GaN-on-SiC for their new designs and products. Meanwhile, silicon LDMOS and gallium arsenide (GaAs) remain the main technologies used for high-volume applications with lower performance requirements.

However, the door has not closed on GaN-on-silicon, reckons Yole. MACOM is pushing its GaN-on-Si products and has just announced its Gen4 GaN product for base stations, with an LDMOS-like cost structure. Over 2016-2020, Yole envisions opportunities for GaN-on-silicon in commercial markets like LTE, SatCom terminals, CATV and RF energy, while GaN-on-SiC will still be the go-to technology for GaN RF. The situation could change drastically, notes Yole, but for now GaN-on-silicon remains a challenger to incumbent GaN-on-SiC technology. ■

www.yole.fr/GaNRF_Market.aspx



Vertical, CMOS and dual-gate approaches to gallium nitride power electronics

US research company HRL Laboratories has published a number of papers concerning III-nitride high-frequency power electronics in the past few months.

Gallium nitride (GaN) and related materials are being developed by researchers across the world for power switching and power microwave/millimeter-wave electronics. This is based on the wide bandgap and high electron mobility of GaN compared with silicon being attractive for reduced size and weight power devices operating at higher frequency. Target applications include components for radar systems, cellular base stations, and power converters.

HRL Laboratories LLC in the USA is a commercial developer of GaN technology that has been making contributions to the GaN research literature for many years. In recent months, the company's research teams have published details of GaN research on vertical tunneling Schottky barrier diodes, a process for complementary metal-oxide-semiconductor (CMOS) circuits, and dual-gate high-electron-mobility transistors (HEMTs).

In addition to research, HRL provides GaN and indium phosphide foundry, monolithic microwave integrated circuit (MMIC), machine shop, and 'open innovation' research partnership services. The company has also developed a range of power amplifiers capable of handling up to 105GHz.

Here we look at HRL's recent work mentioned above.

Vertical Schottky diode

Vertical Schottky diodes and other power devices built using GaN technology could lead to higher current density handling and smaller components compared with the lateral structures that have been the focus of most development until recently.

HRL has developed a GaN vertical tunneling Schottky barrier diode (TBS) that gives good combined on and off

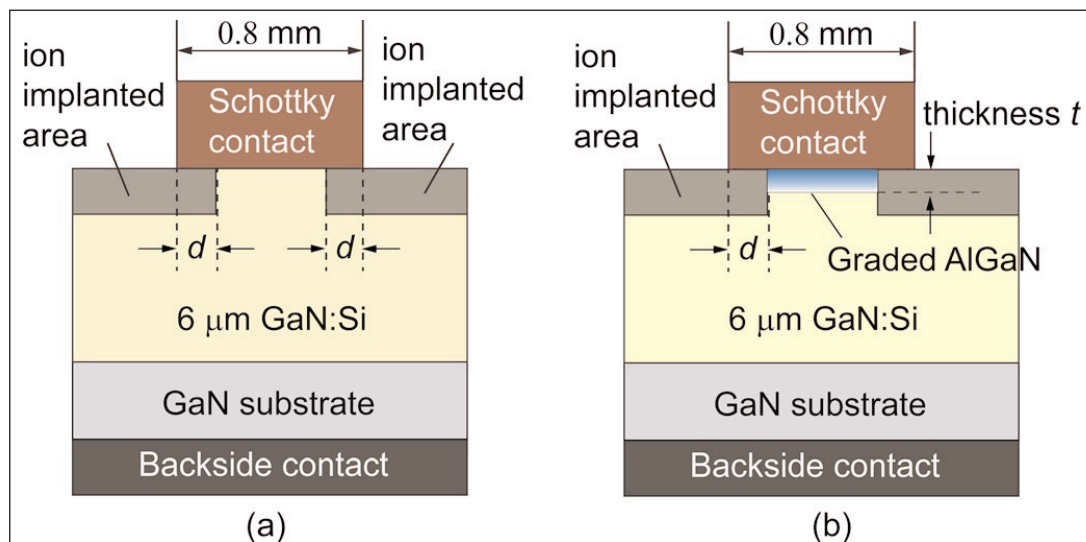


Figure 1. Schematic structures for (a) control sample A, and sample B with high doping, and (b) the sample C with graded AlGaN cap layer.

performance, compared with vertical Schottky barrier diodes (SBDs) [Y. Cao et al, Appl. Phys. Lett., vol108, p112101, 2016], building on previous work [Y. Cao et al, Appl. Phys. Lett., vol108, p062103, 2016; reported in Semiconductor Today 2016 issue 2 (March), p90].

Gallium vertical SBDs suffer from trade offs between on-current and reverse bias breakdown. By applying a thin layer of aluminium gallium nitride (AlGaN) as a tunneling barrier, the HRL team allowed a more highly doped drift layer to be used, increasing on-current without compromising the breakdown voltage.

The new interest in vertical structures has been enabled by reductions in defect densities due to the commercial availability of free-standing and bulk GaN substrates. However, the initial work has largely been on p-n junction diodes that have high turn-on voltages of ~3V arising from the wide bandgap (~3.4eV). Devices with high turn-on voltage suffer from large conduction losses.

SBD structures can reduce turn-on to less than 1V, but usually with lower breakdown voltages. SBDs also have faster performance.

The drift layer of the HRL devices (Figure 1) was 6μm silicon-doped GaN, grown by metal-organic chemical

vapor deposition (MOCVD) at 1040°C. The substrate was 2-inch c-plane free-standing bulk n-GaN. The carbon concentration was reduced to less than $3 \times 10^{15}/\text{cm}^3$ by using a growth pressure of 300Torr and a V/III precursor ratio of 4777.

The tunnel barrier consisted of a 5nm graded AlGaIn layer with Al-concentration varying from 0% to 23%. This was achieved by linearly ramping the flow of trimethyl-aluminium precursor.

Edge-termination of the SBDs was achieved with ion implantation. The edge-termination region overlapped 10 μm with the 0.8mmx0.8mm nickel/gold Schottky contact. A non-alloyed ohmic contact was applied to the back-side of the wafer.

Two SBDs were produced with different silicon-doping levels of the drift layer (A and B): $\sim 1 \times 10^{16}/\text{cm}^3$ and $\sim 3 \times 10^{16}/\text{cm}^3$, respectively. The tunneling SBD (TBS), sample C, had the same silicon doping as sample B.

The TBS allowed a higher on-current compared with sample A, while maintaining good breakdown performance under reverse bias (Figure 2, Table 1).

The HRL researchers compare their TBS device with the performance of Cree's commercial silicon carbide (SiC) junction barrier Schottky diode (JBS, Table 2): "It can be seen that with a slightly smaller area, our TBS diode could achieve twice the on current of the JBS diode at $V_f = 1.6\text{V}$, or reach the same on current of 1A at a 28% lower forward bias. This result indicates that it is possible for a GaN-based Schottky diode to further reduce the conduction loss and improve the efficiency in current 600V systems, where SiC-based diodes are used."

SiC has similar material properties to GaN of wide bandgap and high electron mobility.

