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Two-dimensional materials



Cree abandons sale of Wolfspeed to Infineon • IDT buying GigPeak
Navitas unveils first GaN power ICs • Veeco to acquire Ultratech



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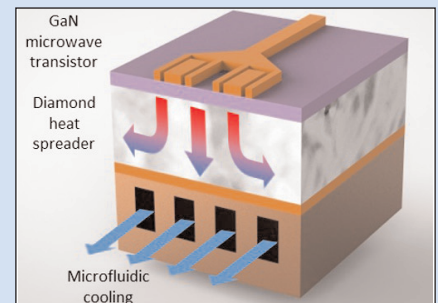
Veeco's New TurboDisc EPIK700 GaN MOCVD System

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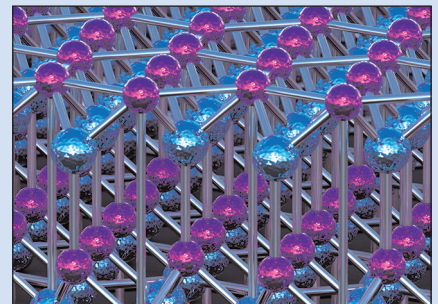
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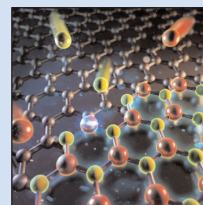
p25 NY-PEMC at SUNY Poly's Albany NanoTech Complex has produced its first SiC-based patterned wafer,



p26 Bristol University has won a £4.3m UK EPSRC grant for a project to develop GaN-on-diamond microwave technology.



p64 Australia's University of Technology Sydney and MIT have demonstrated bright room-temperature single-photon emission from defects in GaN.



Cover: Growth of world's thinnest oxide semiconductor — a 2D zinc oxide on a graphene layer, consisting of inter-connected hexagons of carbon atoms. Zinc atoms are shown as red spheres and oxygen atom as green spheres. (Credit: UNIST.) . **p98**

Focus forced onto profit-making business

In the last issue we reported how China's Fujian Grand Chip had abandoned its takeover of German deposition equipment maker Aixtron SE (Semiconductor Today Dec2016/Jan2017, p28). This came after the Committee on Foreign Investment in the United States (CFIUS) advised the then US President Barack Obama to issue an executive order blocking acquisition of the US business Aixtron Inc (which accounts for nearly 20% of Aixtron SE's staff and over 20% of its global sales).

Now, on page 24 of this issue, we report how US-based LED chip, lamp and lighting fixture maker Cree Inc is terminating last July's agreement to sell its Wolfspeed Power & RF business — which includes the silicon carbide substrate business for power, RF and gemstone applications — for \$850m to Germany's Infineon Technologies, supplementing Infineon's own RF and power products (for such as electro-mobility, renewables and next-generation cellular infrastructure for the Internet of Things) and complementing its acquisition of US-based International Rectifier in early 2015. Likewise, this follows CFIUS raising concerns based on US national security, since Wolfspeed's gallium nitride (GaN) and silicon carbide (SiC) wide-bandgap semiconductor technology has defense applications (particularly in anti-ballistic missile radar and radio jammers). Having aimed to close the deal by end-2016, Cree and Infineon subsequently concluded that they were unable to find ways of modifying the deal to address the regulatory concerns (leading to Infineon paying Cree a \$12.5m termination fee).

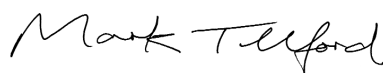
In the case of Aixtron, CFIUS thwarted plans for a Chinese investment group to acquire the entire company. In contrast, Cree's Wolfspeed Power & RF business contributed \$54m of Cree's total \$401m December-quarter revenue (see page 60). Despite this (and Cree's aim to sell it as a non-core business), Wolfspeed's gross margins are above Cree's corporate average, and its income of \$10m made a disproportionately large contribution to Cree's total \$29.9m net income. So, far from being burdened by a loss-making subsidiary, Cree has been forced to retain a profit-making business. Even while it aimed to divest the business, Cree still continued to invest in it (targeting capital spending of \$15m in the current March quarter).

Now, after being forced to abandon the sale, Cree is "going to shift focus back to growing the Wolfspeed business," according to chairman & CEO Chuck Swoboda. Wolfspeed has "performed well this year... The strength of our balance sheet and improving operating cash flow gives us the ability to invest in Wolfspeed, while continuing to pursue our LED and Lighting growth plans," he adds. After being formed from Cree's Power & RF division in September 2015, Wolfspeed will now be reintegrated back into Cree as a division of its main business. Cree executive VP Frank Plastina has hence stepped down as Wolfspeed's CEO and will leave Cree by July, while Wolfspeed's chief operating officer Cengiz Balkas (formerly general manager & VP, Cree Power & RF) will return to being the division's general manager.

Aixtron's thwarted sale to China is a bigger blow to that company. However, after suffering from overcapacity in the LED industry in recent years, Aixtron's efforts to diversify into non-LED MOCVD business such as GaN-based power electronics could at least be a longer-term silver lining, especially with President Trump just announcing a \$54bn (10%) increase in US defense spending.

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

(e.g. GaAs, InP and SiGe wafers, chips and modules for microelectronic and optoelectronic devices such as RFICs, lasers and LEDs in wireless and optical communications, etc).

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

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Automotive LiDAR sensor shipments to exceed 69 million in 2026

Critical autonomous driving functions spurring adoption

Fueled by declining hardware costs and the need to equip vehicles with multiple sensors to ensure 360° coverage, shipments of automotive LiDAR sensor will rise to more than 69 million in 2026, forecasts ABI Research in its 'Advanced Driver Assistance Systems (ADAS)' report, as critical autonomous driving functions — including obstacle detection and simultaneous localization and mapping (SLAM) — will drive the automotive industry's adoption of LiDAR sensors.

"Even the most ambitious vendors expect their solutions to begin shipping in high-volume models by 2019 at the earliest, which will be too late a time for them to capitalize on the rapid spread active safety

technologies that will drive shipments of other sensors, such as radar and camera," says industry analyst James Hodgson. "The scale and frequency of investments in established LiDAR players and more recent OEM and tier-1 startups demonstrates the value that the industry places on LiDAR technology in the development of autonomous vehicles," he adds.

January's Consumer Electronics Show (CES 2017) in Las Vegas saw a number of presentations from LiDAR developers demonstrating low-cost solid-state solutions for mainstream deployment, such as Innoviz Technologies and LeddarTech (the latter of which last year announced a partnership with tier-1

automotive manufacturer Valeo). Further, current market leader Velodyne received a joint investment from Ford and Baidu totaling \$150m in 2016 and recently announced its intention to develop a sub-\$50 solid-state system for widespread implementation.

"2016 saw the necessary formation of new investments, startups and ecosystem partnerships for LiDAR to hit the ground running in the 2019-2020 timeframe," says Hodgson. "The universal focus on low-cost solutions to enable autonomous functions on high-volume models will accelerate LiDAR shipments throughout the next decade," he concludes.

www.abiresearch.com

Infrared LED market to grow at 13% CAGR through 2021

The global infrared light-emitting diode (LED) market will rise at a compound annual growth rate (CAGR) of nearly 13% to \$475.3m in 2021, forecasts a report 'Global Infrared Light-emitting Diode Market 2017-2021' by Technavio. The top vendors highlighted in the report are: Epileds, Epistar, Everlight, Nichia, Osram Opto Semiconductors and Vishay Intertechnology.

The top three revenue-generating application segments are categorized as surveillance, consumer electronics, and automotive.

Surveillance

The surveillance segment accounts for more than 40% of total revenue. These light sources are used for low light levels and night-vision applications in CCTV cameras. "The healthy growth of the CCTV camera market will result in constant demand for infrared LEDs," says Navin Rajendra, a lead analyst at Technavio for lighting research.

Video quality is a major criterion among end-users, and the integration of infrared LEDs has advanced the capability of night vision in CCTV cameras. The demand for CCTV cameras with night-vision ability has been increasing as governments across the globe are investing more towards security.

Consumer electronics

The consumer electronics segment is projected to grow at a CAGR of nearly 16% over the forecast period, driven by the various value-added features such as information security and vital health statistics that they add to products. Increasing emphasis on consumer safety in consumer electronics products is becoming important, leading to the integration of advanced software such as iris recognition (which uses infrared LEDs). Another emerging application for IR LEDs the wearable electronics market (especially the health management sector, where

vital health statistics need to be monitored).

Automotive

"The automotive industry is experiencing innovation in the field of safety systems, infotainment, advanced driver assistance systems, telematics, and autonomous driving. These features actively involve the integration of infrared LEDs for their operation, thereby driving the global market," says Navin.

Additionally, forward-looking infrared systems are being integrated into automobiles to improve night vision. As the automotive industry is moving toward autonomous driving and other automated features, infrared LEDs will be increasingly incorporated to ensure seamless operation of the vehicle, notes the report.

www.technavio.com/report/global-lighting-global-infrared-light-emitting-diode-market-2017-2021

IR component maker Osram Opto targeting VR and AR markets growing at 181% CAGR from \$5.2bn in 2016 to \$162bn in 2020

Global revenue for the virtual reality (VR) and augmented reality (AR) markets (including hardware, software, and services) will rise at a compound annual growth rate (CAGR) of 181% from \$5.2bn in 2016 to \$162bn in 2020, according to market research firm IDC's 'Worldwide Semiannual Augmented and Virtual Reality Spending Guide', with Osram Opto Semiconductors GmbH of Regensburg, Germany in particular looking to work with partners to drive forward the rapidly growing markets.

Initially driven by the gaming industry, virtual reality is expected to serve a wide range of industrial applications, for example health-care, construction, real estate and urban planning as well as the automotive sector. Augmented reality has already risen considerably in industries as well, and last year entered the consumer market with Pokemon Go.

Both virtual reality and augmented reality employ various optoelectronic systems including infrared emitters, proximity sensors, 3D sensors, eye tracking or projection units. Covering the entire product range required – ranging from both visible and infrared diodes, lasers to photodetectors and integrated sensor modules – Osram Opto Semiconductors reckons that it is

well positioned in this field, making it a suitable partner for manufacturers driving VR and AR technologies.

"VR and AR systems can be served partly with standard products like photodiodes or high-power infrared emitters," says Bianka Schnabel, expert for infrared solutions and VR/AR application at Osram Opto. "Other applications, such as 3D sensing for gesture recognition or point sources for VR headsets, require special solutions," she adds.

Osram Opto's product portfolio for VR and AR applications includes LEDs, proximity sensors, photodiodes and lasers, e.g.

- Proximity sensors are used, for example, inside VR headsets to determine whether the headset is being worn and can automatically turn it on or off.
- IR diodes are vital in headsets and controllers, providing infrared light illumination and enabling a connected camera to observe user movements.
- Photodiodes are also used in both headsets and controllers, registering the light emitted by the IR diodes flooding the play area.
- IR lasers are used as part of the infrared illumination units, scanning and determining the play area.

Osram Opto has developed an 850nm-wavelength laser diode

specifically for time-of-flight cameras and structured light applications. The laser diode is available in both multi-mode and single-mode versions and is used for 3D sensors in VR and AR systems.

Specially developed LEDs for near-to-eye projection use, such as the Osram Ostar Projection product family, provide two-channel projection with green as well as red and blue light combined in one package, yielding a very small light engine design.

As part of the portfolio in the mobile device market, Osram Opto also offers a variety of LEDs suitable for different types of applications and designs including backlighting as well as sensors for bio-monitoring and biometric identification methods.

"Our four decades of experience as the leading supplier of optoelectronic components and our proven record on both consumer and industrial markets make us the perfect partner to further develop technologies in VR and AR," believes Schnabel. "We've been at the forefront of these technologies and are excited to be part of moving the market forward, expanding further into gaming and industrial markets."

www.idc.com/tracker/showproductinfo.jsp?prod_id=1381

Photonic integrated circuit market \$2458.9m by 2022

The photonic integrated circuit (IC) market will rise at a compound annual growth rate (CAGR) of 31.3% from \$366.47m in 2015 to \$2458.9m in 2022, forecasts a report from Statistics MRC.

An increase in the level of integration and a decrease in the size of devices are the key factors fueling the market growth, while the low level of digitalization is restraining the market.

On materials, indium phosphide holds the largest market share due to demand for high-speed data transmission. However, the silica-on-silicon segment is expected to grow at the highest CAGR.

Optical communications applications currently command the market due to an increase in data users, whereas optical signal processing is expected to hold the largest share during the forecast period.

In terms of components, the laser segment holds the largest market share, but the multiplexer/demultiplexer segment is expected to grow at the highest CAGR.

By region, North America led the global PIC market in 2015, but Asia-Pacific should see the fastest market growth during the forecast period, due to the rapid developments taking place in biophotonics.

www.strategymrc.com

LED lighting market to grow at 13% CAGR to \$54.28bn in 2022

Market to more than double from \$26.09bn in 2016

The global LED lighting market accounted for \$26.09bn in 2016 and will rise at a compound annual growth rate (CAGR) of about 13% from 2017 to reach \$54.28bn in 2022, according to a report 'LED lighting Market for Residential, Architectural and Outdoor Applications: Global Industry Perspective, Comprehensive Analysis, and Forecast, 2016 – 2022' from Zion Market Research.

As lighting sources for general lighting applications, light-emitting diodes are ten times more efficient than incandescent lighting. Such an attribute, combined with their long working life and reliability, has made them suitable for the next generation of lighting systems (including emergency, backlight, automotive, indoor and outdoor), notes the report. To ensure accurate operation and to control the light intensity, LEDs need an efficient driver, normally implemented by power electronics-based conversion stages to match the LED characteristics with the AC grid voltage and to generate a controllable and high-quality light.

Benefits offered by LED lights over incandescent and fluorescent lamps are the major factor driving LED lighting market growth. In addition, the energy efficiency of LED lights, higher brightness, and longer life span are some of the major reasons offering market opportunities for LED lighting in the coming years, says the report. The continual introduction of new products (with innovative technology) by manufacturers such as Philips and GE are attracting customers globally. However, high production costs are expected to have an adverse impact on the LED lighting market. Nonetheless, screen and display backlighting market development is likely to open new doors for LED lighting demand.

The residential application segment (including lighting for bathrooms, hallways, dining rooms and kitchens) dominated the LED lighting market, comprising over 40% of market share in 2016. Increasing use of LED lighting for outdoor application (such as roadways, traffic lights, tunnels, parking lots, and garages) is expected to provide significant growth opportunities in coming years. Architectural applications include both functional and decorative lighting. Decorative LEDs are used to light up pools, gardens, fountains, and statues. Functional applications include landscaping and building facades.

Europe held the largest share of the global LED lighting market (over 31% in 2016) and is set to continue to dominate during the forecast period. This growth is attributed mainly to the rising demand for outdoor applications paired with stringent energy-efficiency regulation. The significant demand for LED lighting for residential

purposes is the major factor in the surging market growth in this region. Implementation of the European Union (EU) Green Paper can lead to new opportunities for the European LED market in the near future, says the report.

As another leading regional market for LED lighting, North America is expected to see notable growth in the near future. Regulation over energy-efficient products plus high disposable income will help to drive demand for LED lighting for architectural application. The USA is consequently expected to be one of the most lucrative markets for LED lighting manufacturers.

The Asia-Pacific is considered to be the fastest-growing market for LED lighting and is expected to account for a significant market share in years to come. The developing road infrastructure, upcoming development projects, and the booming construction industry in developing countries such as China, India, and Indonesia are expected to create massive demand for LED lighting for residential as well as outdoor applications. This will include roadways, traffic lights, tunnels, parking lots and garages, as well as lighting in bathrooms, hallways, dining rooms, and kitchens.

The Latin American market is comparatively new and is still open for new companies and brands. Brazil will lead in LED lighting implementation, reckons the report, since it is aggressively picking up on the deployment of government-installed LED-based streetlights. The Middle East and Africa is also forecasted to see significant growth in the coming years. The United Arab Emirates (UAE) and Saudi Arabia are also predicted to hold a notable market share in near future.

www.zionmarketresearch.com/report/led-lighting-market

Europe held the largest share of the global LED lighting market (over 31% in 2016) and is set to continue to dominate during the forecast period. This growth is attributed mainly to the rising demand for outdoor applications paired with stringent energy-efficiency regulation. The significant demand for LED lighting for residential purposes is the major factor in the surging market growth in this region

GaAs component market to grow at over 4% to \$9.13bn in 2021

APAC accounted for 78% of revenue in 2016, while growth in Americas driven by 4G network expansion

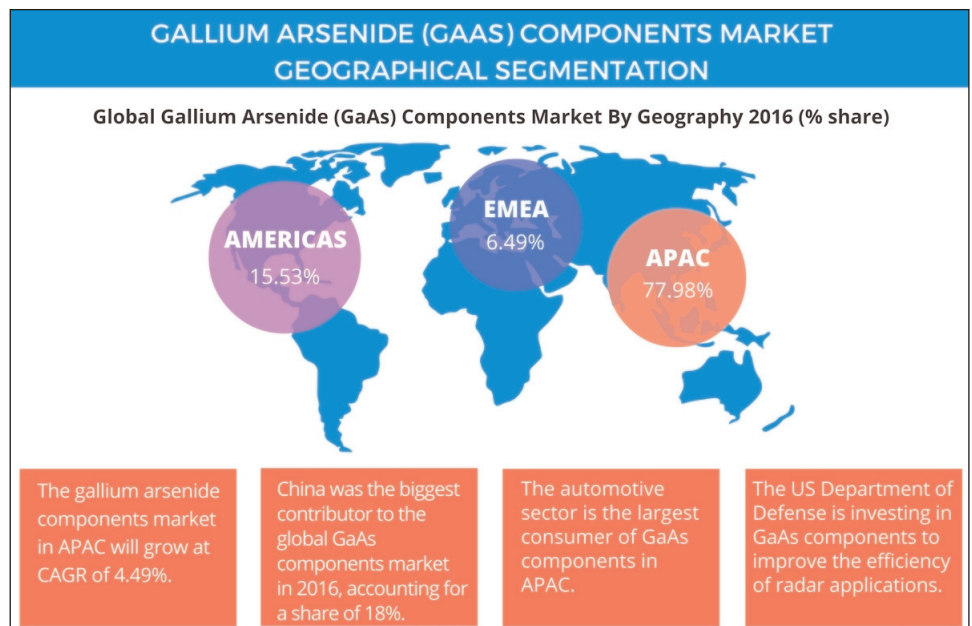
The global gallium arsenide (GaAs) components market will grow at a compound annual growth rate (CAGR) of over 4% to \$9.13bn by 2021, with over 54% of the revenue being generated from the mobile devices segment, according to a report by Technavio. The high growth of this market segment is being driven by rapidly developing 3G and 4G networks.

The rising adoption of smartphones and tablets is acting as a major impetus, with the number of smartphone shipments expected to reach 2 billion by 2020. This growth will drive demand for GaAs components used in mobile handsets, particularly GaAs power amplifiers.

APAC: largest GaAs component market segment

The Asia-Pacific region accounted for almost 78% of total market revenue in 2016, notes the report. "The market dominance is primarily because of the high demand for GaAs components from communication device manufacturers in the region," says Sunil Kumar Singh, a lead analyst at Technavio for embedded systems research. "Also, increasing demand for power applications, along with high-growth economies, is a major driver of the GaAs components market in the region," he adds.

Increasing smartphone penetration in developing countries and rapidly developing wireless infrastructure are driving the high adoption of GaAs components in the region. Companies such as Samsung, LG, HTC and Sony are investing heavily to launch better smartphones, compatible with 3G/4G technologies. These new-generation mobile phones integrate 3–4 times more power amplifiers compared with previous-generation smartphones, which means increased demand for GaAs components.



Americas: expansion of 4G networks driving GaAs components market

Technavio forecasts that the Americas will exhibit a CAGR of 4.31% during the forecast period, driven mostly by the expansion of 4G networks. North America is seeing a rapid expansion of its 4G network to make an easier transition to the upcoming 5G network. Apple and Skyworks Solutions are among the biggest consumers of GaAs components, for application in mobile power amplifiers.

GaAs components also find wide application in radar and defense systems. Currently, the US Department of Defense (DoD) is investing significantly in GaAs components to improve the efficiency of its existing radar applications. GaAs components are also expected to attract demand from the military sector, boosting the revenue contribution from the region.

EMEA: high demand from the automotive industry

In Europe, the Middle East and Africa (EMEA), GaAs components saw maximum adoption from the thriving automotive industry, says

the report. "The region will also invest in the adoption of LEDs for the general lighting and automotive sectors, all of which consume GaAs components," notes Sunil. "In the defense sector, UMS, an MMIC solution provider from the UK, creates a significant demand for GaAs components," he adds.

The various domains of defense (radar, communication, and smart ammunition) are supplied with designs created by UMS or their customers and are based on the UMS technology platform. However, this region will grow more slowly than the other two regions as most semiconductor foundries and manufacturing units are in APAC and the Americas.

The top vendors in the global GaAs component market highlighted in the report are: Skyworks Solutions, Qorvo, and Broadcom. Other prominent vendors include Advanced Wireless Semiconductor Co (AWSC), Analog Devices, MACOM, and Murata Manufacturing.

www.technavio.com/report/global-embedded-systems-global-gallium-arsenide-components-market-2017-2021

Qualcomm and TDK launch joint venture RF360 JV to enable delivery of RF front-end modules and RF filters into fully integrated systems for mobile devices, automotive and IoT

Qualcomm Inc of San Diego, CA, USA and electronics component maker TDK Corp of Tokyo, Japan have completed the formation of their joint venture RF360 Holdings Singapore Pte Ltd (announced in January 2016), which will develop and manufacture radio-frequency front-end (RFFE) filtering solutions.

With more than 4000 staff, the JV aims to enable Qualcomm's RFFE business unit to deliver RFFE modules and RF filters into fully integrated systems for mobile devices and fast-growing business segments, such as Internet of Things (IoT), drones, robotics, automotive applications, connected computing etc. The business being transferred constitutes a part of the TDK SAW Business Group activities.

"The ongoing expansion of mobile communication across multiple industries, and the unprecedented deployment of multi-carrier 4G technologies now reaching over 65 3GPP frequency bands, are driving manufacturers of wireless solutions to higher levels of miniaturization, integration and performance, especially for the RFFE in these devices," says Cristiano Amon, executive vice president of subsidiary Qualcomm Technologies Inc (QTI), and president of Qualcomm's semiconductor business Qualcomm CDMA Technologies (QCT, which is operated by QTI). "Further, 5G will increase the level of complexity even more. To that end, the ability to provide the ecosystem a truly complete solution is essential to enabling our customers to deliver mobile solutions at scale and on time."

RF360 Holdings will have a comprehensive set of filters and filter technologies, including surface acoustic wave (SAW), temperature-compensated surface acoustic wave (TC-SAW) and bulk acoustic wave (BAW), to support the wide range of frequency bands being deployed in networks across the

globe. Moreover, RF360 Holdings will enable the delivery of RFFE modules from QTI that will include front-end components designed and developed by QTI. These components include CMOS, silicon-on-insulator (SOI) and gallium arsenide (GaAs) power amplifiers, a broad portfolio of switches, antenna tuning, low-noise amplifiers (LNAs) and Qualcomm's envelope tracking solution.

Together with RF360 Holdings, QTI says that it will be positioned to design and supply products with end-to-end performance and global scale from the modem/transceiver all the way to the antenna in a fully integrated system.

Deepening collaboration between Qualcomm and TDK

In addition to operating the joint venture, Qualcomm and TDK will deepen their technical cooperation to cover a wide range of technologies for next-generation mobile communications, IoT and automotive applications.

"The deeper collaboration with

RF360 Holdings will enable the delivery of RFFE modules from QTI that will include front-end components designed and developed by QTI. These components include CMOS, silicon-on-insulator and gallium arsenide power amplifiers, a broad portfolio of switches, antenna tuning, low-noise amplifiers (LNAs) and Qualcomm's envelope tracking solution

Qualcomm fits perfectly into our growth strategy," says TDK's president & CEO Shigenao Ishiguro. "It is a further step that aims to open up new promising business opportunities for TDK, while strengthening the company's innovativeness and thus competitiveness in such attractive future markets as sensors, MEMS, wireless charging and batteries," he adds.

Additional transaction details

RF360 Holdings will be a Singapore corporation and will have a global presence, with R&D and manufacturing and/or sales locations in Europe and Asia and its headquarters in Munich, Germany. Christian Block will serve as senior VP & general manager of RFFE, QTI, which includes RF360 Holdings. Block was previously chief technology officer of TDK subsidiary EPCOS AG, and general manager of the TDK SAW Business Group.

As asserted in January 2016, when the agreement to form the joint venture was announced, RF360 Holdings will initially be owned 51% by Qualcomm Global Trading Pte Ltd (QGT) and 49% by EPCOS AG. QGT has an option to acquire (and EPCOS has an option to sell) the remaining interest in the joint venture 30 months after the closing date.

Giving effect to the payment made at closing, additional future payments to TDK based on sales by the joint venture of RF filter functions, as well as Qualcomm and TDK's joint collaboration efforts, and assuming QGT's exercise of its option to acquire EPCOS' interest in the joint venture, the aggregate transaction value is expected to be about \$3bn. Qualcomm expects the transaction to be accretive to non-GAAP earnings per share in the 12 months following the transaction close.

www.tdk.com

www.qualcomm.com

Qualcomm launches RF front-end platform for next-generation global mobile devices

Qualcomm Technologies ships its first GaAs power amplifier modules and first dynamic antenna tuning solution for carrier aggregation

Qualcomm Inc of San Diego, CA, USA says that its subsidiary Qualcomm Technologies Inc (QTI) is introducing a suite of RF front-end (RFFE) solutions, making it the first mobile technology provider to develop and commercialize a comprehensive platform spanning from the digital modem to the antenna port.

The latest additions to Qualcomm's RF360 family of RFFE products are Qualcomm Technologies' first gallium arsenide power amplifier modules (QPA5460, QPA5461, QPA4360 and QPA4361) and the next-generation Qualcomm TruSignal antenna performance enhancement solution (QAT35xx) to drive superior RF performance by utilizing modem intelligence and system-level design and optimization.

The RF360 Holdings Singapore Pte Ltd joint venture between Qualcomm Inc and TDK Corp (launched on 3 February) helps to build Qualcomm Technologies' RFFE technology portfolio. RF360 Holdings brings a legacy of expertise in RF filtering and modules as well as integrated and discrete micro-acoustic components such as multi-technology RF filters, duplexers, multiplexers and extractors, and has an established footprint in flagship smartphones. Qualcomm Technologies hence has the in-house capability and access to develop, integrate, manufacture, assemble, test and deliver both gallium arsenide and CMOS silicon power amplifiers (PAs), bulk acoustic wave (BAW), surface acoustic wave (SAW) and temperature-compensated SAW (TC-SAW) filters and filter modules, high-performance switches, power trackers, antenna tuners and integrated modules — all the components needed for a comprehensive RFFE solution to complement the firm's modem technology for next-generation mobile devices.

New RF front-end modules

As Qualcomm Technologies' first GaAs-based products, the QPA546x and QPA436x multi-mode, multi-band power amplifier (MMPA) modules are optimized for envelope tracking and average power tracking, respectively, and combine high-, mid- and low-band power amplifiers with high-performance switches to provide highly integrated modules for regional and global designs with superior power efficiency. Specifically, QPA5461 is designed to work with the QET4100 envelope tracker and is the first MMPA optimized for high-power user equipment (HPUE) operation, providing high power-efficiency solutions for devices in LTE TDD networks, says the firm.

The QPA546x MMPA is part of a modular front-end solution supporting carrier aggregation that includes a D5328 front-end module (FEMiD) with integrated quadplexer and a D5285 diversity receive (DRX) module. Compatible BAW filters are available for designs requiring higher performance in high bands such as band 41. The D5328 comprises SAW filters, TC-SAW filters and proprietary layer-transfer switches. The D5285 diversity receive module includes SAW filters and layer-transfer switches. This modular configuration offers a low part-count solution with low design-in effort for devices that support leading-edge connectivity features such as Gigabit LTE, LTE-Advanced and 4x4 MIMO.

Next-generation Qualcomm TruSignal antenna performance enhancement solutions

Comprising the QAT3550 impedance tuner, the QAT3514 aperture tuner, QAT3522 antenna diversity switch and advanced modem software, the latest generation of Qualcomm Technologies' TruSignal provides an

antenna performance enhancement technology suite that is said to be the mobile industry's first commercial adaptive antenna tuning solution supporting carrier aggregation. The TruSignal solution is designed to use the modem's intelligent processing power to continuously optimize signal quality and support a consistent user experience across use conditions while maximizing network coverage and battery life for sleek LTE-Advanced mobile devices including smartphones with metal backs. For consumers, this means support for a more consistent data and voice experience indoors and outdoors. For original equipment manufacturers (OEMs), the adaptive tunability of the system helps to reduce time-to-certification by addressing the risk of mismatch from antenna redesign iterations.

"The ability to develop the key RFFE components, coupled with our leading modem expertise, allow us to push the boundary on overall system performance while offering high levels of integration," says James Wilson, VP & general manager, RFFE modules, at Qualcomm Technologies. "Offering a comprehensive end-to-end solution enables us to make it faster and easier for our customers to create tomorrow's mobile devices, while providing better data speeds, more optimized signal performance and fewer dropped calls to consumers," he adds.

The QAT35xx antenna tuning and diversity switch products are supported for use with the Qualcomm Snapdragon 835 processor.

The QPA546x, QPA436x, D5328 and D5285 products are released and sampling now. The QAT35xx solutions are currently in production and are expected to be in commercially available devices soon.

www.qualcomm.com

www.tdk.com

Qorvo's Cees Links receives Lifetime Achievement Award for Wi-Fi innovation

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) says that Cees Links, general manager of its Wireless Connectivity business, has been recognized for his contributions to the Wi-Fi industry with the Design News 2017 Golden Mousetrap Lifetime Achievement Award. Presented in Anaheim, CA, the award honors an individual whose career has been devoted to innovation in the Advanced Design and Manufacturing industry.

"Cees is passionate about building a smarter, more connected world — one where we can live more meaningful lives through the power of billions of interconnected devices," comments James Klein, president, Qorvo Infrastructure and Defense Products. "Many of the communications technology breakthroughs we



use every day are the direct result of his unwavering commitment to this vision."

Links is considered to be a pioneer in wireless data, advancing and integrating mobile computing and continuous networking. He began his career at NCR Computers, where he was responsible for developing the first wireless local-area network (LAN) product in 1990. He continued working in wireless technology under companies including AT&T, Lucent Technologies and Agere Systems, and in 1999 closed a deal with Apple that made wireless LANs a standard feature in notebook computers.

In 2004, Links founded GreenPeak Technologies, a fabless semicon-

ductor company focused on wireless technology for ultra-low-power, remote sense and control networks for consumer electronics. In 2016, GreenPeak was acquired by Qorvo.

As head of the Qorvo Wireless Connectivity business unit, Links leads the design and development of wireless semiconductor systems for connected devices, including advanced RF chips and software for smart-home data communications and the Internet of Things (IoT).

Links helped to establish the Wi-Fi Alliance, as well as the IEEE 802.11 standardization committee, which has become the basis for ZigBee sense and control networking technology and standardization.

www.qorvo.com

<https://www.designnews.com/content/wifi-pioneer-cees-links-sets-his-sights-on-smart-home/155126479047447>

Qorvo launches RF front-end portfolio for TD-LTE band-41

Qorvo has launched a portfolio of RF front ends (RFFEs) for LTE Power Class 2 high-performance user equipment (HPUE). Smartphones incorporating the RFFEs can combine the speed and capacity advantages of high-band spectrum with the coverage advantages of mid-band spectrum, says the firm.

Major mobile network operators using TD-LTE Band 41 (2.5GHz) are requiring Power Class 2 in handsets beginning in 2017 to drive global adoption. High-band spectrum (such as 2.5GHz) carries massive quantities of data at very high speeds but lacks the range of mid- or low-band spectrum. Qorvo says that its Power Class 2 portfolio delivers higher power at the cell edge, optimizing spectral efficiency. Sprint and China Mobile are two network operators using Band 41.

"HPUE provides our customers with up to 30% greater 2.5GHz coverage," notes Sprint's chief

technology officer Dr John Saw. "Qorvo's HPUE-capable technologies were invaluable in helping us demonstrate its feasibility and drive rapid certification of this new standard," he comments. "Qorvo's RFFE portfolio will help smartphone manufacturers quickly develop devices that will connect to our networks," he adds.

"Thanks to our close collaboration with Sprint, Qorvo will play a key role in the rollout of Power Class 2 and HPUE," says Eric Creviston, president of Qorvo's Mobile Products group. "This important new standard will help meet the ever-growing demand for mobile data as we transition to higher frequency bands on the road to 5G."

Qorvo says that its proprietary bulk acoustic wave (BAW) technology and high-efficiency power amplifiers (PAs) make it possible for high frequency bands to transmit data with equal or better per-

formance than lower frequency bands. The firm's HPUE portfolio includes RF Fusion modules for flagship phones and RF Flex modules for mid-tier phones. Two new RF Fusion additions include the compact QM75001H (which reduces board area by 35% and supports both envelope tracking and carrier aggregation) and the highly integrated QM78068 (which incorporates an additional antenna switch and an ultra-high-performance BAW-based Band 7 PA/duplexer). The RF Flex addition is the QM56022 (which integrates high-, mid- and low-band multi-mode PAs packaged in the most popular footprint for mid-tier phones).

Qorvo is showcasing its portfolio of RF front-end solutions at the GSMA Mobile World Congress (MWC 2017) in Barcelona, Spain (27 February – 2 March).

www.mobileworldcongress.com

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Qorvo's quarterly revenue up 33% year-on-year, driven by RF handset content growth

Delayed flagship smartphone launches by Chinese and Korean customers to suppress March-quarter revenue

For fiscal third-quarter 2017 (to end-December 2016), Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has reported revenue of \$825.4m, down 4.4% on \$863.7m last quarter but up 33% on \$619.7m a year ago, driven by strong demand for integrated solutions and highly differentiated discrete components.

There were two 10% customers, the largest comprising about 37% of revenue and Huawei at 11%.

Mobile Products (MP) revenue was \$656.8m, down 7% on \$706.1m last quarter but up 34% on \$489m a year ago, driven by strong RF handset content growth, a low-band PAD ramp and strong Asia customer demand (with China comprising 41% of Mobile revenue, including Huawei's 11%).

Infrastructure & Defense Products (IDP) revenue was a record \$168.6m (up 7% on \$157.6m last quarter and 29% on \$130m a year ago), driven by broad-based growth in WiFi, defense (radar), wireless infrastructure (base stations), the Internet of Things (IoT) and other markets.

"We supported the launch of marquee smartphones and leading China-based OEMs and delivered record revenue in IDP," says president & CEO Bob Bruggeworth. "We did this while qualifying leading technologies for top customer programs, introducing over 100 new products, and achieving key milestones on operational initiatives."

On a non-GAAP basis, gross margin was 44.3%, down from 47.9% a year ago (due to a shift in product mix to low-band PAD [power amplifier duplexer] products) but up on 42.8% last quarter (reflecting improved manufacturing yields for low-band PAD-related products).

Although still above the \$139.8m a year ago, operating expenses (OpEx) have been cut from \$172.9m last quarter to \$157.1m (19% of revenue, better than both the 20% guidance and long-term target). This is due mainly to lower R&D expenses (cut from \$115.7m to \$105m) and personnel costs. Selling, general & administrative (SG&A) expenses also fell, from \$57.2m to \$52.1m.

Operating income has hence risen further, from \$156.9m a year ago and \$196.8m last quarter (operating margin of 22.8% of revenue) to \$208.7m (higher-than-targeted operating margin of 25.3%).

Likewise, net income has risen further, from \$148m (\$1.03 per diluted share) a year ago and \$170.4m (\$1.29 per diluted share) last quarter to \$177.3m (a record \$1.35 per diluted share, at the top of the \$1.15–1.35 guidance range).

Net cash flow provided by operating activities has fallen back from last quarter's \$250m to \$220.4m. Property and equipment expenditures has been increased from \$120m to \$136.5m to support projected premium filter demand, particularly bulk acoustic wave (BAW). Free cash flow was hence \$83.9m (down from \$130m). Qorvo returned \$67m to shareholders under its \$500m share repurchase program (announced in November). During the quarter, cash and short-term investments rose from \$469m to \$495.8m.

During the quarter, Mobile Products secured multiple design wins for complete RF front-end systems combining low-, mid- and high-band RF Fusion placements for smartphones and other connected mobile devices. Qorvo is forecasting strong growth for RF Fusion for cellular across all frequencies. "These solution sales command up to \$10 of

Qorvo content and we expect them to represent an increasing percentage of Mobile revenue, given customer design activity and the breadth of our product portfolio," says Bruggeworth.

Qorvo also secured a mid-band RF Fusion win in support of a flagship smartphone ramping this year. For the high band, the firm's solutions operate up to the ultra-high Band 42. "That is a clear competitive strength that is supported by our recently launched GaAs HBT5 process, which we believe delivers the industry's best performance," says Bruggeworth. As well as bringing up its new HBT5 GaAs process, the firm also migrated new GaAs-based designs from its fab in Greensboro, NC to its fab in Hillsboro, OR.

In IDP, during the quarter Qorvo released its next generation of integrated front-ends for WiFi. "Key to our success on the enterprise and retail side, we launched a broad family of new 802.11ac FEMs enabling smaller, more efficient routers, gateways and other network devices," notes Bruggeworth.

For the smart home and IoT, during the quarter IDP introduced what is reckoned to be the industry's first multi-protocol system-on-a-chip (SoC) to integrate IEEE 802.15.4, ZigBee 3.0, Thread and Bluetooth Low Energy communication protocols in a single chip for sensors and actuators throughout the home.

IDP also saw broad-based design-win activity, highlighted by a complete RF solution win with content above \$5 at a leading WiFi router OEM, multiple gallium nitride (GaN) wins for radar, electronic warfare and wireless infrastructure, and the adoption of BAW filters in automotive applications.

During the quarter, IDP made substantial progress in consolidating

► GaN manufacturing in Richardson, Texas by transferring products from Greensboro, NC, and achieving customer qualification.