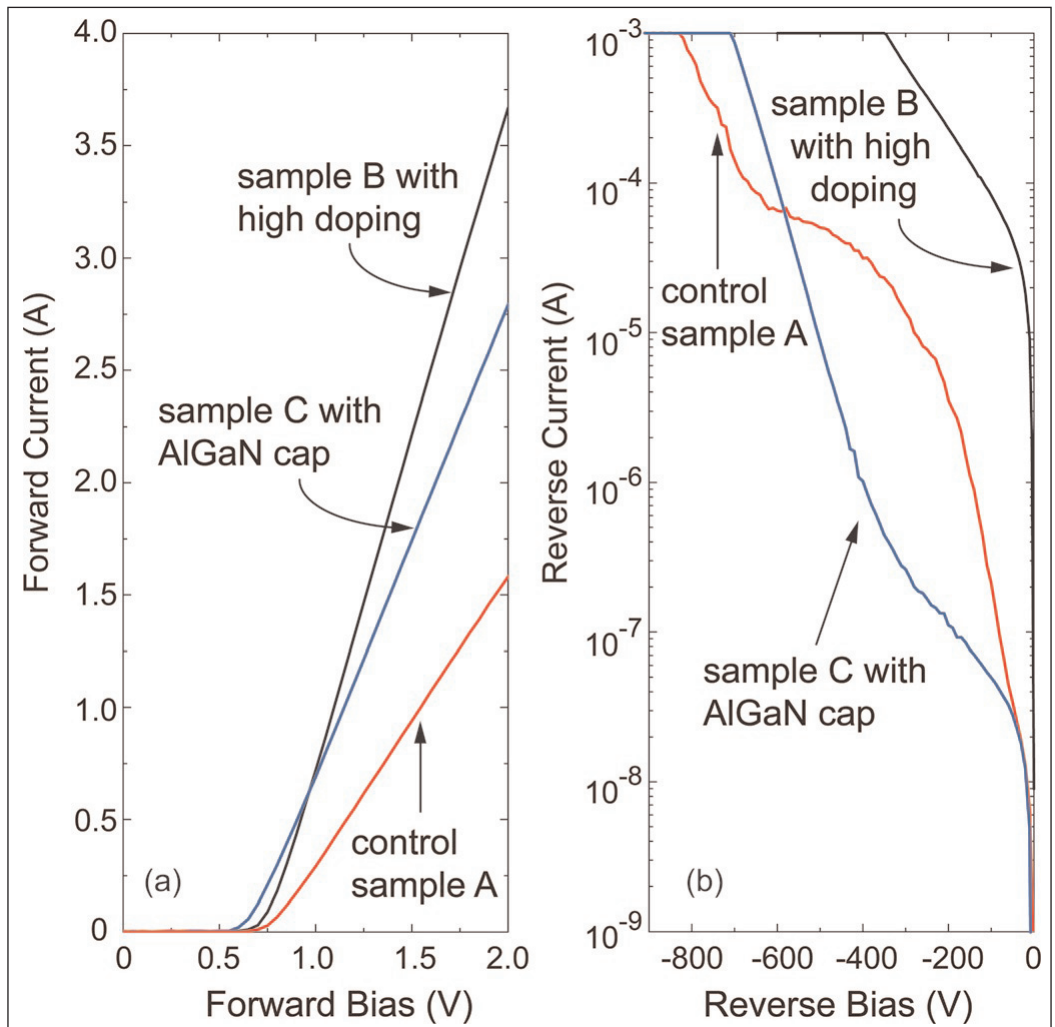


Figure 2. Forward current (a) and reverse current (b) as a function of bias.

Table 1. Performance metrics for HRL vertical Schottky diodes.

Sample	A	B	C (TBS)
Free electron density	$\sim 7.5 \times 10^{14}/\text{cm}^3$	$2.6 \times 10^{15}/\text{cm}^3$	$2.9 \times 10^{15}/\text{cm}^3$
Current (I_{on}) at 1.6V forward voltage (V_f)	1.07A	2.51A	1.95A
Reverse bias breakdown at 1mA	>800V	$\sim 345\text{V}$	700V
Turn-on voltage	0.77V	0.75V	0.67V
Total specific on resistance	$4.94\text{m}\Omega\text{-cm}^2$	$2.17\text{m}\Omega\text{-cm}^2$	$3.06\text{m}\Omega\text{-cm}^2$

Table 2. Comparison of key parameters between HRL's tunneling barrier Schottky diode and Cree's 600V JBS.

	Die area (mm ²)	I_{on} (A) @ $V_f = 1.6\text{V}$	V_f (V) @ $I_{\text{on}} = 1.0\text{A}$
HRL GaN TBS	0.64	2.0	1.15
Cree SiC JBS (CPWR-0600S001)	0.71	1.0	1.6

CMOS fabrication

Moving to lateral devices, HRL claims the first demonstration of GaN (CMOS) field-effect-transistors [Rongming Chu et al, IEEE Electron Device Letters,