To support growth in temperature-compensated surface acoustic wave (TC-SAW) filters, Qorvo transferred what it claims is an industry-leading product from its 4-inch line in Florida to its 6-inch facility in Greensboro and commenced high-volume customer shipments. The firm is also ahead of schedule on its transition from 6-inch to 8-inch BAW filters (so the need for the fab in Farmers Branch near Richardson — acquired in 2016 from Maxim Integrated Products Inc — has been pushed out a bit, and CapEx will be a bit lower in the short term). In addition, the firm has begun work on significantly reducing filter die sizes for both SAW and BAW.

During the quarter, Qorvo released into production its next-generation BAW 5 filter technology (which provides a 40% increase in Q factor for improved insertion loss and a 20% increase in coupling factor to provide wider bandwidths).

"We released a number of solutions utilizing our BAW 5 process in December, including multiplexers and RF Fusion for cellular and WiFi," says Bruggeworth. The firm began open-market sampling and received its first BAW 5 production orders for a key handset design win for its RF Fusion for mobile WiFi.

"Qorvo's RF Fusion for mobile WiFi solutions combined our industry-leading BAW coexistence filters with our WiFi PAs, switches and LNAs," he adds. "RF Fusion for WiFi will be disruptive to today's costly SiP [system-in-package] architectures and smartphones, as carriers introduce License Assisted Access (LAA)," Bruggeworth believes. "Qorvo is a leader in coexist filters, and LAA requires additional coexist filtering in the 5GHz band," he claims.

"We achieved a significant performance milestone in BAW filter resonator performance, and we are competing today on the most complex BAW-based product opportunities," says Bruggeworth.

"We now expect sales of BAW-based products will increase from less than a third of Mobile Products revenue in fiscal year 2018 to approaching 40% in fiscal year 2019, as performance requirements and the need for integrated modules increase. These products will include discrete BAW placements as well as highly integrated front-end integrating BAW and, in some cases, BAW and SAW," he adds. The BAW-related fab (6- and 8-inch in Richardson, Texas) has been underutilized, but utilization is now 50–60% and should rise to over 80% by fiscal fourth-quarter 2018.

"Finally, we're continuing to add state-of-the-art assembly & test capacity in our facility in DeZhou, China," notes Bruggeworth.

For fiscal fourth-quarter 2017 (to end-March), Qorvo expects revenue to fall to \$610-650m (with revenue from China being flat to down slightly quarter-to-quarter). "Guidance primarily reflects a greater than historical sequential decline in the March quarter, as two of our leading customers in China and a tier-1 customer in Korea delayed flagship smartphone launches," says chief financial officer Mark J. Murphy. "The flagship phones will begin to ramp in March, but they're really going to be in high volume in the June quarter," adds Bruggeworth. In addition, IDP revenue should be flattish quarter-to-quarter (though up substantially year-on-year for a fourth consecutive quarter).

Nevertheless, fiscal fourth-quarter gross margin should rise further to 46%, due mainly to improved product mix (lower low-band PAD volumes) and cost-related activities (ongoing productivity and quality efforts). OpEx is forecasted to be

Two of our leading customers in China and a tier-1 customer in Korea delayed flagship smartphone launches. They will begin to ramp in March

up less than 5% sequentially due to development program timing and seasonal payroll effects. Diluted EPS is expected to fall back to \$0.70–0.90. CapEx for fiscal year 2017 should total around \$500m (down from earlier estimates).

"Looking out to the June quarter [fiscal first-quarter 2018], we currently are forecasting normal seasonal sequential growth [up 7–10% quarter-to-quarter]," says Murphy. Gross margin should rise further to 46.5–48%.

"As we move past June through fiscal year 2018, we expect revenue to strengthen [including in China] as new programs launch," says Murphy. For fiscal year 2018, Qorvo expects double-digit revenue growth, driven by continued broad-based growth in IDP and increasing demand for Mobile Products (including multiplexers, diversity receive modules, WiFi, RF Fusion, and RF Flex). The firm is also forecasting year-on-year content gains in marquee smartphones, driven by low-band PADs, envelope trackers and tuners.

"We expect this double-digit growth, along with increased BAW-based product mix, higher utilization rates, and ongoing productivity and quality improvements, will help us achieve 50% gross margin exiting fiscal year 2018," Murphy says.

Qorvo expects OpEx efficiency to continue to improve and projects it to be below 20% of sales for the year. "Hitting our operating model of 30% operating margin remains our objective during fiscal year 2018," says Murphy. IDP in particular is a double-digit growth business that is highly diversified and is closing in rapidly on the firm's target model of 30% operating margin. CapEx will remain elevated in fiscal 2018, but is expected to be down from previous estimates to about \$400m. With double-digit revenue growth of 10–15%, expanding gross margin, improving OpEx efficiency and lower CapEx, Qorvo expects free cash flow to double from fiscal year 2017 to 2018.

www.qorvo.com

Skyworks' quarterly revenue grows more-than-expected 9.4% to \$914.3m

Smartphone content grows at Huawei; Samsung business recovering

For fiscal first-quarter 2017 (to 30 December 2016), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of \$914.3m, down 1.3% on \$926.8m a year ago but up 9.4% (more than the expected 7-9%) on last quarter's \$835.4m and exceeding the guidance of \$925-930m. Growth is being fueled by "global demand for ubiquitous mobile connectivity and the Internet of Things (IoT)," says president & CEO Liam K. Griffin.

Consequently, integrated mobile systems (IMS) comprised slightly more than 60% of revenue, with broad markets about 25%, and the power amplifier (PA) sector just under 15%.

Skyworks' largest customer Foxconn contributed slightly more than 40% of revenue. China comprised about 25% of total revenue. As South Korea's Samsung fell to just below the 10%, China's Huawei in particular became Skyworks' second biggest customer. "They have really stepped up in terms of the content, the richness of content and the reach of technology, providing opportunity for us to deliver mid-band, high-band, low-band solutions, power management, diversity receive, addressed carrier aggregation uplink and downlink," comments Griffin. "They're going to continue to be one of our leaders," he reckons.

On a non-GAAP basis, gross margin was 51.2%, down from 51.4% a year ago but up from 51% last quarter.

Operating expenses were \$113m, up from \$107.5m last quarter and above the expected \$112m, but falling back from 12.9% of revenue to 12.4% (although the target for the future is 13%, as Skyworks "continues to make the necessary investments to further diversify the business in the broader market in IoT").

Operating income was \$354.3m (operating margin of 38.8%), down on \$366.6m (operating margin of 39.6%) a year ago but up from \$318.4m (operating margin of 38.1%) last quarter.

Net income was \$301.6m (a record \$1.61 per diluted share, \$0.03 better than the \$1.58 guidance), up from \$277.6m (\$1.47 per diluted share) last quarter and \$1.60 per diluted share a year ago despite income falling from \$311.2m.

Cash flow generated from operations has risen further, from \$345.3m a year ago and \$455m last quarter to another record of \$495.9m, driven by the higher profitability and ongoing improvements in working capital. In particular, days sales outstanding (DSO) fell further, from 45 days to 37 days, while days of inventory was cut further from 94 days to 86 days (down from 108 days in fiscal Q3/2016).

Capital expenditure has rebounded from just \$15.7m last quarter to \$50m (about 5% of revenue), mostly for the firm's back-end plant, where it continues to expand capacity.

During the quarter, Skyworks repurchased 1.4 million shares at an average price of about \$76 (totaling \$106m). "Historically, we have been returning 40-50% of our free cash flow to the shareholders, so that's something that we will continue to do," notes senior VP & chief financial officer Kris Sennesael.

Overall during the quarter the cash balance hence rose from \$1.08bn to \$1.35bn.

"I am especially pleased with our design-win execution, particularly at marquee customers," says Griffin. "We secured SkyOne platform wins with multiple tier-1 OEMs, extended our leadership position in diversity received systems, and secured a key win in our custom high-band PAD [power amplifier duplexer] portfolio," he adds.

"We ramped fully integrated low-, mid- and high-band solutions integrating SkyBlue technology for Huawei's Mate9 platform, their flagship smartphone. We launched multiple devices across Samsung's entire portfolio and gained momentum in China, with key wins [expanding LTE content] at market leaders Oppo, Vivo, Meizu and Xiaomi," says Griffin.

"All of these wins were captured resulting from the growing complexity and performance requirements inherent in today's advanced mobile architectures. Specifically, we are seeing the continued shift to highly integrated transmit solutions, leveraging our core capabilities in gallium arsenide, temperature-compensated SAW filtering and enhanced power management."

"In addition, we are benefiting from the rapid move toward carrier aggregation, a major catalyst in driving higher data rates with expanding bandwidth in both uplink and downlink transmission. In parallel, we continue to expand our opportunity by growing our content reach with new revolutionary diversity receive systems, specifically targeted at the most complex carrier aggregation challenges, as well as a growing suite of analog solutions from Wi-Fi, GPS, antenna tuning, signal conditioning and more," Griffin continues.

Regarding its broad markets portfolio and IoT, Skyworks "expanded our design-win pipeline to include wins with Netgear home security system, ARRIS cable modems as well as Comcast and Rogers with carrier-grade broadband gateways," says Griffin. "In addition, we secured design-wins supporting the latest voice assistant technology from Amazon [Alexa], Google [Google Home] and Microsoft [Cortana]. We also capitalized on the newest trend towards home Wi-Fi mesh networking, with key wins at

► Linksys, Ubiquiti Networks and other leading OEMs," he adds.

"Finally, we broadened our footprint across the automotive sector, leveraging the diverse array of wireless protocols supporting connected car applications, vehicle-to-vehicle communication and 4G telematics [being designed into Alps' vehicle-to-vehicle intelligent transportation system]. In this past quarter, we were pleased to have consummated a strategic design win at a leading US electric car OEM," Griffin says. "Our Q1 results, strong outlook and design-win momentum reflect solid tracks in spanning out mobile, IoT and broad market portfolio," he adds.

"Given our expanding product pipeline and accelerating design-win momentum, we expect to outperform industry seasonality in the March quarter," says senior VP & chief financial officer Kris Sennesael. For fiscal second-quarter 2017, Skyworks expects revenue of \$840m

(returning to 8% year-on-year growth). Specifically, the broad markets sector in the IoT space should be up about 10–12%. So, despite being a soft quarter (with revenue down \$74–75m from the prior quarter, due to mobile markets being seasonally down), gross margin should still be in the low 50% range, with operating expenses rising to about \$115m as Skyworks continues to invest in growth initiatives (including its IoT business). Diluted earnings per share will fall to \$1.40.

"We are very well positioned for further margin expansion in the second half of 2017 as we expect the next three quarters to see sequential revenue growth [double-digit year-on-year]," says Griffin. "We see a nice bounce back of the Samsung business already starting in Q2 and in the second half of 2017," he notes.

"With the proliferation of 4G/LTE and advent of 5G, system-level

performance requirements are intensifying, driving the need for substantially higher data rates, improved efficiency and reduced latency across an exponentially growing scope of networked devices," says Griffin. "Leveraging our innovative portfolio, carrier aggregation leadership, operational scale and demonstrated ability to deliver highly integrated solutions, Skyworks is uniquely positioned to capitalize on this connectivity megatrend," he reckons.

Given the confidence in its business model and plans to enhance cash returns to shareholders, Skyworks' board of directors has authorized a new \$500m stock repurchase program. The board has also declared a cash dividend of \$0.28 per share, payable on 23 February to stockholders of record at the close of business on 2 February.

www.skyworksinc.com

Skyworks announces new \$500m stock repurchase program

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) says that its board of directors has authorized the repurchase of up to \$500m of the firm's common stock from time to time prior to 17 January 2019, on the open market or in privately negotiated transactions, in compliance

with applicable securities laws and other legal requirements.

The newly authorized stock repurchase program replaces in its entirety the \$400m stock repurchase program that was approved by the board on 19 July 2016 and had \$95m of repurchase authority remaining.

The timing and amount of any

shares repurchased will be determined by the company's management based on its evaluation of market conditions and other factors. The repurchase program may be suspended or discontinued at any time. Any repurchased shares will be available for use in connection with the firm's stock plans and for other corporate purposes.

Skyworks promotes VP of external manufacturing & operations engineering to VP, worldwide operations

Steven C. Machuga has been promoted to Skyworks' VP of worldwide operations.

Machuga has been with the firm since 1999, most recently as VP of external manufacturing & operations engineering. During his years at Skyworks, he has held positions of increasing responsibility in process and product development, operations strategy and execution.

Before joining Skyworks, he worked for Motorola in semiconductor engineering and manufacturing

management roles. Machuga holds a master's degree in chemical engineering from University of Minnesota, Twin Cities and bachelor's degrees in chemical engineering and materials science from the University of Connecticut.

"We are excited to further leverage his skillsets and capabilities as the value for our solutions continues to expand across mobile and Internet of Things ecosystems," says president & CEO Liam K. Griffin. "His extensive manufacturing back-

ground coupled with deep process knowledge will be invaluable in taking Skyworks to the next level of operational efficiency."

Bruce Freyman, who has led Skyworks' worldwide operations since 2005, is retiring and will serve in an advisory role for a transitional period. "We are grateful for Bruce's leadership and dedication, particularly as we expanded our global operational footprint, achieved world-class manufacturing yields and reduced cycle times," comments Griffin.

Skyworks unveils SkyOne Ultra 2.5 generation of front-end modules, targeting China LTE market

Skyworks Solutions Inc of Woburn, MA, USA (which makes analog and mixed-signal semiconductors) has launched its newest SkyOne front-end front-end modules, targeting the high-growth China LTE market.

The SkyOne Ultra 2.5 family includes both global and region-specific architectures, providing the ability to leverage the same printed-circuit board across multiple smartphone platforms optimized for diverse end-markets. Leveraging proven technologies, the new multi-band RF modules utilize the firm's SkyBlue technology to enhance system efficiency and battery life. Further, because the devices allow customers to scale the solution with regional variations, they are suitable for Internet of Things (IoT) appli-

cations requiring full LTE connectivity.

Specifically, SkyOne Ultra 2.5 solutions include the following:

- SKY87020 — a high-efficiency RF front-end power management IC for average power tracking RF power amplifier applications in portable battery-powered devices;
- SKY77360 — a power amplifier module designed for 2G quad-band cellular handsets;
- SKY78113 — a multi-mode multi-band (MMMB) front-end module for WCDMA/LTE bands 8, 12, 13, 20, 26,28, 29;
- SKY78114 — an MMMB front-end module for WCDMA / LTE bands 1, 2, 3, 4, 34, 39; and
- SKY78117 — an MMMB front-end module for FDD/TDD LTE bands 7, 30, 38, 40, 41.

Skyworks is offering the flexible system solution in response to "growing smartphone demand in China as well as the need for highly integrated solutions across adjacent automotive and machine-to-machine applications," says Carlos Bori, VP of sales & marketing. "Our front-end solutions are bringing tremendous value and performance to multiple end-markets, enabling our customers to exceed domestic and global performance requirements via a single device," he adds.

GSMA Intelligence estimates that global 4G LTE connections will reach 2.5 billion by 2020, with 60% of connections coming from developing regions, largely driven by TD-LTE growth in China.

www.skyworksinc.com

AEC-Q100-qualified SOI-based SPDT switch for automotive use

Skyworks' new SKYA21003 is a CMOS silicon-on insulator (SOI) single-pole double-throw (SPDT) switch targeted at automotive LTE cellular and general-purpose RF.

The next-generation product is AEC-Q100 Grade 2 Qualified with guaranteed RF performance across extended temperature limits, making it suitable for LTE cellular telematics modems, remote keyless entry devices, infotainment systems, automated toll transpon-

ders, garage door openers, GPS/navigation platforms, and other wireless control solutions.

The SOI technology ensures what is said to be excellent RF performance without compromising ESD. A wide frequency range (0.1–6GHz) is capable of supporting popular industrial, scientific & medical (ISM) bands, 5GHz Wi-Fi, and future cellular bands. What is claimed to be excellent power handling capability, with P1dB (output power at

1dB gain compression) of 38dBm, meets the need for higher-power carrier LTE aggregation telematics designs.

Skyworks says the SKYA21003 has high-linearity performance and low insertion loss with an operating temperature range from –40°C to +105°C, allowing operation in challenging automotive environments. It is available in a compact quad flat no-lead (QFN) 2mm x 2mm x 0.55mm package.

Skyworks' front-end module for ISM and connected home applications

Skyworks has launched the SKY66105-11, a highly integrated RF front-end module (FEM) designed for high-power industrial, scientific & medical (ISM) and connected home applications operating in the 902–931MHz frequency band.

The US Federal Communications Commission (FCC)-compliant module integrates harmonic filters and shielding, making it suitable for

sensors, smart meters (water, gas, electric) and machine-to-machine applications. The SKY66105-11 features 30dBm output power (P_{out}) which maximizes range while staying within FCC regulatory limits. The module's single-ended 50Ω transmit/receive interface offers a reduced bill of materials and includes a fast ON/OFF time (1–2μs), which results in a reduction in current

and enables rapid timing and multi-protocol arbitration, says Skyworks. The RF blocks operate over a wide supply voltage range (2.0–4.8V) for battery-powered applications.

The device is manufactured in a compact multi-chip module (MCM) 12-pin 8mm x 6mm x 1.05mm package.

www.skyworksinc.com/Product/3192/SKY66105-11

MACOM completes acquisition of AppliedMicro

MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has completed its acquisition (announced on 21 November) of Applied Micro Circuits Corp (AMCC) of Santa Clara, CA, USA (which provides silicon-based computing and connectivity solutions for cloud infrastructure and data centers).

Now a wholly owned subsidiary of MACOM, AppliedMicro's shares are

no longer traded on the NASDAQ Global Select Market.

"AppliedMicro's leadership in MACsec and 100G to 400G single-Lambda PAM4 positions MACOM as a preferred supplier to major enterprise and cloud data-center providers, many of whom are adopting the technologies this year," says MACOM's president & CEO John Croteau.

"MACOM will now be able to support customers with all of the requisite semiconductor content for optical networks — analog, photonic and mixed-signal PHY — from the switch

to fiber for long haul, metro, access, backhaul and data centers," he adds.

"With the transaction now closed, MACOM plans to promptly engage with previously identified potential buyers toward a near-term divestment of AppliedMicro's well-positioned Compute business," Croteau continues. "This portion of the business does not strategically align with our long-term product focus, but we feel confident a successful transaction can be consummated."

www.apm.com

www.macom.com

GlobalFoundries makes available 45nm RF SOI process for 5G mobile communications

GlobalFoundries of Santa Clara, CA, USA (one of the world's largest semiconductor foundries) has announced the availability of its 45nm RF SOI (45RFSOI) technology, making it the first foundry to unveil 300mm RF silicon to support next-generation millimeter-wave (mmWave) beam-forming applications in future 5G base stations and smartphones, it is claimed.

As the firm's most advanced radio-frequency silicon-on-insulator technology, 45RFSOI is optimized for beam-forming front-end modules (FEMs), with back-end-of-line (BEOL) features including thick copper and dielectrics that enable improved RF performance for low-noise amplifiers (LNAs), switches and power amplifiers (PAs). The intrinsic characteristics of SOI combined with RF-centric features enable next-generation RF and mmWave applications, including Internet broadband low earth orbit (LEO) satellites and 5G FEMs.

The fast-emerging 5G and mmWave markets will require innovations in radio technologies, including low power, integrated mmWave radio front ends, antenna phased-array subsystems, and high-performance radio transceivers, says GlobalFoundries. As OEMs integrate more RF content into their smartphones

and new high-speed network standards are introduced, state-of-the-art equipment will require additional RF circuitry to support newer modes of operation. This includes chips that support low latency, higher EIRP (equivalent isotropically radiated power) and high-resolution antenna scanning for ubiquitous coverage and continuous connectivity.

For improved power-handling benefits for devices operating in the gigahertz frequency range, 45RFSOI incorporates a substrate resistivity of greater than 40Ω-cm that maximizes the quality factor for passive devices, reduces parasitic capacitances, and minimizes disparity in phase and voltage swing. The technology supports operation in the mmWave spectrum from 24GHz to the 100GHz band (five times more than 4G operating frequencies).

"Skyworks is pleased to be collaborating with GlobalFoundries to drive innovation in millimeter wave solutions," says Peter Gammel, chief technology officer of Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors).

"GlobalFoundries' leadership in advanced foundry technology, as exemplified by the 45RFSOI process, is enabling Skyworks to create RF

solutions that will revolutionize emerging 5G markets and further advance the deployment of highly integrated RF front-ends for evolving mmWave applications," he adds.

"5G is expected to become the dominant worldwide mobile communications standard of the next decade and will usher in a new paradigm in mobility, multi-GBps data rates, security, low latency, network availability and high quality of service (QoS)," states Bami Bastani, senior VP of GlobalFoundries' RF business unit. The firm's latest RF SOI technology will "help play a critical role in bringing 5G devices and networks to reality," he reckons.

GlobalFoundries' 45RFSOI technology leverages a partially depleted SOI technology base that has been in high-volume production since 2008. It is manufactured at GlobalFoundries' 300mm production line in East Fishkill, NY, USA and will provide the industry with ample capacity to address this high-growth market, it is reckoned.

Process design kits are available. Customers can now start optimizing chip designs to develop differentiated solutions for those seeking high performance in the RF front end for 5G and mmWave phased-arrays.

www.globalfoundries.com

Peregrine announces volume production of 60GHz RF SOI switches

Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has announced availability of volume production parts for its UltraCMOS 60GHz RF SOI switches. The PE42525 and PE426525 extend the firm's high-frequency portfolio into frequencies previously dominated by gallium arsenide technology.

Supporting a wide frequency range from 9kHz to 60GHz, the PE42525 and PE426525 are reflective single-pole double-throw (SPDT) RF switches delivering a fast switching speed of just 8ns and RF T_{RISE}/T_{FALL} time of 3ns, and low current consumption of 390nA. At 50GHz, the PE42525 and PE426525 exhibit high port-to-port isolation of 37dB, low insertion loss of 1.9dB, high power handling, high linearity, and high ESD protection of 1kV HBM.

The PE42525 is suitable for test & measurement (T&M) equipment, microwave-backhaul solutions and higher-frequency switching in 5G systems. The PE426525 also has



an extended temperature range of -55°C to $+125^{\circ}\text{C}$ (compared with the PE42525's -40°C to $+105^{\circ}\text{C}$), making it desirable for harsh-environment applications in industrial markets.

Peregrine announced availability of 60GHz switch samples and evaluation kits in early October at European Microwave Week. "These high-frequency switches are garnering a high adoption rate in multiple markets including 5G, test & measurement (T&M) and defense," says director of marketing Kinana Hussain. "Not only do these switches break paradigms in high frequency, they also break paradigms in SOI fast switching," he adds.

The new 60GHz switches join Peregrine's high-frequency product portfolio, which includes multiple switches, an image-reject mixer, and monolithic phase and amplitude controllers (MPACs). Its proprietary UltraCMOS technology platform enables these products to reach high frequencies without compromising performance or reliability, the firm adds.

The PE42525 and PE426525 are each available as a flip-chip die with 500 μm bump pitch — reckoned to be the best form factor for high-frequency performance, as it eliminates performance variations due to wire-bond length.

Production parts and evaluation kits are available now. For 1000-unit orders, the PE42525 die costs \$40 each and the PE426525 costs \$48 each.

www.psemi.com/products/rf-switches/pe42525

www.psemi.com/products/rf-switches/pe426525

Sivers IMA launching SiGe-based 16+16 beam-forming transceiver RFIC chip for 60GHz WiGig

At the 2017 Mobile World Congress (MWC) in Barcelona, Spain (27 February – 2 March), Sivers IMA of Kista, north of Stockholm in Sweden (which makes microwave and millimeter-wave components used in telecom links, radar sensors and test & measurement equipment) is launching the TRX-BF01, a carrier-grade WiGig/802.11ad-compliant 16+16 beam-forming transceiver RFIC targeting datacom and telecom network infrastructure applications. The TRX-BF01 can be used in high-speed fixed wireless access (FWA), meshed networking and backhaul as well as fronthaul solutions. It is currently supporting

the 60GHz V-band.

The continued 10x growth in mobile data traffic until 2022 (according to November's Ericsson Mobility report) is pushing the boundaries for new and innovative wireless solutions, says the firm. WiGig, millimetre-wave and beam-forming will be vital technologies to support this growth, it adds.

The TRX-BF01 has 16 Tx +16 Rx digitally controlled beam-forming channels, all in one chip. It includes all building blocks in silicon germanium (SiGe) in a small 12.5mm x 12.5mm embedded wafer-level ball grid array (eWLB) capsule. The built-in full

phase-locked loop (PLL) and voltage-controlled oscillator (VCO) are claimed to have excellent phase noise and hence offer best-in-class error vector magnitude (EVM) performance and can be used with 64 QAM single carrier modulation, compliant to the 802.11ad standard, allowing speeds up to 7Gbps in air. Compared with many CMOS RFICs for millimetre-wave frequencies, SiGe offers more than 100 times higher output power per Tx channel in some cases, it is reckoned.

Prototypes of the new chip are available to key customers and partners in second-quarter 2017.

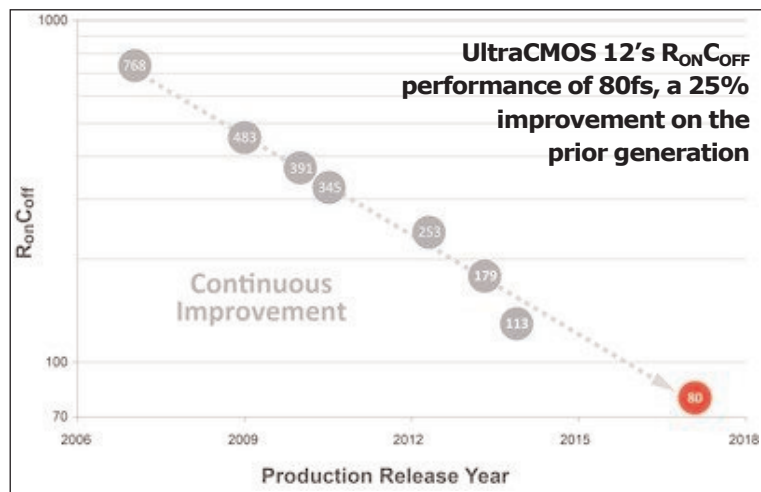
www.siversima.com

Peregrine introduces UltraCMOS 12 RF SOI platform

Industry-best $R_{ON}C_{OFF}$ of 80fs a 25% improvement on UltraCMOS 11

Peregrine Semiconductor has unveiled its UltraCMOS 12 technology platform. Now in production, the next-generation RF SOI platform has what is claimed to be the industry's lowest $R_{ON}C_{OFF}$ performance level of 80fs — a 25% improvement over the last generation. To develop the 300mm UltraCMOS 12 platform, Peregrine collaborated with full-service semiconductor foundry GlobalFoundries Inc of Milpitas, CA.

As a key metric for RF switching, Peregrine's performance benchmark for each new generation of the UltraCMOS platform is $R_{ON}C_{OFF}$, the product of how much loss occurs when a radio signal goes through a switch in its ON state (on-resistance) and how much the radio signal leaks through the capacitor in its OFF state (off-capacitance). With each new UltraCMOS generation, Peregrine targets a 20% improvement in $R_{ON}C_{OFF}$, but UltraCMOS 12 has surpassed this.



"For nearly three decades, Peregrine's UltraCMOS technology platform has been at the forefront of RF SOI performance — especially for RF switching," says Alain Duvallet, VP of RF process technology. "This legacy continues with today's introduction of the UltraCMOS 12 platform."

Like the two prior generations UltraCMOS 10 and 11, UltraCMOS 12 technology uses a custom fabrication flow from GlobalFoundries. Introduced

in July 2015, UltraCMOS 11 was the industry's first RF SOI 300mm platform. Introduced in October 2013, UltraCMOS 10 delivered the industry's best $R_{ON}C_{OFF}$ performance at the time.

"Our joint development with Peregrine continues to produce remarkable results," comments Raj Nair, GlobalFoundries' VP of technology development. "This new RF SOI technology reaffirms our commitment to the RF market and is another example of how GlobalFoundries can provide industry-leading levels of performance, reliability and scalability."

www.globalfoundries.com
www.psemi.com

Peregrine opens Austin development center

New office to accelerate development of UltraCMOS products for mobile applications

Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has opened its new development center in Austin, Texas, which will accelerate the development of UltraCMOS products for mobile applications including power amplifiers, low-noise amplifiers and switches. The new office is staffed with 13 experienced RF integrated circuit developers and is seeking candidates for further expansion. Located at 3801 S. Capital of Texas Hwy, Suite 150, Austin, TX, the new development center includes laboratory and office space.



David Bockelman, who leads Peregrine's new Austin office.

mobile wireless solutions business unit. "Peregrine is extremely fortunate to be able to open an office in the region and immediately staff it with the region's top talent. Our new Austin team members are

"Austin is one of the few hot beds for IC development, and it has been on our radar for several years as a location with a high potential for expansion," says Dylan Kelly, VP & general manager of Peregrine's

experts in their field, with the added benefit of having worked together as a proven team for the last nine years," he adds.

The Austin office will be led by 25-year industry veteran David Bockelman, who most recently served as senior R&D manager at Avago Technologies/Broadcom. He was previously VP of engineering at Austin-based Javelin Semiconductor Inc. Bockelman holds a Ph.D. in electrical engineering from the University of Florida and a BSEE and MSEE from Georgia Institute of Technology.

Now hiring, the Austin development center is accepting applications.

www.psemi.com/careers/job-listings

ACCO launches CMOS RF front-end module for Internet of Things applications

Fabless semiconductor firm ACCO Semiconductor Inc of Sunnyvale, CA, USA, which develops RF front-end components including multi-mode multi-band power amplifiers (MMPA) manufactured in standard high-volume bulk CMOS processes, has launched the AC81030, an integrated RF front-end module for Internet of Things (IoT) applications. Provided in a low-profile 4.1mm x 5.8mm LGA package, the complete CMOS front-end module offers what is claimed to be the first cost-effective solution to economically serve the global market with one device. The high level of integration allows IoT module makers to be faster to market with simpler lower-cost designs without sacrificing functionality, the firm adds.

Since the cellular IoT market is in its early growth stage, a wide variety of frequency band and mode requirements exists. Operators are looking to maximize return on their infrastructure investments with IoT solutions that can coexist on existing networks. 3GPP has addressed this by standardizing on several different cellular technologies within LTE. However, each air interface addresses particular market needs, resulting in fragmented requirements for chipsets and RF front-end components. Existing competing solutions requiring dedicated components for each frequency band resulted in the development of

costly customized products for each operator and geographic region, says ACCO.

Developed in collaboration with a leading LTE system-on-chip (SoC) provider, the AC81030 enables SoC and IoT module makers to have a single reference design or product stock-keeping unit (SKU) that addresses several market segments worldwide. Through economies of scale, better inventory management and a simplified supply chain, ACCO claims that solutions based on the AC81030 can reduce the total cost of ownership that is critical to the growth of the cellular IoT market.

"ACCO's integrated RF front-end module has enabled Altair to design the first single-SKU IoT Cat M1 reference design, addressing needs for our customers globally," comments Eran Eshed, VP of worldwide sales & marketing at Israel-based LTE chipset provider Altair Semiconductor. "We look forward to continuing to work with ACCO as the IoT market expands."

ACCO has developed

The use of standard CMOS process brings the advantages of Moore's Law to the final non-silicon holdout in cellular IoT solutions, the RF front-end

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, claims ACCO. The use of CMOS in the RF front-end is said to improve 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.

"ACCO has uniquely simplified the RF front-end for cellular IoT through CMOS integration, helping to bring IoT devices to market faster and with lower cost," comments Chris Taylor, director RF & Wireless Components at market research firm Strategy Analytics.

"The use of standard CMOS process brings the advantages of Moore's Law to the final non-silicon holdout in cellular IoT solutions, the RF front-end," says ACCO's CEO Greg Caltabiano. "This allows the entire cellular IoT market to ride the same decreasing cost curve while increasing functionality and reliability, as experienced in the rest of the electronics industry."

www.acco-semi.com

InResonance to represent Anokiwave in Sweden

Anokiwave Inc of San Diego, CA, USA, which provides highly integrated silicon core chips and III-V front-end integrated circuits for millimeter-wave (mmW) markets and active electronically scanned array (AESA)-based terminals, has signed a representative agreement for InResonance to support new customers and opportunities for its highly integrated active antenna

core IC solutions in Sweden.

InResonance has wide experience in both microwave design as well as sales & marketing and is focused on the Swedish wireless market, specializing on in-design of RF and microwave components of strategic importance.

"This agreement strengthens the technical support we can provide to customers in Sweden and increases

our ability to promote our 5G active antenna core IC solutions in the region," says Vincent Pelliccia, Anokiwave's VP of business development. "With detailed knowledge of the Swedish wireless market, InResonance is ideally positioned to drive the adoption of our IC solutions into the 5G, radar and SatCom markets," he believes.

www.inresonance.se

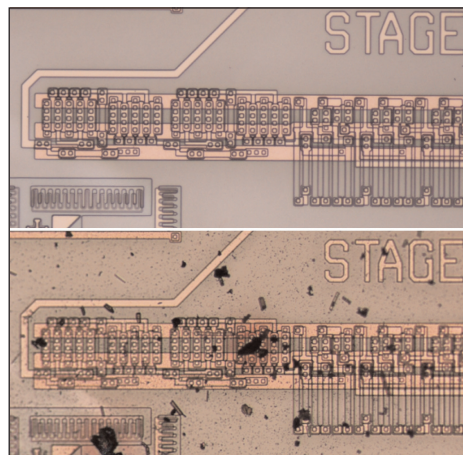
NASA demos SiC-based ICs operating over 100 times longer under Venus-like temperatures and atmosphere

Development has Earth-relevant applications such as aircraft engines

The Glenn Research Center in Cleveland of US National Aeronautics and Space Administration (NASA) has completed a technology demonstration that could enable new scientific missions to the surface of Venus. The team demonstrated the first prolonged operation of silicon carbide (SiC)-based electronics in the harsh conditions found on Venus ('Prolonged silicon carbide integrated circuit operation in Venus surface atmospheric conditions', AIP Advances 6, 125119 (2016)).

"With further technology development, such electronics could drastically improve Venus lander designs and mission concepts, enabling the first long-duration missions to the surface of Venus," says Phil Neudeck, lead electronics engineer for the project.

Existing Venus landers can only operate on the planet's surface for a few hours due to the extreme atmospheric conditions. The surface temperature on Venus is nearly 860°F, which is hotter than most ovens, and the planet has a high-pressure carbon dioxide atmosphere. Because commercial electronics don't work in this environment, the electronics on past Venus landers have been pro-



IC before (above) and after (below) testing in Venus atmospheric conditions. (Credits: NASA.)

tected by thermal and pressure-resistant vessels. These vessels only last a few hours, and they add substantial mass and expense to a mission.

To overcome these challenges, the Glenn team developed and implemented extremely durable silicon carbide integrated circuits. They then electrically tested two of these ICs in the Glenn Extreme Environments Rig (GEER), which can precisely simulate the conditions expected on Venus' surface. The ICs withstood the Venus surface temperature and atmospheric conditions for 521 hours – operating

more than 100 times longer than previously demonstrated Venus mission electronics.

"We demonstrated vastly longer electrical operation with chips directly exposed (no cooling and no protective chip packaging) to a high-fidelity physical and chemical reproduction of Venus' surface atmosphere," says Neudeck. "Both integrated circuits still worked after the end of the test."

Earlier this year, the team demonstrated nearly identical silicon carbide ICs for more than 1000 hours at 900°F in Earth-atmosphere oven testing. The integrated circuits were originally designed to operate in hot regions of fuel-efficient aircraft engines.

"This work not only enables the potential for new science in extended Venus surface and other planetary exploration, but it also has potentially significant impact for a range of Earth-relevant applications, such as in aircraft engines to enable new capabilities, improve operations, and reduce emissions," says Gary Hunter, principle investigator for Venus surface electronics development.

<http://aip.scitation.org/doi/full/10.1063/1.4973429>

www.nasa.gov/glenn

CS ManTech 2017

Indian Wells, California, 22–25 May

This year's CS ManTech is in final preparation for the event at the Hyatt Regency Indian Wells Resort & Spa on 22–25 May.

Registration is open for the workshop, conference and exhibits.

Visit: www.csmantech.org

EU project CHALLENGE kicks off

€8m, 4-year project targets cubic 3C-SiC 600–1200V power devices for electric vehicles

The European Union's Horizon 2020 project CHALLENGE ('3C-SiC hetero-epitaxially grown on silicon compliance substrates and new 3C-SiC substrates for sustainable wide-band-gap power devices') officially started with its Kick-off meeting in Brussels on 23 January.

Funded with €7,997,822 over 48 months under the Nanotechnologies, advanced Materials, Biotechnology and Production work program (NMBP-02-2016 — topic 'Advanced Materials for Power Electronics based on wide bandgap semiconductor devices technology'), CHALLENGE will focus on the growth, processing and optimization of devices based on cubic silicon carbide (3C-SiC) technology, which it is reckoned can have a large impact on the future power device

market (which is segmented by voltage rating).

In particular, CHALLENGE aims to improve power efficiency in the consumer market spanning 600–1200V, which is growing rapidly and is forecasted to rise from \$100m in 2020 to \$300m in 2023. The low cost of the 3C-SiC approach and the scalability of the material makes the technology extremely competitive in the motor drives of hybrid/electric vehicles (HEVs). However, the research is strategic, as it has applications in several fields: from telecoms to automotive, from consumer electronics to electrical household appliances, and from industrial applications to home automation.

CHALLENGE involves 14 partners (including 9 private companies)

from 7 countries with expertise across the whole supply chain (equipment, materials, characterisations, processing, power devices, simulations). The partners include: Consiglio Nazionale delle Ricerche (Italy), University of Erlangen (Germany), LPE SPA (Italy), NOVASiC SA (France), Anvil Semiconductors Ltd (UK), ASCATRON AB (Sweden), University of Milano-Bicocca (Italy), Silvaco Europe Ltd (UK), MOVERIM Consulting sprl (Belgium), Ion Beam Services (France), University of Linköping (Sweden), University of Warwick (UK), STMicroelectronics (Italy), and CUSIC (Japan).