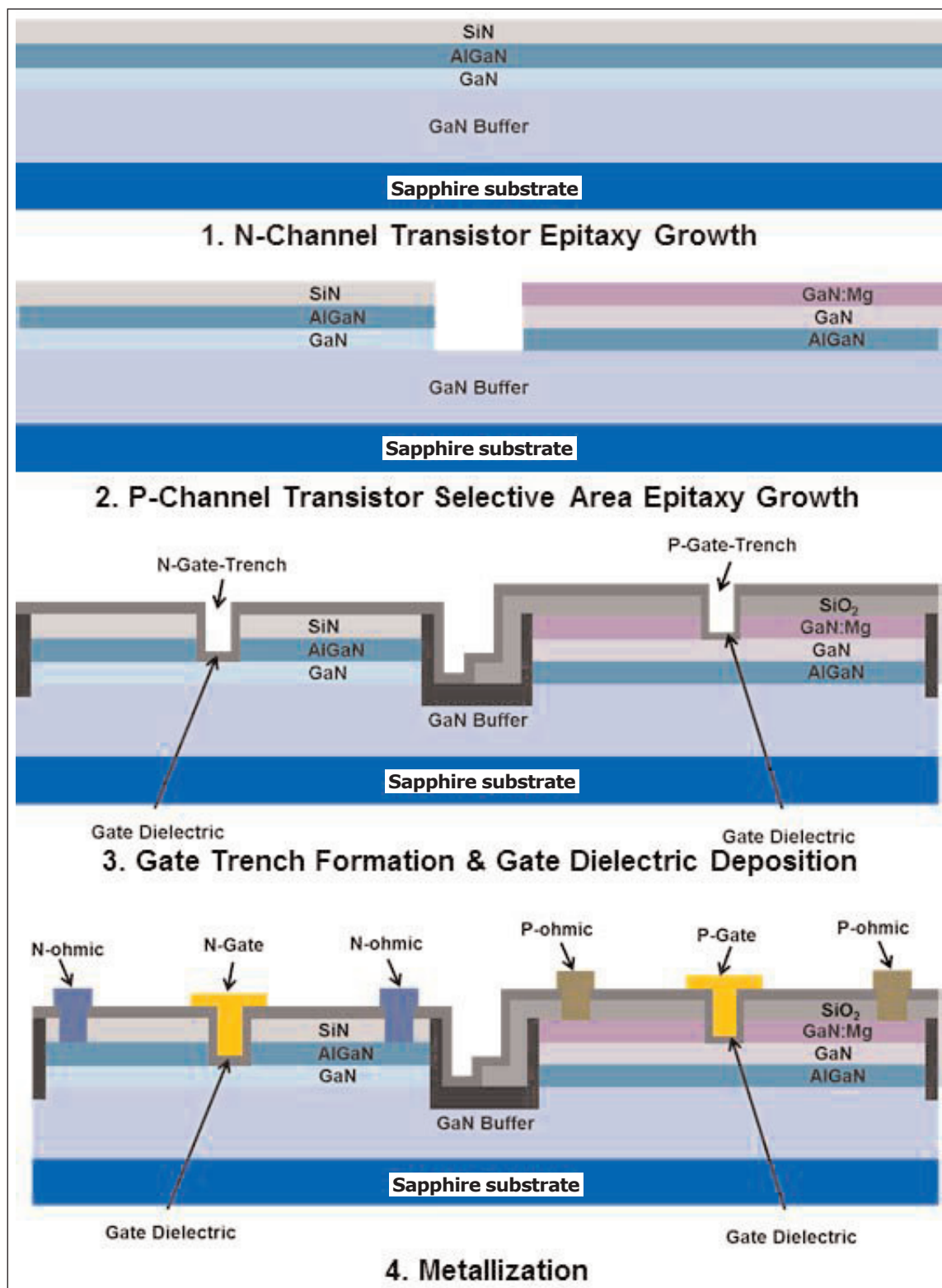


Figure 3. Major steps for fabricating GaN NMOS and PMOS on the same wafer.

published online 6 January 2016]. The team used the technology to create CMOS inverter circuits.

Present applications mostly use discrete transistors rather than integrated circuits (ICs). HRL sees a need for an IC approach to achieve the full benefits of GaN electronics at low cost. Parasitic inductance is one aspect that would be improved — discrete GaN components have to be slowed down to avoid voltage instability from chip-to-chip effects. ICs also have

reduced assembly and packaging costs.

Dr Rongming Chu, HRL senior staff research engineer and principal investigator, comments: "In the near term, GaN CMOS IC applications could include power integrated circuits that manage electricity more efficiently while having a significantly smaller form factor and lower cost, and integrated circuits that can operate in harsh environments." Longer term, he believes, GaN CMOS has the potential to replace silicon CMOS in a wide range of products.

The GaN CMOS processing began with MOCVD of the NMOS layers on sapphire (Figure 3). The $\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$ top barrier was 5nm thick. The silicon nitride (SiN) encapsulation was 50nm.

The PMOS layers were applied by etching down to the GaN buffer in selected regions and MOCVD re-growth. The structure consisted of a 30nm $\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$ back barrier, 20nm of undoped GaN and a 50nm magnesium-doped GaN hole supply layer.

Transistor fabrication began with ion implantation for device isolation, followed by gate trench low-energy plasma etch, AlN/SiN gate dielectric stack MOCVD, titanium/aluminium-based NMOS and nickel/gold PMOS ohmic source/drain formation, and nickel/gold gate electrode and interconnect deposition. The PMOS source/drain contacts were annealed in oxygen.

The researchers report that the NMOS and PMOS structures both exhibited enhancement-mode behavior

in long gate devices — i.e. normally-off at 0V gate potential, which is desired in power devices for fail safety and efficiency. The channel mobilities were $300\text{cm}^2/\text{V}\cdot\text{s}$ and $20\text{cm}^2/\text{V}\cdot\text{s}$ for NMOS and PMOS, respectively.

The researchers report that discrete NMOS devices with the same gate stack structure have achieved channel mobilities of more than $1000\text{cm}^2/\text{V}\cdot\text{s}$. The team comments: "Further improvement of the GaN CMOS process is needed to improve the NMOS mobility to what was achievable with a discrete device process."

The PMOS mobility was higher than for bulk p-GaN ($\sim 10\text{cm}^2/\text{V}\cdot\text{s}$) but lower than reported values for two-dimensional hole gases (2DHGs, $\sim 40\text{cm}^2/\text{V}\cdot\text{s}$). The researchers believe that PMOS improvements could come from "optimizing epitaxial regrowth, gate trench etch, and gate dielectric deposition".

Devices with $0.5\mu\text{m}$ and $75\mu\text{m}$ respective gate length and width had threshold voltages around 0V. For the NMOS device the on-resistance at +5V gate was $10\Omega\cdot\text{mm}$. The PMOS on-resistance was much higher: $1314\Omega\cdot\text{mm}$ at -5V gate. The PMOS device also suffered from buffer leakage when the drain bias was greater than 2V. The researchers suggest that the leakage could be caused by

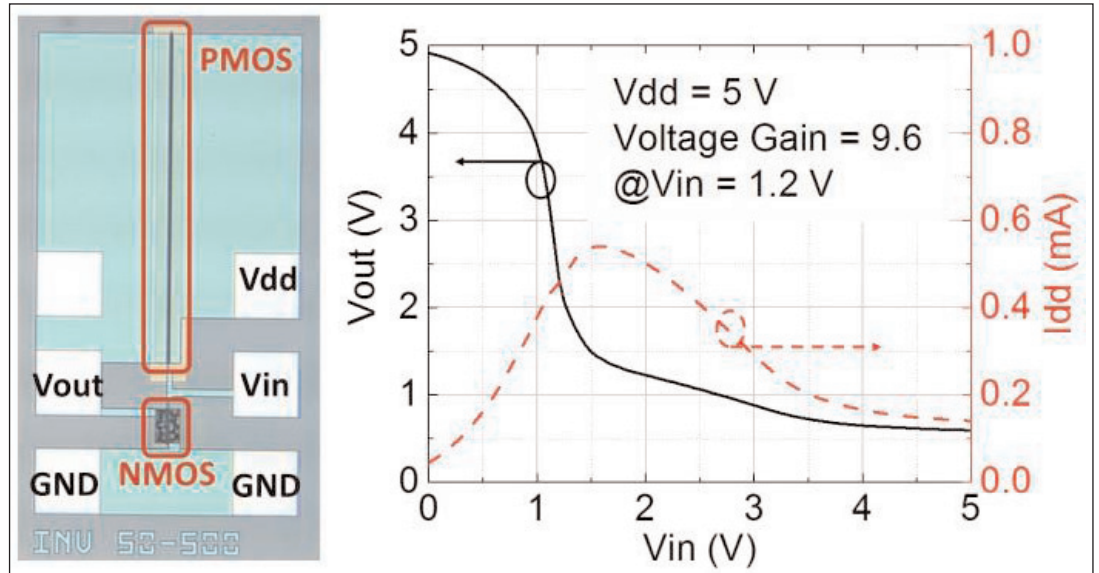


Figure 4. Microscope top-view photograph and measured voltage transfer curve of fabricated GaN CMOS inverter IC.