At the kick-off meeting, partners presented the six work packages and discussed key managerial and financial issues.

<http://cordis.europa.eu/project/>

Cree terminates sale of Wolfspeed to Infineon following CFIUS' national security concerns

Wolfspeed to be reintegrated into Cree

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA is terminating last July's agreement to sell its Wolfspeed Power & RF division — which includes the silicon carbide (SiC) substrate business for power, RF and gemstone applications — to Infineon Technologies AG of Munich, Germany for \$850m in cash (€740m).

Based in Research Triangle Park, NC, USA and part of Cree for almost three decades, Wolfspeed is a provider of SiC-based power and GaN-on-SiC-based RF power solutions. With more than 550 staff and an IP portfolio of about 2000 patents and patent applications, the acquisition would have complemented Infineon's previous acquisition of International Rectifier in early 2015, while the SiC-based product portfolio would have added to Infineon's existing range.

However, on 8 February, based on communications with the Committee on Foreign Investment in the United States (CFIUS), Cree and Infineon said that the transaction in its existing form was unlikely to be approved by CFIUS, and that they were therefore exploring ways of modifying the transaction in order to mitigate or address the regulatory concerns (then re-filing with CFIUS). Cree and Infineon now say that they have been unable to identify alternatives that would address the national security concerns of CFIUS.

"In light of this development, we are going to shift our focus back to growing the Wolfspeed business," says Cree's chairman & CEO Chuck Swoboda. "The Wolfspeed business has performed well this year as our customers have further realized the value of our unique technology and is on a great path as a part of Cree.

The strength of our balance sheet and improving operating cash flow gives us the ability to invest in Wolfspeed, while continuing to pursue our LED and Lighting growth plans. We believe investing to grow all three businesses will create the most value for our shareholders," he adds. "I thank [Infineon CEO] Dr Ploss and the rest of the Infineon team for the significant amount of time and commitment they invested trying to successfully complete the transaction," continues Swoboda.

The termination of the transaction with Infineon will trigger a termination fee of \$12.5m being paid to Cree. Also, as a result of Cree's decision to focus on running the business, Wolfspeed will now be reported as a separate segment of Cree's continuing operations.

www.infineon.com

www.wolfspeed.com

New York Power Electronics Manufacturing Consortium produces its first SiC-based patterned wafers

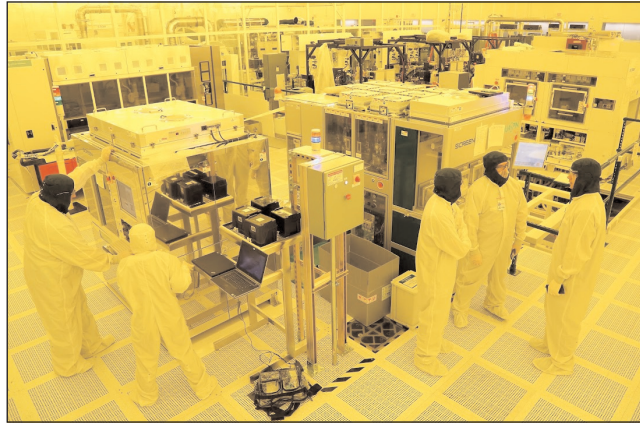
First wafer produced via SUNY Poly's 150mm SiC line in partnership with PEMC founding member General Electric

The New York Power Electronics Manufacturing Consortium (NY-PEMC) at SUNY Polytechnic Institute's Albany NanoTech Complex has produced its first silicon carbide (SiC)-based patterned wafer, using SUNY Poly's 150mm SiC processing line (which is claimed to be the first in the USA dedicated to the SiC wafer platform).

"The New York Power Electronics Manufacturing Consortium, led by SUNY Poly, in partnership with New York State and with founding member General Electric, is fast approaching production strength for power electronics," says SUNY Poly's interim president Dr Bahgat Sammakia. "We look forward to continuing to collaborate with GE, New York State, and Empire State Development as SUNY Poly provides SiC wafer production capabilities at its Albany campus, and complementary packaging at its Utica campus, supporting a unique synergy for high-tech research, development, and deployment," he adds.

"This is a significant milestone that brings the NY-PEMC another step closer to full production," notes Empire State Development president, CEO & commissioner Howard Zemsky. "By tapping into the state's skilled workforce and our world-class research and development centers, this public-private partnership will further solidify Upstate New York as the epicenter of developing and producing next-generation chip technologies," he adds.

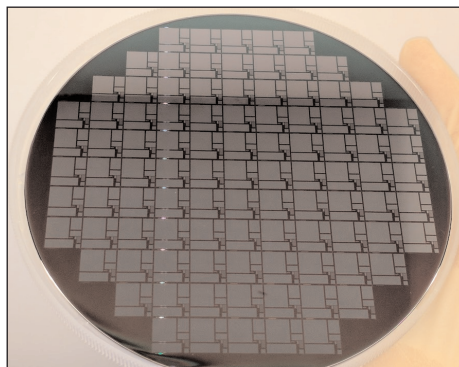
"As the SiC-based wafer production line continues to advance its capabilities, including reaching this production milestone, General Electric values our strong partnership with SUNY Polytechnic Institute and New York State," comments Danielle Merfeld, vice president &



The 150mm SiC fab at NY-PEMC.

Niskayuna site leader at GE Global Research. "Through the Power Electronics Manufacturing Consortium, we have an opportunity to place the Capital Region, Utica and Upstate New York at the center of the next revolution in power efficiency for electrical machines and systems of all kinds."

The accomplishment is the first step in the qualification of metal-oxide semiconductor field-effect transistor (MOSFET) production for power electronics applications by SUNY Poly's SiC processing line, which is critical because MOSFETs are the most ubiquitous transistors currently in use. SiC-based chips provide next-generation capabilities by enabling power devices to get smaller, faster and more efficient as incumbent silicon reaches its physical limits. In particular, SiC-based



NY-PEMC's first patterned SiC wafer.

power electronic devices have the capacity to handle much higher frequencies and temperatures than Si-based devices, which reduces the size and cost of filtering and cooling systems that often must be included as part of an overall system. Additionally, SiC devices can be half the size of similar silicon devices, providing

increased power density and reliability. With the improved qualities, SiC-based power devices can enhance a wide range of applications, including in the automotive, clean energy and aeronautics industries, for example.

"The first lot start and first patterned wafer are two goals that have now been achieved, signifying a powerful first step for the PEMC and its production of SiC-based wafers," says Dr Jeffrey Hedrick, principal investigator for NY-PEMC & vice president of SUNY Poly. "We look forward to even more technological achievements as the NY-PEMC further develops the leading-edge SiC-focused capabilities," he adds.

SUNY Poly and GE lead the consortium with the goal of developing and producing low-cost, high-performance 6" SiC wafers. The NY-PEMC is a public-private partnership announced in mid-2014. SUNY Poly's 150mm SiC fab is located at its Albany NanoTech Complex, with production coordinated with SUNY Poly's Computer Chip Commercialization Center (Quad-C) at its Utica campus, where the SiC-based power chips will be packaged.

www.ny-pemc.org

www.geglobalresearch.com

UK's EPSRC awards University of Bristol £4.3m grant to develop GaN-on-diamond microwave technology

Diamond growth to be combined with micro-fluidics using phase-change materials to aid heat extraction

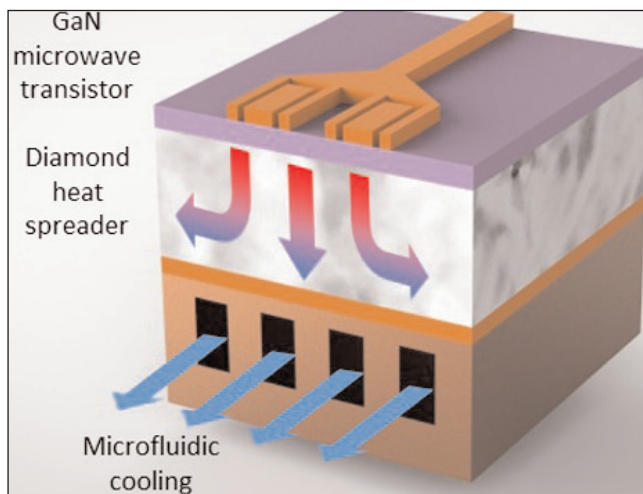
The University of Bristol has been awarded a £4.3m grant from the UK's Engineering and Physical Sciences Research Council (EPSRC) to lead a new project to develop gallium nitride (GaN)-on-diamond microwave technology.

The university notes that the next-generation technology is expected to underpin future high-power radio frequency and microwave communications, space and defence systems, paving the way for 5G and 6G mobile phone networks and much more comprehensive radar systems. Bristol will work with a consortium of four other universities (Cardiff, Glasgow, Cambridge and Birmingham) as well as industry partners during the five-year project.

"Global demand for high-power microwave electronic devices that can deliver power densities well exceeding current technology is increasing," says project leader professor Martin Kuball of Bristol's School of Physics. "In particular, GaN-based high-electron-mobility transistors (HEMTs) are a key enabling technology for high-efficiency military and civilian microwave systems, and increasingly for renewable energy plants," he adds.

Since data transmission in a mobile communication systems requires a certain amount of energy per bit, and in 5G the number of bits transmitted per second will be immense (and future systems will ask for even more), existing microwave devices that are used to transmit bits in 4G networks do not have the power needed.

The vision of the new project is to develop transformative GaN-on-diamond HEMTs and monolithic microwave integrated circuits (MMICs) as a technology step beyond existing microwave devices.



Ultra-high power GaN-on-diamond microwave device for communication and radar applications.
GaN-Diamond-article[1].jpg

Energy flows in these can be as high as the heat flux on the surface of the sun, say the researchers, and diamond — due to its ultra-high thermal conductivity — is the only material that can handle them. The devices can allow the implementation of future communications networks and radar systems with capabilities beyond what is presently possible, it is reckoned.

"We will develop new diamond growth approaches that maximize diamond thermal conductivity close to the active GaN device area," says Kuball. "In present research GaN-on-diamond devices, a thin dielectric layer is required on the GaN surface to enable seeding and successful deposition of diamond onto the GaN. Unfortunately, most of the thermal

This represents a disruptive change in capability that will allow the realization of new system architectures — e.g. for radio-frequency seekers and medical applications

barrier in these devices then exists at this GaN-dielectric-diamond interface, which has much poorer thermal conductivity than desired," he adds. "Any reduction in this thermal resistance — either by removing the need for a dielectric seeding layer for diamond growth or by optimizing the grain structure of the diamond near the seeding — would be of huge benefit. Novel diamond growth will

be combined with innovative micro-fluidics using phase-change materials — a dramatically more powerful approach than conventional micro-fluidics — to further aid heat extraction."

The outcome should be devices with a more than fivefold increase in RF power compared with the existing state-of-the-art GaN-on-silicon carbide HEMTs that are currently commercially available. Alternatively and equally valuably, a step-change shrinkage in MMIC or power amplifier (PA) size is possible, delivering an increase in efficiency through the removal of combining networks as well as a reduction in power amplifier cost. The researchers reckon that this represents a disruptive change in capability that will allow the realization of new system architectures — for example, for radio-frequency seekers and medical applications — and enable the bandwidths needed to deliver 5G and beyond. Reduced requirements for cooling/increased reliability will result in major system-level cost savings, it is added.

www.bristol.ac.uk/physics/people/martin-h-kuball/overview.html

AKHAN issued global patent covering fabrication of diamond semiconductor materials

AKHAN Semiconductor Inc of Gurnee, IL, USA, which specializes in the fabrication and application of lab-grown, electronics-grade nanocrystalline (NCD)-based materials & devices for semiconductor and electronic applications, says that the Taiwan Patent Office has issued it a patent that covers a method for the fabrication of diamond semiconductor materials, ubiquitous in application for automotive, aerospace, consumer electronics, military, defense, and telecommunications systems, amongst others.

The patent (1557776) is a foreign counterpart of other issued and pending patents (including US Patent Application #61/513,569)

owned by AKHAN that are used in its Miraj Diamond Platform products. As a landmark patent, the claims protect uses far beyond the existing applications, including microprocessor applications. Covering the base materials common to nearly all semiconductor components, the intellectual property can be realized in everything from diodes, transistors and power inverters to fully functioning diamond chips such as integrated circuitry, says AKHAN.

"The claims in this patent will play an important role in incorporating diamond semiconductor materials in today and the next generation of electronics systems," believes founder & CEO Adam Khan. "This patent originates from a filing in

2012," he notes.

Diamond-based technology is capable of increasing power density as well as creating faster, lighter and simpler devices for consumer use, claims AKHAN. Cheaper and thinner than its silicon counterparts, diamond-based electronics can keep devices cool due to better internal heat conduction and greater battery life, the firm adds.

The latest patent adds to the other key patents in the field of diamond semiconductor that are owned by AKHAN, including the ability to fabricate transparent electronics, as well as the ability to form reliable metal contacts to diamond semiconductor systems.

www.akhansemi.com

TRAK launches compact 25W Ku-band transceiver incorporating GaN SSPA for commercial airborne applications

TRAK Microwave (a Smiths Microwave brand that designs and manufactures RF and microwave assemblies, subsystems, components and time & frequency systems for defense, space and commercial applications) says that its new HPT Ku-band transceiver functions as a complete airborne SatCom solution, integrating the necessary gallium nitride (GaN) solid-state power amplifier (SSPA), up-converters, down-converters and digital control technology to offer a highly modular yet easily maintained system complete with interoperability features and multiple built-in-test (BIT) functions.

Leveraging the higher maximum channel temperature limit of GaN devices along with built-in SSPA protection against high VSWR (voltage standing wave ratio) loads, the 25W HPT system offers high standard reliability and stability, it is claimed. For applications that



TRAK's new HPT 25W Ku-band transceiver.

require additional commercial air transport use assurance, an optional vibration-insensitive OCXO installed on a vibration isolation platform is available.

The HPT can transmit at 13.75–14.5GHz from an IF frequency of 950–1700MHz with a gain variation of less than 1.0dB over any 36MHz band and provides the

frequency block down-conversion from 10.7–11.7GHz to the low-band IF of 950–1950MHz or from 11.7–12.75GHz to the high-band IF of 1100–2150MHz. The receive bands are selectable with commands over

the Ethernet bus.

Qualified for commercial airborne environments, this type-N RF TX/RX and TNC IF TX/RX compact and highly integrated device operates at temperatures from –15°C to +55°C.

www.trak.com/files/products/KU-Band-25-W-High-Power-Transceiver.pdf

Navitas delivers first GaN power ICs

Navitas Semiconductor Inc of El Segundo, CA, USA has announced immediate availability (to qualified partners) of production-qualified iDrive gallium nitride power ICs (in 5mm x 6mm QFN packages) using its proprietary 'AllGaN' technology.

The NV6131, NV6105 and NV6115 offer a high-efficiency 650V, 160mΩ power field-effect transistor (FET) with increasing integration of digital and analog circuits, leading to what is claimed to be groundbreaking speed, energy efficiency, power density and reduced system cost.

GaN can enable up to 100x higher frequencies than silicon. However, driving, controlling and protecting such high-speed power devices has been an industry challenge that has limited adoption, says Navitas. By integrating these critical digital and analog circuits monolithically with the GaN power device, these system-level problems have been eliminated, it is claimed. Navitas

says that its GaN Power ICs with iDrive provide optimized and robust performance for any application. A 10–100x increase in system operating frequency is combined with higher efficiencies to enable up to a 5x boost in power densities and 20% lower system costs, it is said.

"By integrating all gate-drive-related circuitry, virtually all frequency-related power losses are eliminated, opening the door to significant frequency and efficiency gains," says CEO Gene Sheridan. "We anticipate a major upgrade cycle in mobile fast chargers, thin TVs, high-efficiency data centers, LED lighting, solar and electric vehicle markets as this new high-speed revolution in power electronics gets underway," he adds.

"The Center for Power Electronics Systems (CPES) at Virginia Tech has been pioneering the advancement of high-frequency power systems for over three decades," says Dr Fred Lee, the university's distin-

guished and globally recognized professor. "The invention of GaN power ICs represents a major industry breakthrough and is a critical ingredient to make high-speed, high-efficiency power systems a reality," he comments.

"GaN has the potential to displace a large percentage of the \$15bn power silicon market, but adoption has been partially limited by the system challenges in cost-effectively driving and controlling the GaN power device at high speeds," notes power semiconductor market researcher Dr Hong Lin at Yole Développement. "The integration of logic, analog and power in a GaN power IC solves this remaining roadblock and positions GaN to realize its full potential."

Navitas will demonstrate the new NV61xx series at the Applied Power Electronics Conference & Exposition (APEC) in Tampa (26–30 March).

www.apec-conf.org

Navitas launches first integrated half-bridge GaN power IC

Navitas has launched what it says is the first integrated half-bridge GaN power IC. The proprietary 'AllGaN' half-bridge GaN power IC with iDrive monolithically integrates all the functions required to deliver switching speeds of up to 2MHz and enables a reduction in size, cost and weight while delivering faster charging. Previously, older silicon-based half-bridge components suffered from slow switching and parasitic power losses, slowing speeds by up to 30x, the firm adds.

The first half-bridge GaN power IC is the 650V-rated NV6250, in a 6mm x 8mm QFN package complete with dual drivers, level shifter, dual 560mΩ power FETs, boot-strap circuit and extensive protection features. Simple, low-power digital PWM inputs switch the half-bridge effortlessly at all frequencies, with significant ease-of-use and layout flexibility for the power system designer, claims Navitas. The

NV6250 is compatible with a wide range of analog and digital controllers from multiple IC partners.

"High-voltage, high-speed power systems are now commercially viable and will enable a new class of high-density, fast-charging and lower-cost power systems," says CEO Gene Sheridan. "Since Navitas first demonstrated the half-bridge at APEC 2015, we have worked closely with partners to create the next generation of adapters and chargers with breakthrough size and efficiency. Our earlier announcement of the AllGaN platform's JEDEC qualification demonstrates GaN's maturity and readiness," he adds.

"The perennial difficulty with the half-bridge topology in high-frequency applications is how to power and control the high-side switch precisely, quickly and efficiently," comments Dr Milan M. Jovanovic, senior VP of R&D at power supply manufacturer Delta.

"By integrating the critical level-shifting, boot-strap, and dual-drive functions, all in GaN, major practical challenges have been solved, paving the way for MHz high-voltage power systems," he adds.

"MIT has studied the opportunities and the limitations in high-frequency power converters for more than a decade," says professor David Perreault, leader of MIT's RLE (Research Laboratory of Electronics) Power Electronics Research Group. "One key bottleneck in many designs has been the limitation in high-speed level shifting and driving of high-side devices," he adds. "The introduction of high-voltage GaN power ICs with integrated, high-speed drivers has tremendous potential in many applications."

Samples and demonstration boards for the NV6250 are available now to qualified customers, with production planned for Q2/2017.

www.navitassemi.com

Saab offers GaN-based AESA radar for India's Tejas LCA fighter aircraft

Sweden-based defence and security firm Saab AB is providing a sensor package for India's Tejas LCA Mk1A fighter aircraft, consisting of a Saab AESA fighter radar closely integrated with a compact electronic warfare suite using gallium nitride-based AESA technology.

In partnership with Indian industry, Saab is offering a solution that will bring the required airborne electronically scanned array (AESA) fighter radar and electronic warfare (EW) capability to India and the Indian Air Force.

The AESA fighter radar has been developed by Saab using antenna technology based on technologies using gallium nitride (GaN) and silicon carbide (SiC) substrates in combination with the latest generation of exciter/receiver and processor technology, giving optimum installed performance in a dense signal environment.

The radar has a complete mode suite that includes air-to-air, air-to-ground and air-to-sea capabilities. A built-in memory provides a tool to record a large amount of data from flights. Integration in the LCA Mk1A fighter aircraft is enabled by

the limited space, power and cooling required.

The EW suite consists of sensors and transmitters developed by Saab and is a compact solution that provides essential situational awareness and self-protection. The heart of the suite is an electronic warfare receiver that is connected to a front-end receiver and fin tip antennas inside the aircraft. Also included is an external AESA jammer pod.

The radar warning system is based on ultra-wideband digital receivers and has high probability of intercept, good sensitivity and high selectivity for handling complex signal environments, it is claimed.

The AESA jammer pod is small in size, low on weight and drag. Self-protection is based on wideband digital RF memory (DRFM) that provides advanced jamming tech-

The AESA fighter radar has been developed by Saab using antenna technology based on technologies using GaN and SiC substrates

niques and arbitrary combination of jamming waveforms. Transmission is performed using GaN-based AESAs. The EW suite also includes ground support systems and recording capability for advanced mission planning and post-flight analysis.

The AESA fighter radar and electronic warfare units have no ITAR (International Traffic in Arms Regulations)-restricted components, due to the high degree of Saab in-house developed and manufactured building blocks. Also, using contemporary technology provides adaptability and growth potential: technologies are re-used between variants and platforms in order to minimize life-cycle cost (LCC).

"In our partnership, the transfer of technology will secure an indigenous Indian capability for series production, maintenance, repair and overhaul capability," says Anders Carp, head of Saab business area Surveillance. "Testing and development of the fighter sensor package will have synergies with the systems developed for Gripen," he adds.

www.saab.com

Advantech Wireless wins multi-million dollar contract for ruggedized military-grade SATCOM terminals and GaN-based amplifiers

Advantech Wireless Inc of Montreal, Canada (which manufactures satellite, RF equipment and microwave broadband communications systems) has received a multi-million dollar contract from a NATO member country to provide its ruggedized military-grade SATCOM terminals including its new lineup of GaN-based solid-state power amplifiers (SSPAs). The firm is providing complete terminals for the tactical environment based on its proprietary antenna control systems and

fully integrated design.

"Advantech Wireless has over 25 years of experience enabling military forces and government agencies, delivering cutting-edge innovations in communications that solve mission-critical communications challenges," says Cristi Damian, VP business development. "These fully integrated all outdoor systems, include advanced modem technology, sophisticated SATCOM antenna control systems, and the state-of-the-art GaN-based solid-

state power amplifiers."

The second-generation GaN-based SSPAs/BUCs (block up-converters) from Advantech Wireless feature what is claimed to be exceptional linearity and operating efficiency. The systems are also said to be the smallest fully integrated units on the market. With built-in design features, they are suitable for harsh environments, Satcom-on-the-Move (SOTM) and man-pack terminal deployments.

www.advantechwireless.com

EPC opens eGaN FET and IC Applications Center in Virginia and appoints senior applications engineer

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 opened an Applications Center in Blacksburg, Virginia that will support R&D on the applications of eGaN transistors and ICs. In addition to traditional FET and IC power conversion applications, GaN technology has enabled emerging applications such as wireless power transfer, LiDAR for autonomous vehicles, and envelope tracking for high-bandwidth 4G and 5G communications.

In support of the center's opening, Suvankar Biswas Ph.D. has been



appointed as senior applications engineer. Dr Biswas' experience includes work involving converter topology for the integration of photovoltaic modules, grid-tied inverters, and storage. He also has research experience in the integration of harvested power in mobile devices, power delivery architecture in mobile platform-level systems, and plug-in hybrid vehicles and their connectivity with the smart grid.

Biswas is an active member of IEEE with numerous peer-reviewed published articles. He obtained his

bachelor of electrical engineering degree from the Indian Institute of Technology Kharagpur and his doctorate degree from the University of Minnesota.

"The opening of the Blacksburg Applications Center is an important component of our continuous efforts to focus on customer partnerships when designing eGaN technology-based solutions and demonstrating eGaN transistors' superior performance over MOS-FETs and LDMOS," says CEO & co-founder Alex Lidow. "We are very pleased to have Biswas joining us at this time of widespread, fast-growing adoption of GaN-based solutions."

www.epc-co.com

EPC development board shows ultra-fast transition capability of eGaN FETs over MOSFETs for LiDAR laser drivers

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA — which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications — has announced the availability of the EPC9126, a 100V high-current pulsed laser diode driver evaluation board.

In a LiDAR system (used for detecting objects in autonomous vehicle applications) speed and accuracy of detection is critical. EPC says that, as demonstrated by the new board, the rapid transition capability of eGaN FETs provides power pulses to drive the laser up to ten times faster than an equivalent MOSFET, enhancing the overall performance of a LiDAR system.

Intended primarily to drive laser diodes, the EPC9126 development board features an EPC2016C ground-referenced eGaN FET driven by a Texas Instruments UCC27611 gate driver. The EPC2016C is a 100V maximum



voltage device capable of current pulses up to 75A with total pulse widths as low as 5ns. The board can accommodate an EPC2001C 100V eGaN FET with a pulse current rating of up to 150A for users needing higher current capability.

The board includes multiple ultra-low inductance connection options for mounting laser diodes and can drive these via a discharging a capacitor (as shipped) or directly from a power bus. The board does not include a laser diode, which must be supplied by the user to evaluate specific applications. The printed circuit board is designed to

minimize the power loop inductance while maintaining mounting flexibility for the laser diode. It includes multiple on-board passive probes for voltages and discharge capacitor current measurement, and comes equipped with SMA connections for input

and sensing designed for 50_ measurement systems. In addition, the user can enable an optional precision narrow pulse generator. Finally, the board can also be used for other applications requiring a ground-referenced eGaN FET, for example in Class E or similar circuits.

The EPC9126 100V high-current pulsed laser diode driver evaluation board is priced at \$181.25 and is available from Digi-Key.

<http://digikey.com/Suppliers/us/Efficient-Power-Conversion.page>
www.epc-co.com/epc/Products/DemoBoards/EPC9126.aspx

GaN Systems releases thermal RC models for transistors to enhance accuracy of power system SPICE simulations

GaN Systems Inc of Ottawa, Ontario, Canada — a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications — says that it has seen a surge in the number of customers designing and deploying power systems using its GaN transistors, as they recognize that GaN devices significantly improve power efficiency and power density. By using GaN transistors instead of legacy silicon components, users can enter the market with 50W–50kW power systems that are up to 5x smaller and 3x lighter, reckons the firm.

To support customers that are modeling new systems using SPICE

simulations, GaN Systems has released individual computer models for each of its products as well as a new application note, GN007 'Modeling Thermal Behavior of GaN Systems' GaNPX Using RC Thermal SPICE Model'. The GN007 application note can be downloaded from the Download section of the company website. Individual models can be downloaded from their respective product page.

GaN Systems' transistors are provided in a feature-rich GaNPX package that is designed for extreme speed and current. The low-profile GaNPX package has high power dissipation and low inductance, which enables fast, MHz power

switching. Users can now verify the package's optimal thermal performance by using the GN007 SPICE model protocol.

"Our customers are constantly pushing on design limits that only our GaN can enable," says Larry Spaziani, VP of sales & marketing. "We've invested in expert thermal simulations that use state-of-the-art finite element analysis (FEA) tools to model our best-in-class power devices," he adds. "The models have been converted into easy-to-use SPICE models and have been verified both in multiple simulation environments and in the test lab."

www.gansystems.com/whitepapers.php

GaN Systems co-founder & CTO delivers WiPDA keynote address showcasing GaN's value to automotive market

GaN Systems' co-founder & chief technology officer John Roberts delivered the keynote address at the 4th IEEE Power Electronics Society Workshop on Wide Bandgap Power Devices & Applications (WiPDA) in Fayetteville in November.

The presentation 'GaN Power Transistors — Powering Up' (to an audience of device scientists, circuit designers, and application engineers) focused on the existing

state of high-current GaN power transistors and discussed how GaN Systems' 100V and 650V GaN transistors can meet automotive power systems requirements.

Roberts has been a champion of gallium nitride technology for over a decade. Over that period, he has spearheaded the research, development, manufacturing and large-scale production of GaN devices that are now being designed into

power systems across the consumer, data-center, industrial, transportation and energy markets.

Roberts shared his perspective on where power design engineers are using GaN transistors to solve power management challenges. He also presented examples where GaN transistors have been used to make systems more efficient, smaller, lighter and less costly.

www.wipda2016.org

Thales to supply GaN-based CWI transmitters to Danish navy for fire control systems

France's Thales Group has been awarded a contract by the Danish Defence Acquisition and Logistics Organization to deliver 14 continuous wave illumination (CWI) transmitters to be integrated in the existing Evolved Sea Sparrow Missile (ESSM) fire control systems on-board the Absalon- and Iver Huitfeldt-class vessels of the Royal Danish Navy.

The CWI transmitter is a component in the fire control chain by providing

the X-band signal to illuminate the threat and allow the ESSM medium-range surface-to-air US missile, to home in on the reflected signal.

Thales's CWI transmitter uses GaN technology and incorporates a proven missile waveform generator (MWFG) building block. The design is scalable to support emerging missile modes and threats.

"The CWI transmitter is an important product in our strategy as it

strengthens our ability to provide complete ESSM fire control solutions in the market," says Geert van der Molen, Surface radars and above water systems VP at Thales in The Netherlands.

Delivery of the first system will be in mid-2019 and the last in 2021. A second contract was signed for the sustainment support of the CWI systems until 2049.

www.thalesgroup.com

ALLOS' doping-free 600V HEMT epi technology running on both Aixtron G5 and Veeco K465i at customer

Project yields performance and cost comparison of two MOCVD platforms for GaN-on-silicon

Technology engineering & licensing firm ALLOS Semiconductors GmbH of Dresden, Germany says the latest generation of its gallium nitride on silicon (GaN-on-Si) process has achieved excellent isolation without doping. Applying this technology, ALLOS recently concluded the development of customized epitaxial structures with very low leakage for a power electronics customer. The epiwafer growth processes were established in the customer's Aixtron G5 and Veeco K465i metal-organic chemical vapor deposition (MOCVD) reactors so, besides providing the desired epiwafer and device performance, the project has also allowed a unique performance and cost comparison of the two major reactor platforms used in the GaN-on-Si industry.

ALLOS says that, since starting its GaN-on-Si epi technology business in 2014, it has invested heavily in technology development and has achieved several breakthroughs. Key elements are very low leakage currents, superior crystal quality, and a focus on manufacturability.

Low leakage is seen as a prerequisite for mass-market adoption of GaN-on-Si for power electronic applications (such as power supplies and motor drives). ALLOS says that its technology fulfills the required low vertical leakage current of less than $0.1\mu\text{A}/\text{mm}^2$ at 600V, while using growth conditions optimized to achieve ALLOS' crystal quality without using carbon or other dopants to isolate the GaN.

Carbon doping became popular in the GaN-on-Si industry in recent years as it can be easily employed to increase isolation. Unfortunately, commonly used techniques to increase carbon levels result in degradation in crystal quality, which can have severe negative side-effects on crucial performance

and quality characteristics, notes ALLOS. Consequently, the firm has worked on novel ways to accomplish very low leakage without compromising crystal quality. The core of these innovations is growing extremely high-quality epilayers without doping, based on ALLOS' patented and proprietary growth techniques and epi structures.

"Another concern many deciders are sharing with us is possible conflicts with incumbents who own strong IP around using carbon doping," says chief marketing officer Alexander Loesing. "Avoiding such conflicts is another benefit of not using carbon."

In parallel, ALLOS continues to implement its 'design for manufacturability' strategy. Features relevant for the epiwafer making process and for using these epiwafers for device production in existing silicon-based processing lines are taken into account and are optimized according to market requirements. ALLOS claims that, using this technology, its customers can produce cost-efficient GaN-on-Si epiwafers of up to 200mm diameter that meet the SEMI-standard specification for thickness and bow, are very reliable in device making, and show excellent electrical performance.

ALLOS' latest technology generation was recently transferred to and adapted for a power electronics customer. The project requirements included developing customized interlayer and superlattice-based epi structures with up to 7 μm total thickness for 150mm and 200mm wafer diameters. Additional project objectives included speci-

fied device-level parameters and establishing the epi process in both the Aixtron G5 and Veeco K465i reactors used for GaN-on-Si by the customer (these two most widely used reactor types in the industry). The same epi structures were grown in both tools, with good, reproducible results, says ALLOS. Differences between results in the two reactors in terms of epiwafer characteristics and device performance were small, and each reactor type showed merits and demerits, the firm comments.

Regardless of hardware and handling differences, ALLOS achieved what are claimed to be industry-leading results in both reactor types. These include crystal quality x-ray diffraction (XRD) full width at half maximum (FWHM) values of 330 arcsec for (002) and 420 arcsec for (102), threading dislocation densities of $2 \times 10^8 \text{cm}^{-2}$, no meltback and no cracks on the entire wafer, tightly controlled bow of less than 30 μm for SEMI-standard thick wafers, mobility of $2000 \text{cm}^2/\text{Vs}$ and sheet resistance of $350\Omega/\text{sq}$. A sheet resistance uniformity of 1.5–3% (standard deviation) was achieved, depending on the platform. All device-level requirements were met, in particular low vertical leakage of $<0.1\mu\text{A}/\text{mm}^2$. Beside these technical parameters, economic factors such as consumption, yield, reliability, maintenance and throughput for each epi process have also been analysed.

"ALLOS' vast experience in installing its technology on many different reactor platforms and the robustness of our technology were essential in achieving the excellent results on the two hardware platforms in this project," says chief technology officer Dr Atsushi Nishikawa. "However, for the first time the same epiwafer structures

Commonly used techniques to increase carbon levels result in degradation in crystal quality

were grown in two alternative reactor types in parallel, and the epiwafers were processed and characterized under equal conditions in the same facility. Based on hundreds of runs, this provides a unique performance and cost comparison of MOCVD reactors to the customer. It also gives them all the information they need for choosing their future production platform," he adds.

The results demonstrate that the choice of the right hardware is

important but not paramount, says ALLOS. In both reactors, superb crystal quality and very low leakage without carbon doping were achieved, and this was possible for both interlayer and superlattice structures. "We often hear that there are demands to purchase new reactors to allow developers to achieve the desired epiwafer quality," says Nishikawa. "Certainly, there are such cases, but often the truth is that you don't need to wait, and

the grass can already today become green regardless of which side of the river you are on," he adds.

"ALLOS remains neutral on reactor platform decisions and guided by our customers' requirements," states Loesing. "We can deliver our technology in any MOCVD reactor the customer might already have, while being able to provide fact-based advice on reactor purchasing decisions in other cases," he adds.

www.allos-semiconductors.com

EpiGaN named to 2017 Global Cleantech 100

At the 15th annual Cleantech Forum San Francisco, EpiGaN nv of Hasselt, near Antwerp, Belgium, which supplies gallium nitride on silicon (GaN-on-Si) and gallium nitride on silicon carbide (GaN-on-SiC) epitaxial wafers for power switching and RF devices, has been named again among the 2017 Global Cleantech 100, produced by San Francisco-based Cleantech Group (CTG).

Featuring companies positioned to solve future clean technology challenges, the Global Cleantech 100 lists private companies with the highest potential for a market impact within a 5–10 year timeframe. The list is collated by combining proprietary CTG research data with weighted qualitative judgments from hundreds of nominations and an 86-person expert panel.

Incorporated in 2010, EpiGaN was founded by chief executive officer Dr Marianne Germain, chief technology officer Dr Joff Derluyn and chief operating officer Dr Stefan Degroote as a spin-off of nanoelectronics research center Imec of Leuven, Belgium. The founders jointly developed GaN-on-Si technology at Imec, part of which has been licensed to EpiGaN. EpiGaN was joined in 2011 by start-up investment firms Robert Bosch Venture Capital, Capricorn Clean-Tech Fund and LRM (to enable the installation of its wafer production facility) and in August 2016 by ACAPITAL. In January 2016, the

firm signed a global representation agreement for its 150mm and 200mm GaN-on-Si power semiconductor product solutions with silicon substrate maker SunEdison Semiconductor of St. Peters, MO, USA.

"Innovating with GaN technology enables drastic energy savings, as well as volume and weight reductions of power systems, enabling miniaturization and significant cost reduction in areas where traditional silicon solutions cannot meet current or future system requirements," says EpiGaN's CEO & co-founder Dr Marianne Germain. "GaN applications are very numerous, ranging from power supply for IT systems to data servers, motor drives or solar inverters, or even wireless charging. EpiGaN's product portfolio covers state-of-the-art solutions for low-loss power switching, radio-frequency/mobile communication power and sensor applications," she adds. "At our production facility in Hasselt (Belgium), we have developed unique GaN-on-Si and GaN-on-SiC technologies, which are more robust and enable a significant increase of the number of chips per wafer. Already available for wafer diameters up to 200mm, our solutions offer the superior material quality and necessary cost-reduction path for expanding the market adoption of GaN technology to more applications," Germain reckons.

To qualify for the CTG list, companies must be independent,

for-profit cleantech companies that are not traded on any major stock exchange. This year, a record number of nominations were received (9900 companies from 77 countries). They were weighted and scored to produce a short list of 325. These nominees were reviewed by CTG's expert panel, resulting in a finalized list of 100 companies from 17 countries.

The 86-member CTG expert panel was drawn equally from leading financial investors and representatives of multi-national corporations and industrials active in technology and innovation scouting across Asia, Europe, and North America. The diversity of panelists results in a list of companies that command an expansive base of support from many important players within the global cleantech ecosystem, says CTG.

"The purpose of the Global Cleantech 100 program is to act as our barometric read on how the facets that contribute to the emergence and maturing of an innovation theme like cleantech are changing year on year," says Cleantech Group's CEO Richard Youngman. "Now in its 8th year, we see more signals of the mainstreaming of clean technologies, sustainability, and resource efficiency towards the point where this is just the normal way of doing business."

www.epigan.com

www.i3connect.com/gct100/the-list

NI AWR Design Environment version 13 adds features and enhancements to boost RF and microwave design engineering productivity

RF/microwave electronic design automation (EDA) software provider NI (formerly AWR Corp) of El Segundo, CA, USA has released Version 13, the first major update in 2017 to the NI AWR Design Environment software portfolio.

V13 provides key new capabilities and major enhancements to better address the design challenges associated with highly integrated RF/microwave components commonly found in communications, phased-array radar and other electronic systems.

Design Environment V13 introduces innovations in design flow management and simulation, supporting monolithic microwave integrated circuit (MMIC), radio frequency integrated circuit (RFIC), multi-chip module (MCM) and printed circuit board (PCB) technologies. Simulation capabilities have been expanded within the Microwave Office APLAC harmonic balance (HB) and Visual System Simulator (VSS) system-level simulation engines and speed improvements have been made to both its AXIEM planar 3D and Analyst arbitrary 3D electromagnetic (EM) solvers.