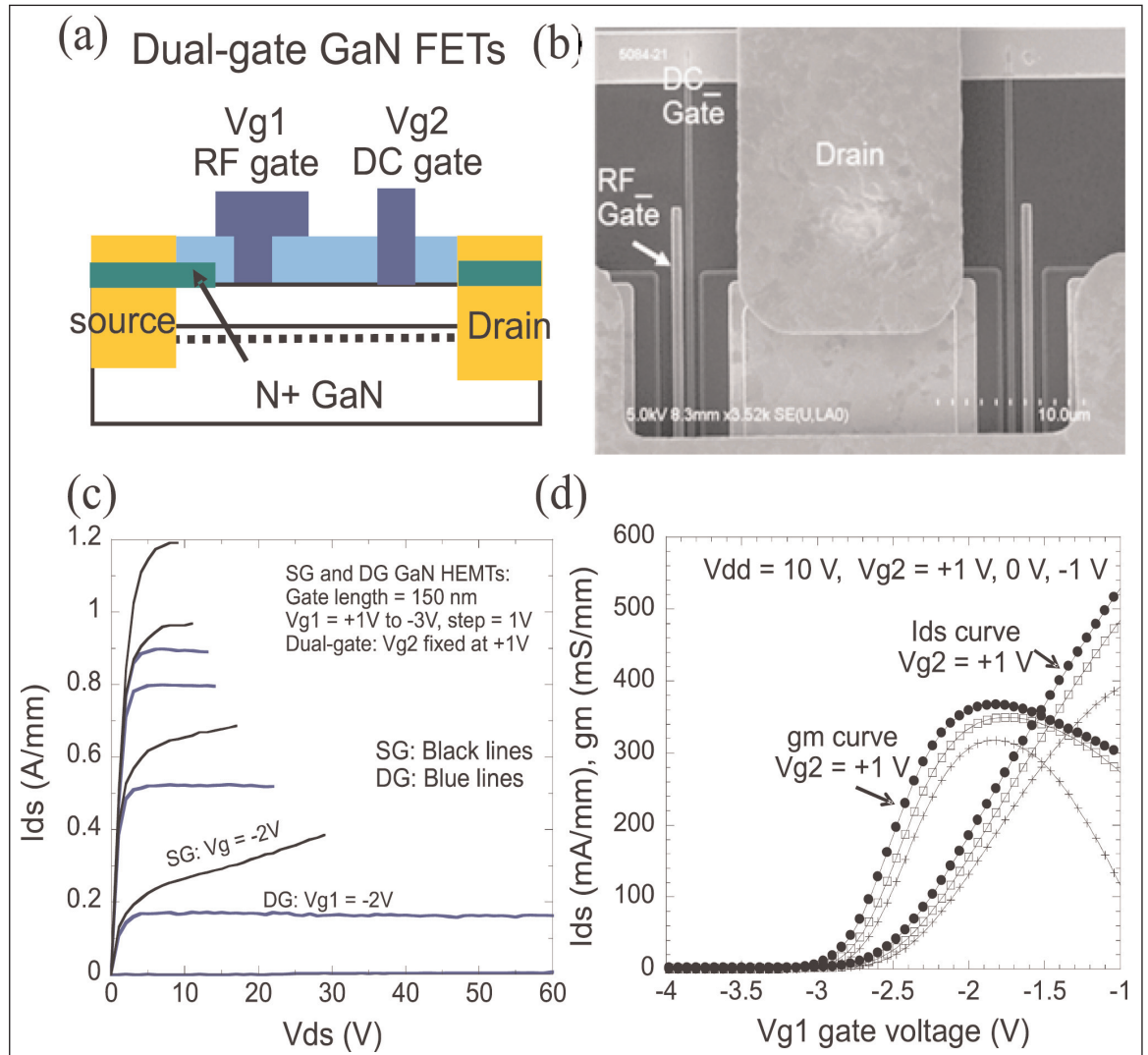


Figure 5. (a)–(b) A schematic diagram of dual-gate field-plated GaN HEMT with a $0.5\mu\text{m}$ -long n^+ source ledge is shown with an SEM photograph. (c) Measured pulsed current–voltage (I – V) curves of single-gate (SG) and dual-gate (DG) devices with 250ns pulses, where output conductance of DG device is greatly reduced, and (d) transfer curves of $4\times 37.5\mu\text{m}$ dual-gate field-plated GaN HEMT.

parallel conduction at the MOCVD re-growth interface between the PMOS layer and the original GaN buffer.

The $0.5\mu\text{m}$ transistors were used in CMOS inverter circuits (Figure 4). The gate widths of the PMOS and NMOS transistors were $500\mu\text{m}$ and $50\mu\text{m}$, respectively. The (differential) voltage gain was 9.6 at 1.2V input with 5V DC bias. The current drawn by the circuit (I_{dd}) peaked at 1.5V input (V_{in}), where the inverter switched off.

The researchers comment: "Thanks to the CMOS configuration, the I_{dd} was considerably lower when the V_{in} was at 0V and 5V, suggesting low static power consumption. The static power consumption could be further decreased by reducing the off-state leakage of the NMOS and PMOS."

With 5V pulses with steps of 10ns rise/fall times, the output swung between 0V and $\sim 5\text{V}$ with 90ns fall time and 670ns rise time.

The researchers comment: "Slower rise time is due to higher on-resistance of the PMOS. Although the performance is yet to be improved, the functional inverter IC proves the feasibility of the GaN CMOS technology."

Dual-gate HEMTs

Finally, HRL has used dual-gate and cascode GaN HEMTs to achieve power-added efficiency (PAE) figures in the 8.0–12.0GHz X-band close to the theoretical maximum of 78.5% [J. S. Moon et al, IEEE Electron Device Letters, vol. 37, p272, 2016]. The team writes:

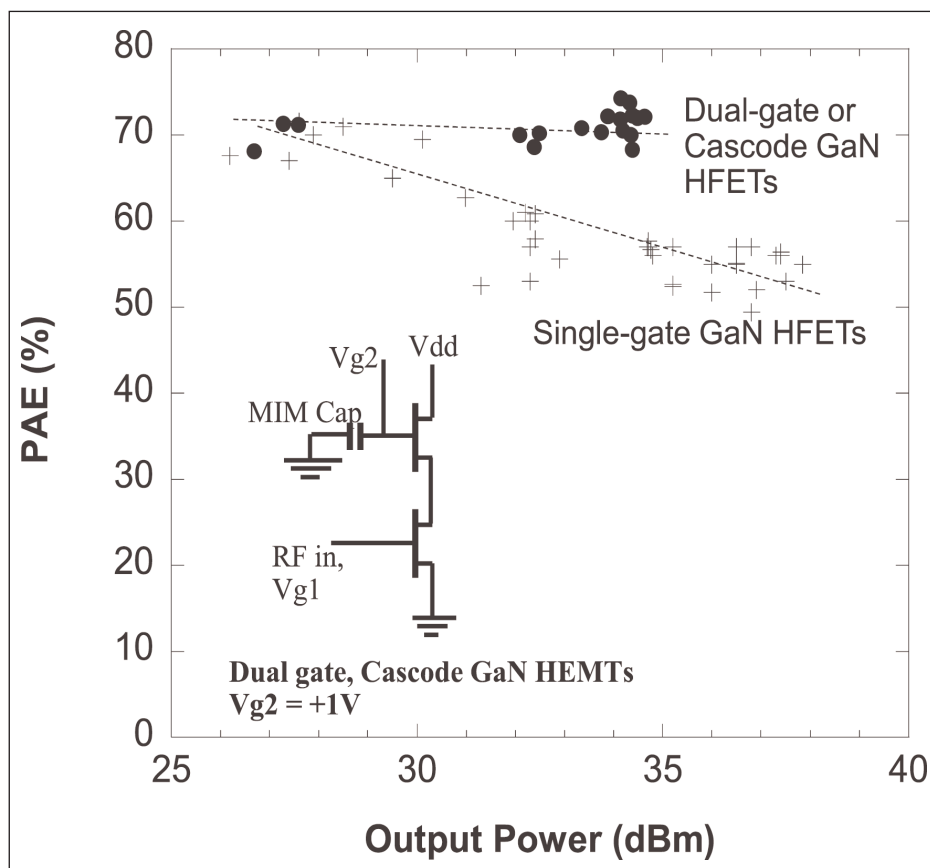


Figure 6. Measured PAE versus output power of GaN HEMTs at 10GHz without harmonic tuning.