Design automation and simulation have been enhanced for multi-chip modules, with greater support for multi-technology process design kits (PDKs) within a single project, new support for OpenAccess (schematic) databases and APLAC co-simulation support for Spectre RFIC netlists, as well as simplified EM layout and port creation. For PCB design, a new import wizard supports ODB++ and IPC2851 databases to provide interoperability with mainstream third-party PCB layout tools. New layout editing capabilities have also been added, along with simplified multi-technology management. Furthermore, the new EM Socket II architecture within

V13 offers improved third-party EM simulation flows for AWR Connected partner solutions from ANSYS, CST and Sonnet, giving designers access to alternate EM simulators within NI AWR Design Environment.

V13 addresses specific system requirements with highly accurate simulated RF front-end component measurements provided through new communication libraries for 5G candidate modulation waveforms and phased-array behavioral model enhancements. RF power amplifier (PA) designers can now use the system-level load-pull analysis in VSS to generate contours for communication performance metrics such as adjacent channel power ratio (ACPR) and error vector magnitude (EVM). RF filter designers can take advantage of new capabilities in the iFilter synthesis tool to accelerate their product development and designers of passive and control components such as transformers, couplers and mixers can benefit from the new synthesis capabilities and powerful new optimization methods using proprietary genetic algorithms for more robust designs.

In addition to design automation and simulation enhancements, user support has been expanded to bring new insight to the software in terms of interactive guided help and knowledge base content.

V13's new and expanded features include:

Design Environment V13 introduces innovations in design flow management and simulation, supporting MMIC, RFIC, multi-chip module and printed-circuit board technologies

Design Environment and Automation:

- advanced multi-technology project support;
- new optimization methods;
- iFilter adds transmission zeros;
- OpenAccess schematic import/export;
- graph marker improvements;
- marching waveforms for HB/transient analysis;
- additional synthesis wizards (passives and mixers).

Circuit/System Simulation and Models/Libraries:

- transient and transient-assisted HB (TAHB) improvements;
- expanded circuit envelope simulation;
- passive model enhancements;
- spectre netlist co-simulation;
- new 5G candidate waveform library;
- new system load pull (ACPR, EVM) and nested source/load pull;
- enhanced LTE-A, radar and phased array model libraries.

EM Simulation and Modeling:

- simulation speed and solver improvements (meshing, ports and matrix solve);
- improved AFS algorithms;
- improved EM ports;
- analyst surface roughness model;
- new 3D editor commands;
- enhanced bi-directional links to HFSS, CST and Sonnet.

Physical Design and Layout:

- PCB layout import (ODB++ and IPC2851);
- expanded shape preprocessor modifier;
- enhanced layout editing.

User Support:

- new guided help (GH) interactive documentation;
- enhanced online knowledge base (KB).

NI AWR Design Environment V13 is available immediately for existing customers.

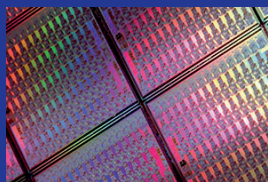
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AXT's Q4 revenue up 12% year-on-year to a higher-than-expected \$20.3m

Full-year loss of \$2.2m in 2015 turned into \$5.6m profit in 2016

For fourth-quarter 2016, AXT Inc of Fremont, CA, USA — which makes gallium arsenide, indium phosphide and germanium substrates and raw materials — has reported revenue down 7.3% on \$21.9m last quarter to \$20.3m. This included \$4.3m from raw material joint ventures (down 12.2% on \$4.9m last quarter) and \$16m from substrate sales (down 5.9% on \$17m last quarter). However, Q4 revenue is up 12% on \$18.1m a year ago, and above the \$18.5–19.5m guidance.

Of total revenue, North America comprised 6% (down from 11% last quarter), Asia Pacific 71% (up from 66%) and Europe 23% (level). No customer generated more than 10% of revenue (compared with one last quarter), while the top five generated about 35% of revenue (down from 38%), showing diversification of products and customers.

After a modest decline in InP sales in Q3 (while the GPON and EPON markets in China took a pause to rebalance after two years of strong growth), InP bounced back in Q4 as AXT continues to benefit from the demand for passive optical network (PON) equipment. InP remains about 30% of total revenue, although semi-insulating and semiconducting GaAs combined is still bigger. Sales of semi-insulating GaAs showed weakness in Q4 due to short-term events or adjustment at customers, while sales of semiconducting GaAs were generally flat on last quarter, supported largely by demand from traditional markets.

"Positive Q4 results capped off a year of growth and diversification," says CEO Morris Young. Full-year revenue grew 4.9% from \$77.5m in 2015 to \$81.3m in 2016. Specifically, substrate sales grew by 12.7% from 2015's \$58.2m to \$65.6m. However, revenue from raw material joint ventures fell by 18.6% from \$19.3m to \$15.7m. This was due

mainly to gallium pricing falling by 30% in first-half 2016 (leading AXT to furlough one of its gallium factories for about 6 months), although it has recovered by 10–15% since bottoming in September/October. "We saw healthy demand across our substrate product portfolio, driven by a growing number of exciting technology applications."

"We continued to demonstrate improvement in our business model, achieving meaningful gross margin expansion and delivering solid profitability and positive cash flow," notes Young.

Gross margin has grown further, from 17.1% a year ago and 34.6% last quarter to 37.1% (the highest seen in many years), due to favorable product mix and good progress in manufacturing efficiency programs implemented over the last 18 months as well as yield improvements. Full-year gross margin rose from 21.7% in 2015 to 32.4% in 2016.

Operating expenses rose only slightly, from \$4.8m a year ago and \$4.9m last quarter to \$5.2m. Despite this, full-year operating expenses have been cut from \$21.7m in 2015 to \$20m in 2016.

Net profit was \$2.2m (\$0.06 per diluted share, exceeding guidance of \$0.02–0.04), level with \$2.2m (\$0.07 per diluted share) last quarter but improving on a loss of \$1.2m (\$0.04 per diluted share) a year ago. Compared with a net loss of \$2.2m (\$0.07 per basic share) for full-year 2015, full-year 2016 saw a net profit of \$5.6m (\$0.17 per diluted share).

Depreciation and amortization was steady at \$1.3m. Capital expenditure (CapEx) rebounded from just \$0.5m last quarter to \$0.9m (amounting to less than \$4m for full-year 2016, below the usual \$4–6m annually). During the quarter, cash, cash equivalents and investments hence rose \$6.4m from \$47.3m to \$53.7m.

"Improvement in the second half of

Q4 is encouraging, but a bit more time perhaps is needed to sort out the inventories," comments Young. "As InP remains as an emerging material, we expect to see some lumpiness in our sales of the InP product in any give quarter but feel confident that InP will be a primary source of growth and opportunity in our business for the foreseeable future [as we look ahead in 2017," he adds. "We also hope to see traction in the 3D sensing market later this year [boosting GaAs sales]."

For Q1/2017, AXT expects revenue of \$19.5–20.5m (similar to Q4) but earnings per share to drop to \$0.02–0.04 as gross margin falls back from the recent peak to the low 30s. Specifically, InP revenue will fall slightly, but semi-insulating GaAs sales should rebound (after customers rebalanced inventory) while semiconducting GaAs revenue is roughly flat. Germanium revenue should rise slightly, as satellite activity is strong. Raw materials revenue will be flat to down slightly.

"The industry transition from the 2.5G to 10G PONs will provide further growth opportunities in second-half 2017," believes Young.

"We're watching with interest the continued market development of VCSELs for 3D sensing applications such as gaming, mobile phones, smart TV's, high speed communications and high-power material processors," Young says. "We will see meaningful revenue traction in 3D sensing applications beginning in late 2017 and are preparing our business today for increased demand, including R&D investments, capacity planning and sales readiness," he adds. "The competitive landscape of substrate suppliers that can meet this specification is limited. Therefore we expect to be a player in this market and view this opportunity as another exciting growth driver."

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SPTS president Kevin Crofton appointed chairman of UK's Compound Semiconductor Applications Catapult

Kevin Crofton has been appointed the chairman of the Compound Semiconductor Applications Catapult (based in South Wales), which will be the 11th Catapult to be established by UK Government agency Innovate UK. The Catapults comprise a network of centers where UK businesses, scientists and engineers work side by side on late-stage R&D, with the aim of transforming high-potential ideas in specific areas into new products and services, helping to drive future economic growth. The UK national Compound Semiconductor Applications Catapult was announced in early 2016, backed by government funding of £50m (£10m per year up to 2020–21) and spearheaded by epi-wafer foundry and substrate maker IQE plc of Cardiff, Wales, UK and Cardiff University.

Crofton is corporate VP of Orbotech Inc (which provides PCB and FPD inspection and repair equipment for the packaging sector) and president of SPTS Technologies Ltd of Newport, Wales, UK, an Orbotech company that manufactures etch, physical vapor deposition (PVD) and chemical vapor deposition (CVD) and thermal wafer processing solutions for the MEMS, advanced packaging, LED, high-speed RF on GaAs, and power management device markets). Crofton is also a member of the board of directors of global industry association Semiconductor Equipment and Materials International (SEMI), and is board chair of the governing council of the



Kevin Crofton.

MEMS Industry Group, as well as participating and presenting at SEMI, MEMS and 3D-IC/TSV forums.

It is reckoned that Crofton's 25 years of experience in the semiconductor capital equipment sector (including executive roles in the USA and UK) and his insight in the rapidly growing compound semiconductor market will be invaluable in establishing the Catapult within the compound semiconductor cluster in South Wales.

"Kevin's experience and expertise will spearhead the development of the new Catapult, and ensure we are maximising the business opportunities from the important compound semiconductors market," comments Innovate UK's chief executive Ruth McKernan.

The global market for compound semiconductors is forecast to rise to £75–125bn by 2025, according to data from BCC Research and MarketsAndMarkets. It is reckoned that, due to its research base in this field (which has led to the creation of many companies along the value chain), the UK has the potential to take advantage of this market opportunity. "The Government's investment in the Compound Semiconductor Application Catapult (CSAC) is testament to our track record as a leader in advanced electronics — a strength that we

will build on through our Industrial Strategy to ensure that the UK remains at the forefront of innovation," states the UK's Universities and Science Minister Jo Johnson. "The appointment of Kevin Crofton as chair and his wealth of industry experience will help drive this and continue the Catapult's vital role in developing new technologies."

"Much of the advance technology powering our mobile phones and other devices is being pioneered right here in Wales," says Secretary of State for Wales, Alun Cairns. "We have a highly skilled workforce here in Wales and innovations like the catapult will lead to the creation of high-skilled and high-paid jobs," he adds. "This is the first Catapult to be located in Wales," notes Wales' Skills & Science Minister, Julie James. "The Compound Semiconductor Applications Catapult is a key pillar in the development of the world's first compound semiconductor cluster, which recognizes the industrial strength around the M4 corridor and the economic impact that this technology will bring," he adds.

"We expect the Catapult to bridge some of the primary research, development and test challenges that exist in the UK compound semiconductor sector," says Crofton. "We expect to help to accelerate innovation among existing companies and to aid spin-out companies in their success."

www.catapult.org.uk/catapult-centres/compound-semiconductor-applications-catapult

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Cardiff University's Institute for Compound Semiconductors receives £13m EU funding

Funding to help build, equip and run cleanroom

The European Union has awarded £13m in funding to the new Institute for Compound Semiconductors (ICS), based at Cardiff University's Innovation Campus. The funding will contribute to building, equipping and running a cleanroom.

As a UK-based translational research center in compound semiconductors, ICS aims to turn its laboratory research into products and services by working with commercial partners.

"Investing in world leading facilities so that academia and industry can collaborate and drive forward research in this sector will be an important boost to the Welsh economy," says Mark Drakeford AM, Cabinet Secretary for Finance and Local Government in the Welsh Government. "This EU funding will encourage high-quality well-paid employment in the participating companies and the creation of spin-out companies, new start-ups as well as attracting innovative compound semiconductor companies from across the UK and Europe," he adds.

"This EU funding is a vital component in our bid to generate prosperity in South Wales through industrial innovation," comments professor Colin Riordan, president & vice-chancellor of Cardiff University. "By investing in high-quality facilities and talented researchers, and by building long-standing commercial partnerships, Cardiff University's Innovation System will help deliver prosperity for Wales," he believes.

"The role of compound semiconductors as an enabling technology for a wide range of next-generation applications, from high-speed communications to autonomous vehicles, is widely acknowledged worldwide, with major initiatives underway by blue-chip organizations, academic institutions and government agencies, particularly in Asia and the USA," notes Dr Drew Nelson, CEO of Cardiff-based epiwafer foundry and substrate maker IQE plc, which is a partner with Cardiff University in the joint venture Compound Semiconductor Centre (CSC) formed in August

2015. "In Europe, Wales is uniquely positioned with a critical mass of compound semiconductor expertise to exploit the enormous commercial opportunities that will doubtlessly be generated," he adds. "Today's announcement of £13m investment by the Welsh European Funding Office (WEFO) significantly adds weight and credibility to Wales becoming a global hub in this key enabling technology that will drive innovation over the coming years and decades."

The funding builds on long-running work between Cardiff University, IQE, and the Welsh and UK Governments to develop a hub of compound semiconductor expertise in South Wales, and includes awards of £17.3m from the UK Research Partnership Investment Fund and £12m from Welsh Government to support the development of the wider ICS facility.

www.cardiff.ac.uk/innovation/campus-investment/translational-research-facility/institute-for-compound-semiconductors

IQE honoured at the European Business Awards

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK was honored at an event on 30 November at London Stock Exchange for The European Business Awards (sponsored by RSM).

IQE was one of 55 European firms chosen by a panel of independent judges (including senior businesses and academic leaders) to be 'National Champions' in Europe's largest business competition. IQE was recognized for its close work with the Welsh Government and Cardiff University to achieve "key milestones in developing an advanced, high-tech manufacturing capability with the vision of establishing the world's first Compound Semiconductor Cluster in Wales".



Chris Meadows (middle) collecting the 'National Champions' certificate from representatives of sponsor RSM.

IQE will now represent the UK in the next stage and put forward a video giving an insight into the story of its business and success. Competing against all other country National Champions for the public

vote, the firm with the most votes will be named 'National Public Champion' for The UK at the Gala Final in spring 2017. The first phase of online voting is now open.

The second public vote will see all of the National Public Champions from different countries compete against each other to become the overall European Public Champion.

The European Business Awards were established to support the development of a stronger and more successful business community in Europe. This year it engaged with over 33,000 firms in 34 countries.

www.iqep.com
www.businessawardseurope.com/vote/detail-new/united-kingdom/20779

Veeco's Q4 revenue grows 9% to \$93.6m

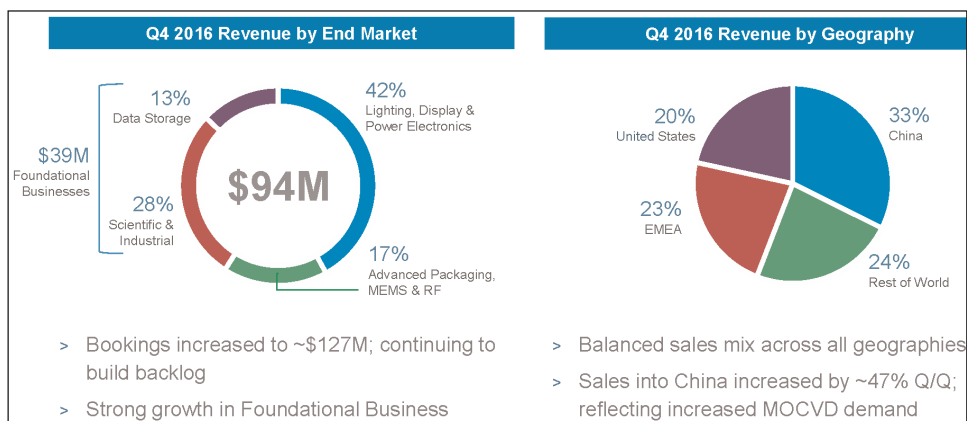
Revenue to rise significantly from Q3/2017 with sharp recovery in MOCVD shipments forecasted

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue for full-year 2016 of \$332.5m, down 30% on \$477m for 2015.

Specifically, the Lighting, Display & Power Electronics segment has fallen from 61% of total revenue to 41%. In contrast, evidencing diversification of Veeco's business, revenue for the Advanced Packaging, MEMS & RF segment grew by 10% — rising from 13% to 21% of total revenue — reflecting further penetration of Precision Surface Processing (PSP) systems into Advanced Packaging applications across multiple customers. Veeco's Foundational Businesses contributed 38% of total revenue (\$128m), including the Scientific & Industrial segment rising from 13% to 22% (the highest-revenue year for MBE since 2012) and the Data Storage segment from 13% to 16%.

Correspondingly, by geographical region, the China market plummeted from 51% to 26% of total revenue, as the USA rose from 18% to 26%, the Europe, Middle East & Africa (EMEA) from 13% to 25%, and the rest of the world from 18% to 23%.

However, for fourth-quarter 2016, revenue was \$93.6m, down 12% on \$106.5m a year ago but up 9% on \$85.5m last quarter. Specifically, Advanced Packaging, MEMS & RF grew sequentially by about 30%, rebounding from 14% to 17% of total revenue, led by PSP sales to RF filter manufacturers. Foundational Businesses rebounded strongly from \$24m last quarter to \$39m, rising from 28% of total revenue to 41%, including Scientific & Industrial rebounding from 16% to 28% (supported by shipments of MBE systems for high-power laser diode applications) and Data Storage rising slightly from 12% to 13%. Lighting, Display & Power Electronics comprised 42% of total revenue, as



Veeco continues to ship metal-organic chemical vapor deposition (MOCVD) systems from previously announced orders.

By geographical region, China has rebounded from 25% of total revenue last quarter to 33% (reflecting an increase in MOCVD demand driving China revenue up by 47%). EMEA was unchanged at 23% while USA fell from 22% to 20%, and the rest of the world (including Southeast Asia and Japan) fell back from 30% to 24% of total revenue.

"Fourth quarter financial results marked a strong finish to a challenging year," comments chairman & CEO John R. Peeler.

"While down 30% year-on-year [in annual revenue], we took the challenge by focusing on operational execution and reducing our cost structure," says chief financial officer Shubham Maheshwari.

On a non-GAAP basis, gross margin was 39.2% for Q4/2016, down from 40.3% last quarter (reflecting the impact of duplicate expenses incurred for the manufacturing consolidation initiative) but up from 36.8% a year ago. Full-year gross margin has risen from 38% for 2015 to 40.8% for 2016. "We improved gross margins for the third consecutive year, delivering on our objective to achieve gross margins of 40% or better," notes Peeler. The performance "underscores our focus on improving through-cycle profitability," he adds.