"The technology offers record performance for combined PAE, output power, and gain among reported GaN HEMTs in the X-band."

The researchers used dual-gate HEMTs with field plates (FP) on semi-insulating SiC (Figure 5). The source–drain distance was $3\mu\text{m}$. The source–drain ohmic electrodes were titanium/aluminium. The gates for the RF signal was 150nm long. The DC gate was 250nm. The gates were recessed with $\sim 15\text{nm}$ AlGaIn between the electrode and channel.

The dual-gate devices are seen as being equivalent to cascode pairs of transistors, one with common-gate connected in series to one with a common-source. Previous reports of GaN HEMT cascode circuits demonstrated PAE values up to 45% at 8.2GHz, along with 3.5W/mm power density and 12dB associated gain.

The epitaxial material had a double heterojunction to give a back barrier: $\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}/\text{GaN}/\text{Al}_{0.04}\text{Ga}_{0.96}\text{N}$. There was also a $0.5\mu\text{m}$ n^+ -GaN cap layer, which was used to create a ledge on the source side to improve access to the channel.

The devices had surface passivation consisting of 75nm of silicon nitride, which also provided support for the field plates. The gates consisted of platinum/gold. The RF gate had a 550nm overhang to effect the field plate.

In Maury load-pull measurements at 10GHz without harmonic tuning, the devices demonstrated 13.7dB power gain at peak power added efficiency of 71%. The linear gain was 17dB. Comparison single-gate HEMTs with $2.5\mu\text{m}$ source–drain gap and field plates had 13dB power gain at peak PAE of 67%, and 16dB linear gain. The output power of both devices was about 27.4dBm (0.55W).

Cascode connected GaN HEMT pairs performed similar to the dual-gate device with $\sim 13.4\text{dB}$ associated power at PAE of 71–74%. These PAE values are the highest PAE reported in GaN HEMTs at 10GHz with a few Watt level output power. The peak output power was 2.3–2.5W.

The researchers attribute a more than 10% PAE improvement of dual-gate and cascode GaN field-plate HEMTs over single-gate devices at 2W output power (33dBm) to "improved output resistance, gain, and pinch-off characteristics" (Figure 6). ■

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



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Indium gallium arsenide MOSFET used as radio-frequency switch

Chinese researchers see great potential in the future for the first RF switches based on InGaAs MOSFET technology.

Researchers in China claim the first radio frequency (RF) switch device based on indium gallium arsenide (InGaAs)-channel metal-oxide-semiconductor field-effect transistor (MOSFET) technology [Zhou Jiahui et al, J. Semicond. 2016, vol37, p024005]

Such technology is being developed to boost the performance of present-day complementary metal-oxide semiconductor (CMOS) very-large-scale integrated circuits used in mass-consumer electronics.

RF switches are among the key components in mobile phone wireless communications and GPS systems. Traditionally, these devices have been produced using gallium arsenide high-electron-mobility transistors (HEMTs), although more recently silicon and gallium nitride (GaN) alternatives have been developed.

Chinese Academy of Sciences' Institute of Microelectronics and Guilin University of Electronic Technology grew the material for the device (Figure 1) by molecular beam epitaxy (MBE) on semi-insulating GaAs substrate: 300nm aluminium gallium arsenide ($\text{Al}_{0.26}\text{Ga}_{0.74}\text{As}$) buffer, 7nm $\text{In}_{0.4}\text{Ga}_{0.6}\text{As}$ channel, 5nm indium gallium phosphide ($\text{In}_{0.49}\text{Ga}_{0.51}\text{P}$) barrier, 50nm n-GaAs cap, and 10nm n- $\text{In}_{0.54}\text{Ga}_{0.46}\text{As}$ cap.

Mesa isolation and channel formation were achieved by wet etching. The structure was cleaned to remove native oxide and excess arsenic before ammonium sulfide passivation.

The aluminium oxide (Al_2O_3) gate dielectric insulation was applied using atomic layer deposition (ALD). The dielectric was annealed at 400°C in nitrogen. The gate electrode was annealed nickel/gold. The gate length and width were 0.3 μm and 300 μm , respectively.

The source/drain electrodes were formed by etching away the aluminium oxide and electron-beam evaporation of nickel/germanium/gold/nickel/germanium/gold.

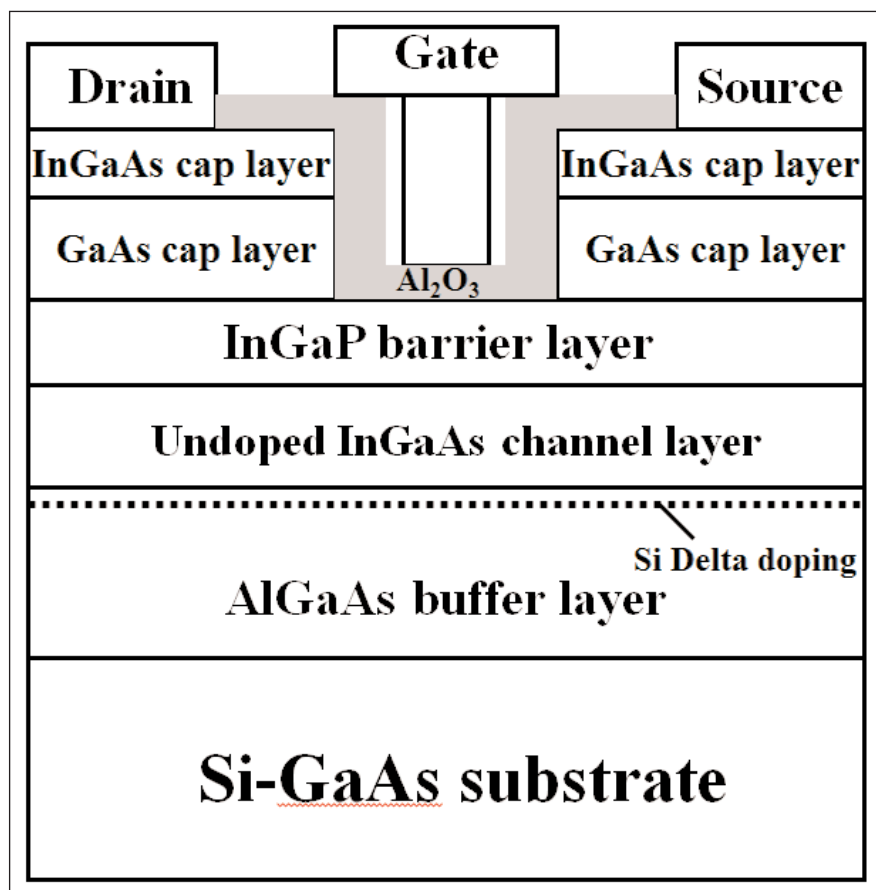


Figure 1. Schematic cross section of $\text{In}_{0.4}\text{Ga}_{0.6}\text{As}$ MOSFET with 10nm Al_2O_3 .

A final 300°C anneal completed the fabrication.

To operate as a switch, a gate bias resistor is used to give a circuit (Figure 2) almost equivalent to a two-port device that is a resistor when on and a capacitor when off. The bias resistance needs to be large to isolate the radio-frequency signal.

The MOSFET had a maximum drain current of 250mA/mm and specific turn-on resistance of 0.72 $\Omega\text{-mm}^2$. With 2V drain bias, the maximum transconductance was 370mS/mm with -0.1V gate potential.

The on/off current ratio was about 106 at room temperature with 50mV drain bias, "2-3 orders of magnitude higher than conventional HEMTs," according to the

Figure 2. (a) Micrograph of RF switch device. (b) Device equivalent circuit.

researchers. A subthreshold swing of 220mV/decade was also achieved.

Gate leakage was less than 10^{-4} A/cm² in the gate potential range of -8V to +7V with 1V drain bias, "3-5 orders of magnitude lower than conventional HEMTs," according to the team.

As an RF switch, the device demonstrated an insertion loss less than 1.8dB in the range 0.1GHz to 10GHz. The minimum was 0.27dB. Isolation was greater than 20dB between 0.1GHz and 7.5GHz with a 68dB maximum. The best performance was achieved at the 0.1GHz end.

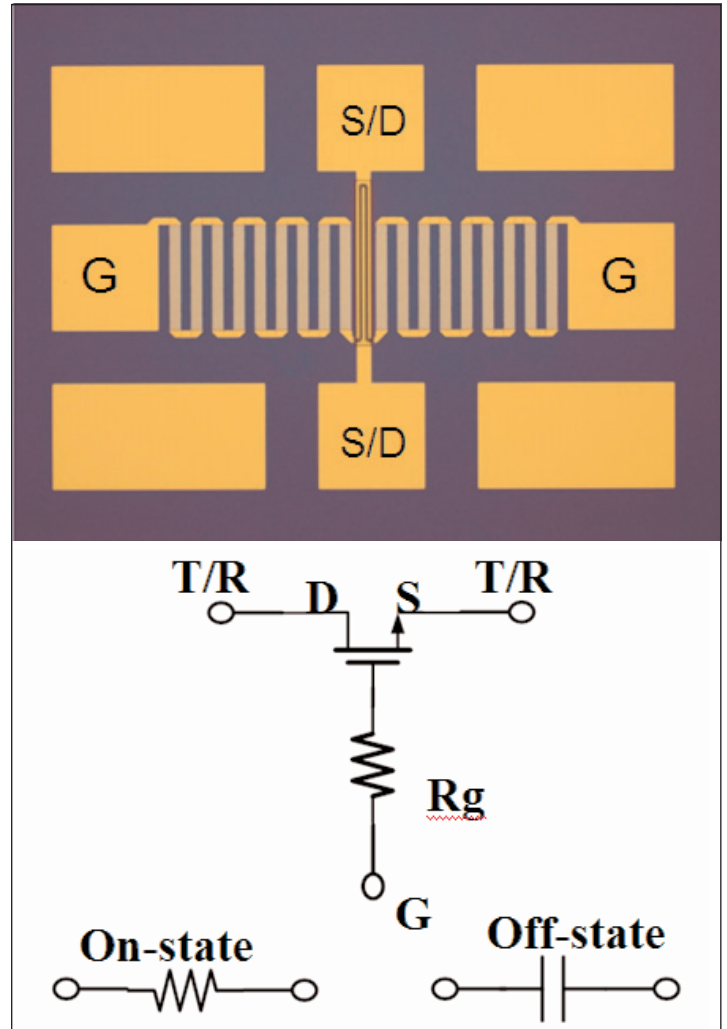
The researchers comment: "The insertion loss and isolation of the proposed InGaAs MOSFET switch are 0.27-0.49dB and 35-68dB in the frequency range from 0.1 to 3GHz, which are better than conventional switches."

The handling power of the device was up to 533mW/mm in the on-state and 3667mW/mm in the off-state.

The researchers conclude: "The drain saturation current density and handling power can be improved by increasing the thickness of InGaAs channel. Compared with the conventional GaAs HEMTs, InGaAs MOSFET has a greater potential for RF switches in the future." ■

<http://dx.doi.org/10.1088/1674-4926/37/2/024005>

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III-V field-effect transistor transconductance record

Increased carrier concentration in a re-designed access region yields 3.45mS/ μ m at 0.5V drain bias.

Massachusetts Institute of Technology in the USA has claimed record transconductance performance for a self-aligned planar indium gallium arsenide (InGaAs) quantum-well metal-oxide-semiconductor field-effect transistor (MOSFET) [Jianqiang Lin et al, IEEE Electron Device Letters, published online 19 February 2016].

The maximum transconductance of 3.45mS/ μ m at 0.5V drain bias was attributed to a re-designed access region with increased carrier concentration. The new design overcomes problems with source starvation and the consequent shift of the virtual source point into the access region, reducing gate control of channel conductivity.

The researchers comment that 3.45mS/ μ m is a record value among III-V FETs of any kind, including MOSFETs and high-electron-mobility transistors (HEMTs).

Funding for the research came from US Defense Threat Reduction Agency, US National Science Foundation Energy Efficient Electronics Science Center, Lam Research, Northrop Grumman and Singapore-MIT Alliance for Research and Technology Center. The research is aimed at future high-performance low-power CMOS electronics.

The researchers produced two heterostructures with different n+-cap designs (Figure 1). In one, design A, the n+-cap is directly in contact with the InGaAs channel layers. The other, design B, has an undoped indium phosphide (InP) spacer.

Design B with undoped spacer is similar to the structure used in MIT's previous transistor work. The researchers comment: "The elimination of the undoped InP spacer in design A results in a higher electron density in the InGaAs/InAs/InGaAs channel layer in the as-grown structure."

The heterostructures were fabricated into self-aligned transistors with 15nm access regions and 2.5nm hafnium dioxide high-k dielectric/metal gate (HK/MG) structure. The equivalent oxide thickness (EOT) was 0.5nm. The gate was recessed using a combination of dry etch and a self-limiting digital etch. The digital etch allows precision engineering of the transistor dimensions. The process can reach surface roughness values as low as 0.2nm root-mean-square.

Design A devices with 1 μ m gate length have achieved subthreshold swing values of 66.6mV/decade at 10mV drain bias. This matches the lowest subthreshold swing reported for any planar InGaAs MOSFET, according to

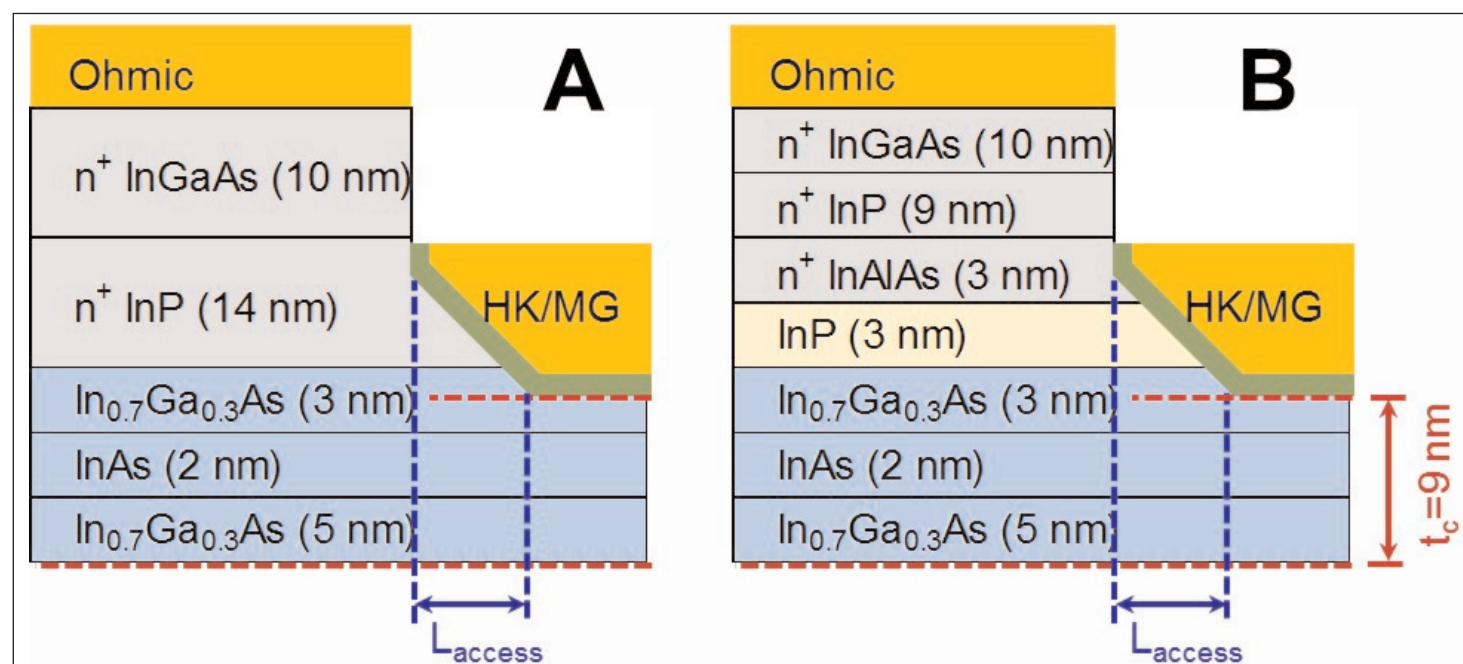


Figure 1. Simplified device cross-section schematic and respective heterostructures used. Layers labeled with n+ are silicon-doped $3 \times 10^{19}/\text{cm}^3$ – $4 \times 10^{19}/\text{cm}^3$, otherwise they are undoped.

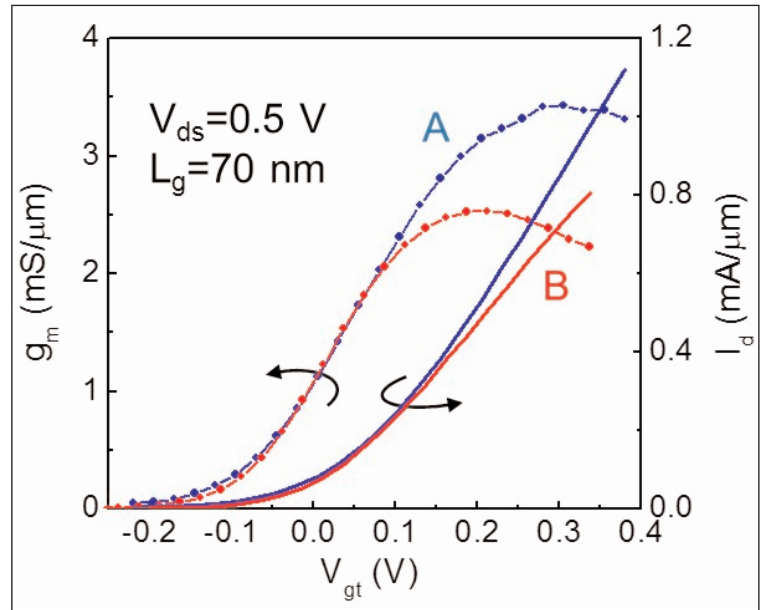
Figure 2. Transconductance (g_m) versus over-gate overdrive with respect to threshold ($V_{gt} = V_{gs} - V_t$) and drain current (I_d) transfer characteristics of 70nm MOSFETs A and B.

the researchers. Devices with 70nm gate length achieved subthreshold swings of 150mV/decade and 115mV/decade for 0.5V and 0.05V drain, respectively.

The 70nm MOSFET achieved a maximum transconductance of 3.45mS/ μ m at 0.5V drain (Figure 2). The team reports: "This represents an 11% improvement over the previous records in planar InGaAs MOSFETs and HEMTs, both at 3.1mS/ μ m." A comparison device using design B managed a peak transconductance of only 2.55mS/ μ m at the same bias. ■

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www.goodfellow.com

Goodfellow supplies small
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Cambridge Fluid Systems

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Cambridge CB3 8SQ,
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Fax: +44 (0)1954 786818

www.cambridge-fluid.com**CS CLEAN SYSTEMS AG**

Fraunhoferstrasse 4,
Ismaning, 85737,
Germany

Tel: +49 89 96 24 00 0

Fax: +49 89 96 24 00 122

www.cscleansystems.com**SAES Pure Gas Inc**

4175 Santa Fe Road,
San Luis Obispo,
CA 93401,
USA

Tel: +1 805 541 9299

Fax: +1 805 541 9399

www.saesgetters.com**11 Process monitoring
and control****k-Space Associates Inc**

2182 Bishop Circle
East, Dexter,
MI 48130,
USA

Tel: +1 734 426 7977

Fax: +1 734 426 7955

www.k-space.com

k-Space Associates Inc specializes in
in-situ, real-time thin-film process
monitoring tools for MBE, MOCVD,
PVD, and thermal evaporation.
Applications and materials include
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optoelectronic, and photovoltaic
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**KLA-Tencor**

One Technology Dr,
1-2221I, Milpitas, CA 95035, USA
Tel: +1 408 875 3000
Fax: +1 408 875 4144

www.kla-tencor.com**LayTec AG**

Seesener Str.
10-13,
10709 Berlin,
Germany

Tel: +49 30 89 00 55 0

Fax: +49 30 89 00 180

www.laytec.dewww.laytec.de

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Bregstrasse 90, D-78120
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Germany

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Fax: +49 7723 9197 22

www.wepcontrol.com

12 Inspection equipment

Bruker AXS GmbH

Oestliche Rheinbrueckenstrasse 49,
Karlsruhe, 76187,
Germany

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Fax: +49 (0)721 595 4587

www.bruker-axs.de

13 Characterization equipment

J.A. Woollam Co. Inc.

645 M Street Suite 102,
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www.jawoollam.com

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Westerville, OH 43082,
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Fax: +1 614 818 1600

www.lakeshore.com

14 Chip test equipment

Keithley Instruments Inc

28775 Aurora Road,
Cleveland, OH 44139,
USA

Tel: +1 440.248.0400
Fax: +1 440.248.6168

www.keithley.com

15 Assembly/packaging materials

ePAK International Inc

4926 Spicewood Springs Road,
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USA

Tel: +1 512 231 8083
Fax: +1 512 231 8183

www.epak.com

Gel-Pak

31398 Huntwood Avenue,
Hayward, CA 94544, USA

Tel: +1 510 576 2220
Fax: +1 510 576 2282

www.gelpak.com

Wafer World Inc

(see section 3 for full contact details)

Materion Advanced Materials Group

2978 Main Street,
Buffalo, NY 14214,
USA

Tel: +1 716 837 1000
Fax: +1 716 833 2926

www.williams-adv.com

16 Assembly/packaging equipment

Ismeca Europe Semiconductor SA

Helvetie 283, La Chaux-de-Fonds,
2301, Switzerland

Tel: +41 329257111
Fax: +41 329257115

www.ismeca.com

Kulicke & Soffa Industries

1005 Virginia Drive,
Fort Washington,
PA 19034,
USA

Tel: +1 215 784 6000
Fax: +1 215 784 6001

www.kns.com

Palomar Technologies Inc

2728 Loker Avenue West,
Carlsbad, CA 92010,
USA

Tel: +1 760 931 3600
Fax: +1 760 931 5191

www.PalomarTechnologies.com

TECDIA Inc

2700 Augustine Drive, Suite 110,
Santa Clara, CA 95054,
USA

Tel: +1 408 748 0100
Fax: +1 408 748 0111

www.tecdia.com

17 Assembly/packaging foundry

Quik-Pak

10987 Via Frontera,
San Diego, CA 92127, USA

Tel: +1 858 674 4676
Fax: +1 8586 74 4681

www.quikicpak.com

18 Chip foundry

Compound Semiconductor Technologies Ltd

Block 7, Kelvin Campus,
West of Scotland, Glasgow,
Scotland G20 0TH,
UK

Tel: +44 141 579 3000
Fax: +44 141 579 3040

www.compoundsemi.co.uk

United Monolithic Semiconductors

Route departementale 128,
BP46, Orsay, 91401,
France

Tel: +33 1 69 33 04 72
Fax: +33 169 33 02 92

www.ums-gaas.com

19 Facility equipment

MEI, LLC

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USA

Tel: +1 541 917 3626
Fax: +1 541 917 3623

www.marlerenterprises.net

20 Facility consumables

W.L. Gore & Associates

401 Airport Rd, Elkton,
MD 21921-4236,
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Fax: +1 410 506 8749

www.gore.com

21 Computer hardware & software

Ansoft Corp

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Fax: +1 412 471 9427

www.ansoft.com

Crosslight Software Inc

121-3989 Henning Dr.,
Burnaby, BC, V5C 6P8, Canada

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Fax: +1 604 320 1734

www.crosslight.com

Semiconductor Technology Research Inc

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www.mw-zander.com

24 Consulting**Fishbone Consulting SARL**

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E-mail: rocs@jedec.org

www.jedec.org/home/gaas

16–19 May 2016

2016 CS MANTECH (International Conference on Compound Semiconductor Manufacturing Technology)

Hyatt Regency Miami, FL, USA

E-mail: conferencechairman@gaasmantech.org

www.csmantech.org

22–27 May 2016

Microwave Week 2016, incorporating: IEEE MTT-S International Microwave Symposium (IMS2016)

IEEE Radio Frequency Integrated Circuits Symposium (RFIC 2016)

87th Automatic RF Technologies Group (ARFTG) Microwave Measurement Conference -

San Francisco, CA, USA

E-mail: Nannette@mpassociates.com

www.ims2016.org

24–25 May 2016

Imec Technology Forum Brussels (ITF2016 Brussels)

SQUARE Brussels Meeting Centre, Belgium

E-mail: Annouck.Vanrompay@imec.be

www.itf2016.be/brussels

5–10 June 2016

CLEO 2016:

Conference on Lasers and Electro-Optics

San Jose Convention Center, CA, USA

E-mail: info@cleoconference.org

www.cleoconference.org

7–9 June 2016

SEMICON Russia 2016

Moscow, Russia

E-mail: esuvorov@semi.org

www.semiconrussia.org

13–17 June 2016

2016 Symposia on VLSI Technology & Circuits

Hilton Hawaiian Village, Honolulu, HI, USA

E-mail: vlsi@vlsisymposium.org

www.vlsisymposium.org

22–24 June 2016

Intersolar Europe

Messe München, Germany

E-mail: info@intersolar.de

www.intersolar.de

26–30 June 2016

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4–8 July 2016

International Union of Materials Research Societies' International Conference on Electronic Materials (IUMRS-ICEM 2016)

Suntec, Singapore

E-mail: icem2016@meetmatt.net

www.mrs.org.sg/icem2016

10–15 July 2016

18th International Conference on Metal Organic Vapor Phase Epitaxy (ICMOVPE XVIII)

Sheraton San Diego Hotel & Marina, CA, USA

E-mail: info@mrs.org

www.mrs.org/icmovpe-xviii

11 July 2016

ITF2016 USA

San Francisco Marriott Marquis, CA, USA

E-mail: Annouck.Vanrompay@imec.be

www.itf2016.be/page.aspx/2217

11–13 July 2016

IEEE Photonics Society's 2016 Summer Topicals Meeting Series – 'Emerging Technologies for Green Photonics'

Newport Beach Marriott Hotel, CA, USA

E-mail: i.donnelly@ieee.org

www.sum-ieee.org

11–14 July 2016

Intersolar North America (co-located with ees North America and SEMICON West)

San Francisco, CA, USA

E-mail: info@intersolar.us

www.intersolar.us

12–14 July 2016

SEMICON West 2016

Moscone Center, San Francisco, CA, USA

E-mail: semiconwest@xpressreg.net

www.semiconwest.org

24–26 August 2016

13th International Group IV Photonics Conference (GFP 2016)

Grand Kempinski Hotel Shanghai, China

E-mail: m.figueroa@ieee.org

www.gfp-ieee.org

28 August – 1 September 2016

SPIE Optics + Photonics 2016

San Diego Convention Center, CA, USA

E-mail: customerservice@spie.org

<http://spie.org/optics-photonics1>

6–7 September 2016

2nd International Forum on Sapphire Market & Technologies

E-mail: veyrier@yole.fr

www.i-micronews.com/events/yole-events/eventdetail/142/-/2nd-int-forum-on-sapphire-market-technologies.html alongside:

6–9 September 2016

18th China International Optoelectronic Exposition (CIOE 2016)

Shenzhen Convention & Exhibition Center (SZCEC), China

E-mail: cioe@cioe.cn

www.cioe.cn/en

7–9 September 2016

SEMICON Taiwan 2016

Taipei Nangang Exhibition Center, Taiwan

E-mail: semicontaiwan@semi.org

www.semicontaiwan.org

12–15 September 2016

25th International Semiconductor Laser Conference (ISLC 2016)

Kobe Meriken Park Oriental Hotel, Kobe, Japan

E-mail: islc2016@ics-inc.co.jp

www.islc2016.org

19–22 September 2016

LED China 2016

Shanghai New International Expo Centre (SNIEC), China

E-mail: led-trust@ubm.com

www.LEDChina-sh.com

2–6 October 2016

29th IEEE Photonics Conference (IPC 2016)

Waikoloa, Hawaii, USA

E-mail: c.c.scott@ieee.org

www.ipc-ieee.org

10–13 October 2016

2016 IEEE SOI-3D-Subthreshold Microelectronics Technology Unified Conference (S3S SOI/3D/SubVt) – 'Energy Efficient Technology for the Internet of Things'

Hyatt Regency San Francisco Airport, Burlingame, CA, USA

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<http://s3sconference.org>

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