Reflecting the momentum of cost-reduction efforts, operating expenses have been cut from \$38m a year ago and \$34.6m last quarter to \$33m in Q4/2016 (with R&D expenses cut from \$19.3m a year ago to \$17.2m, and selling, general & administrative and other expenses cut from \$18.7m a year ago to \$15.7m). Full-year operating expenses were cut from \$151.6m in 2015 to \$144m in 2016, despite R&D expenses rising from \$74.5m to \$77.7m, since selling, general & administrative and other expenses were cut from \$77.1m to \$66m (reflecting a partial-year impact of cost-reduction efforts).

Compared with net income of \$22.1m (\$0.54 per diluted share) in 2015, full-year 2016 saw a net loss of \$11.3m (\$0.29 per diluted share). However, for Q4/2016 Veeco has reported net income of \$3.8m (\$0.09 per diluted share), exceeding the original guidance of between a loss of -\$3m (\$0.07 per share) and a profit of +\$3m (\$0.07 per share). This compares with income of \$0.6m (\$0.01 per diluted share) a year ago and a net loss of \$1.8m (\$0.05 per diluted share) last quarter.

Adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) for Q4/2016 was \$6.2m, up from \$4.4m a year ago and doubling from \$2.9m last quarter. Full-year adjusted EBITDA was \$4.2m, down from \$41.7m in 2015.

During Q4/2016, cash, cash equivalents and short-term invest-

ments rose by \$7m from \$337m to \$344m. However, for full-year 2016, Veeco used \$24m of net cash in operations, as it insourced manufacturing of certain Ion Beam products and made capital investments in R&D to support product development in Advanced Packaging and Power Electronics.

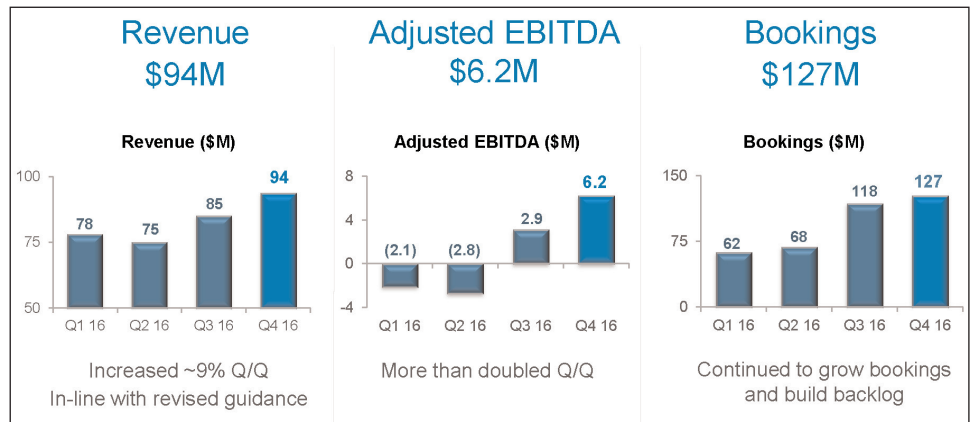
Order bookings were \$127m in Q4, up 7% on \$118m last quarter and 18.7% on \$107m a year ago, bolstered by continued momentum in Lighting, Displays & Power Electronics as well as a strong performance in the Scientific & Industrial markets. Order backlog by \$32m from \$177m last quarter to \$209m.

"Entering 2017, we are seeing healthy LED industry dynamics and positive business momentum," says Peeler.

During Q4/2016, Veeco secured its largest ever single business deal — an exclusive, multi-year agreement with Germany's Osram Opto Semiconductors GmbH to supply MOCVD and PSP systems for its new high-volume LED production facility in Kulim, Malaysia (comprising a large proportion of Q4 bookings). "We expect to ship a majority of the systems for that fab in second-half 2017, as per their current ramp plans," notes Maheshwari. "You should expect us to carry this backlog for a couple of quarters, and as a result we currently see our Q2 revenues tracking flat to Q1," he adds.

Supported by strength in MOCVD business, for Q1/2017 Veeco expects revenue of \$85–100m, roughly flat quarter-to-quarter despite Q1 revenues normally being seasonally lower compared with Q4. Gross margin should be 38–40%. "We are still incurring duplicate expenses associated with manufacturing consolidation, which is having a temporary slightly negative impact [of 1%]," notes Maheshwari. "Gross margins should begin to improve from Q2 once this consolidation initiative is behind us... We remain committed to our gross margin goal of 40% or above [for full-year 2017]."

OpEx should be cut further in Q1, to \$31–32m. Net income should be



\$0–6m (\$0.00–0.16 per share).

Adjusted EBITDA will be \$5–11m.

"LED industry momentum continues to remain strong, and we expect to further build backlog in Q1," says Maheshwari. Revenue is therefore expected to improve significantly from Q3/2017.

"In the TV markets, tight supply for LCD panels has led to higher pricing and improved profitability for the panel manufacturers," notes Peeler. Market research firm IHS projects that panel supply will remain constrained over the next couple of years, which has spurred plans for new capacity in China. "At the same time, demand has rapidly shifted to larger-size panels and 4K TVs, which require 30–35% more LEDs per unit," he adds. "We are also seeing positive demand trends for fine-pitch digital signage." Revenue from fine-pitch LEDs is forecasted to rise at a compound annual growth rate of 25% through 2020.

"These large-scale displays are rapidly being adopted for both indoor and outdoor use, and demand for fine-pitch LEDs has increased more quickly than anticipated. As a result, we've seen higher MOCVD utilization rates at second-tier LED manufacturers [especially in China] to support this growing demand," says Peeler. "These positive trends for LED unit demand also bode well for the MOCVD industry. Analysts are forecasting a sharp recovery in MOCVD reactor shipments in 2017."

"Last year, there were only about 110 K465i-equivalent MOCVD reactors shipped into the customer base. We estimate 180–260 K465i-equivalent reactors will ship in 2017,

and Veeco is poised to benefit," reckons Peeler. "We are the industry leader in blue LEDs for the fifth consecutive year, and we continue to win business across the breadth of LED manufacturers. For example, we recently displaced the long-standing incumbent at one of the last remaining customers who had not switched to EPIK," he adds. "We're targeting red, orange, yellow LED opportunities with our K475i [arsenic phosphide (As/P)] MOCVD system, and while it will take a while to build share, we are making good progress. Since launching the product last year [in February 2016], we've successfully penetrated five customers, and secured follow-on business from each."

In mid-January, Veeco completed a public offering of six-year convertible notes, maturing in 2023 (upsized from \$230m to \$345m), which netted proceeds of \$336m. These will be used to finance the acquisition (agreed at the beginning of February) of Ultratech Inc of San Jose, CA, USA (which designs and makes lithography, laser-processing and inspection systems used to manufacture microelectronic devices and LEDs) for about \$815m.

"Ultratech will establish Veeco as a leading equipment supplier to the Advanced Packaging industry," says Peeler. The proposed combination is expected to "increase our scale, diversify our revenue and provide a stable platform to drive long-term shareholder value," he adds. Subject to regulatory clearance and approval by Ultratech's stockholders, the deal is expected to close in Q2/2017.

www.veeco.com

Veeco to acquire Ultratech for \$815m

Veeco has signed a definitive agreement to acquire Ultratech Inc of San Jose, CA, USA, which designs and makes lithography, laser-processing and inspection systems used to manufacture microelectronic devices and LEDs. The boards of directors of both firms have unanimously approved the deal.

Ultratech shareholders will receive (i) \$21.75 per share in cash and (ii) 0.2675 of a share of Veeco common stock for each Ultratech share outstanding. Based on Veeco's closing stock price on 1 February, the transaction is valued at about \$28.64 per Ultratech share. The total transaction is hence valued at about \$815m and the implied enterprise value is \$550m, net of Ultratech's cash balance at end-December 2016. Post transaction, it is projected that Ultratech shareholders will own about 15% of the combined firm.

Ultratech provides lithography equipment for advanced packaging applications and for LEDs, and is a

pioneer in laser spike anneal technology used for the production of microelectronic devices. In addition, it offers wafer inspection solutions leveraging its proprietary coherent gradient sensing (CGS) technology that address a wide variety of semiconductor applications.

"The strategic combination will establish Veeco as a leading equipment supplier in the high-growth advanced packaging industry," reckons Veeco's chairman & CEO John R. Peeler. "Ultratech's leadership in lithography together with Veeco's Precision Surface Processing (PSP) solutions form a strong technology portfolio to address the most critical advanced packaging applications," he adds. "Our complementary end-market exposure and customer relationships will create the ideal platform to accelerate growth," he believes. "Ultratech is a great fit with our strategy to profitably grow our business and diversify our revenue. We expect this transaction to be immediately

accretive to adjusted EBITDA and non-GAAP EPS," concludes Peeler.

"Both companies have a strong heritage of developing innovative and cutting-edge technologies," comments Ultratech's chairman & CEO Arthur W. Zafiropoulos. "The combined company will create a formidable team to execute against growth opportunities and deliver significant value to customers and shareholders," he believes.

Veeco expects to realize about \$15m in annualized run-rate synergies within 24 months after closing the acquisition (expected in second-quarter 2017, subject to approval by Ultratech shareholders, regulatory approvals in the USA, and other customary closing conditions). This should be achieved through increased efficiencies and leveraging the scale of the combined businesses. The combined firm is expected to have an efficient balance sheet, benefiting from the deployment of excess cash.

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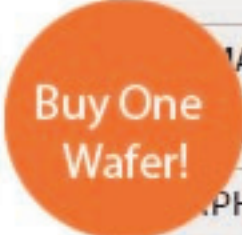
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| ITO GLASS | 500 | | | |
| LINBO3 | | | | |
| NITRIDE ON SILICON | | | | |
| SAPPHIRE | | | | |
| SILICON | | | | |

Hitachi and Picosun collaborate on PE-ALD

Hitachi High-Technologies Corp of Tokyo, Japan and Picosun Oy of Espoo, Finland have announced a technical cooperation on plasma-enhanced atomic layer deposition (PE-ALD) to advance thin-film coating using their jointly developed microwave electron cyclotron resonance (ECR) ALD technology.

In the PE-ALD reactor, Hitachi High-Tech's ECR plasma generator is integrated with Picosun's industry-proven, digitally controlled ALD system. The firms say that the quality of the deposited materials is consequently substantially better, and claim that the deposition process is more precise than exist-

ing traditional ALD and plasma-enhanced ALD methods.

The firms add that superior results for various nitride and oxide films have already been confirmed on 300mm wafers, and other process applications are under evaluation.

www.hitachi-hightech.com/global
www.picosun.com

Riber receives order for research MBE system

Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has received an order from Ohio State University for a Compact 21DZ MBE system, for delivery in 2017. The system will be used for research on infrared imaging sensors and other advanced semiconductor devices, using anti-

mony-based compounds.

The Compact 21DZ system is a part of a new generation of the Compact21 series, which has seen strong commercial development since its launch, says Riber. With more than 125 systems installed worldwide, the active fleet of Compact 21 systems lays a solid foundation for the development of services and component activities,

reckons the firm.

The latest commercial success in the USA coincides with the increased scale up of US subsidiary Riber Inc following the acquisition of MBE Control Solutions of Santa Barbara, CA, USA in 2015. This also strengthens the international recognition of Riber's solutions dedicated to research.

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ClassOne to reduce cost of operation for copper plating

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 a new company-wide initiative to reduce costs of operation (CoO) in copper plating processes.

"From the beginning, our mission has been to bring more advanced and lower priced plating capabilities to all the emerging markets who work with smaller wafers," says president Kevin Witt. "Our Solstice systems are already the industry's most affordable tools for $\leq 200\text{mm}$ plating," he claims. "Now we want to enable economies on the cost of ownership side, as well — perhaps reducing those expenses by as much as 25–30%."

The firm sees potential for shrinking copper plating CoO by reducing chemical consumption, extending



ClassOne's Solstice plating system.

the life of consumables and equipment parts, increasing and optimizing throughput, and enhancing chamber performance, among other areas. Company representatives stated that they are working toward innovative ways to increase

efficiencies, minimize waste, streamline operation and optimize performance in each of the copper plating processes.

"Copper plating is an extremely hot area of interest right now in a great many emerging markets," notes Witt. "That's why ClassOne focuses serious attention on it. We want to continue to be the go-to guys for absolutely everything having to do with copper plating on smaller wafers," he adds. "That's why you'll be seeing more new copper-related announcements coming from ClassOne in the coming weeks and months."

ClassOne Technology offers new wet processing tools specifically designed for users of 75–200mm wafers, including three different models of Solstice electroplating systems for production and development as well as the Trident families of spin-rinse-dryers and spray solvent tools.

www.classone.com/products

Entegris launches higher-purity gas purification system platform as it expands manufacturing in Asia

Entegris Inc of Billerica, MA, USA, which provides specialty chemicals and materials handling solutions, has launched a new platform for gas purification that improves wafer yields for semiconductor and LED applications.

Displayed at the SEMICON Korea 2017 trade show in Seoul (8–10 February), the new family of GateKeeper gas purification systems (GPS) applies new purification media to provide what is claimed to be best-in-class gas purity at a wide range of flow rates with a reduced equipment footprint. With expanded capacity in South Korea, Entegris now manufactures GateKeeper GPS systems in both North America and Asia.

"Our customers face unprecedented contamination control challenges to efficiently manufacture today's

increasingly complex leading-edge-devices," says Clint Haris, senior VP of Microcontamination Control.

"The new GateKeeper GPS family of systems provide the advanced solutions required to maximize yield in these environments," he adds. "In conjunction with these new technology introductions, we continue our investments in our North America and Asia facilities to expand our global service and manufacturing capabilities."

Semiconductor processes for advanced nodes, as well as LED manufacturing requirements, call for increased purity to remove defect-causing contaminants found in process gases. The GateKeeper GPS family of systems removes a variety of contaminants from gas streams down to the parts-per-trillion level and can be configured to

a wide range of flow rates. Gases purified include CDA, N_2 , H_2 , H_2 for extreme ultraviolet (EUV), Ar and NH_3 . Additionally, manufacturers are looking for tools that require significantly less sub-fab floor space. The reduced footprint allows users to devote valuable sub-fab floor space to other tool needs or increase purification capacity with additional systems.

"We collaborated closely with our customers to identify purity requirements to meet their need to remove new contaminants and increased sensitivity to known contaminants," says Jordan Ruple, director of Gas Purification Product Management. "As a result, we are proud to be the first to offer this level of purity — in a variety of gases and flow rates — for systems of this size," he adds.

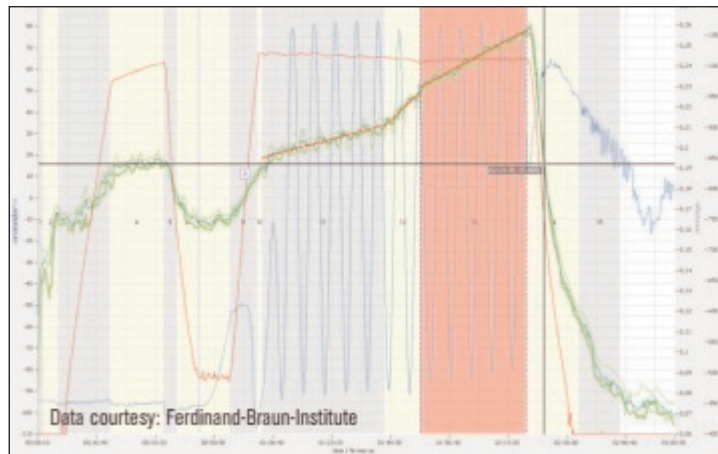
www.entegris.com

LayTec's EpiNet 2017 software enables in-situ wafer bow measurement in multi-pocket satellite configuration

In-situ metrology system maker LayTec AG of Berlin, Germany says that the new release of its control and analysis software EpiNet 2017 provides a solution for the problem that, while in-situ reflectance and temperature on a multi-pocket satellite susceptor can be measured very accurately, in-situ curvature monitoring is trickier because it is rather challenging to find the wafer center.

In the susceptor layout for a gallium nitride (GaN)/sapphire run at Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH), pocket #8 was loaded with a single 2" reference wafer, pockets #5 and #6 contain three 2" wafers each, and pockets #1-4 and 7 have dummy wafers.

In the Figure, the wafer bow signals of the pockets loaded with



In-situ measurements of GaN/sapphire run (standard buffer growth on sapphire as used for LEDs): green transients – curvature signals; red – temperature; blue – reflectance. Curvature signals of the three loaded pockets are in good compliance. The signal-to-noise ratio stays within spec also on multi-pocket satellites.

epitaxial wafers are compared. The values of the multi-pockets comply

nicely with those of the single-pocket, says LayTec. Analytical functions for wafer bow such as curve slope (marked by a red line) work well for both single- and multi-pocket.

In addition, the signal-to-noise ratio (SNR) of the measurements on multi-pockets (shown without filtering) stays within spec (like that of the

single-wafer pocket).

www.laytec.de/epinet

MIT optimizes QCL epitaxy using LayTec's EpiCurve TT

Metrology system maker LayTec AG of Berlin, Germany says that new in-situ results by Dr Christine Wang and colleagues at the MIT Lincoln Laboratory in the USA have been presented in a recent paper (Wang C.A. et al, 'Sensitivity of heterointerfaces on emission wavelength of quantum cascade lasers', Journal of Crystal Growth (2016); <http://dx.doi.org/10.1016/j.jcrysgro.2016.11.029>).

The team worked on improving metal-organic chemical vapor deposition (MOCVD) growth of indium phosphide (InP)-based quantum cascade lasers (QCLs) in a Veeco D-125 multi-wafer (3x2") reactor. Wang reported two major findings: (1) The growth of high-performance QCL structures requires the deposition of a complex sequence of coupled quantum wells (AlInAs, GaInAs). During this process, the cumulative indium surface segregation must be carefully compensated in the growth recipe to keep

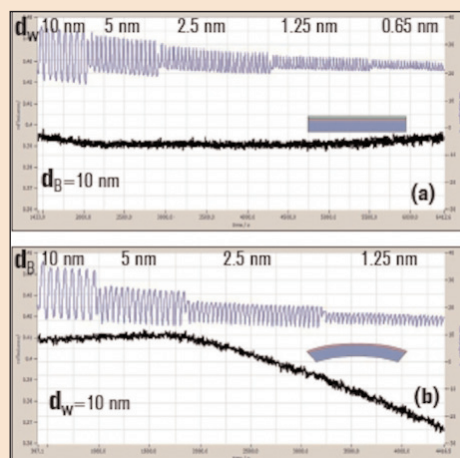


Figure 1: In-situ measurements of AlInAs/GaInAs MQWs: reflectance at 450nm (blue) and wafer curvature (black): (a) varying GaInAs well layer thickness d_w with constant 10nm AlInAs barrier layer thickness d_b ; (b) varying AlInAs barrier layer thickness d_b with constant GaInAs 10nm well layer thickness d_w .

the targeted lattice matching throughout the full QCL structure. (2) Even under optimized growth

conditions, a certain interface grading is unavoidable, especially at the GaInAs-to-AlInAs interfaces. However, optimum QCL performance can be achieved by taking into account these interface grading effects in the calculations of the QCL target structure.

EpiCurve TT was the key to these findings. Figure 1(a) shows in-situ reflectance at a wavelength of 450nm and the curvature of the two decisive MQW runs. Reflectance oscillations correspond to each barrier and well layer, and each layer is easily resolved. In figure 1(b), the high-resolution wafer bow sensing verified the compressive strain accumulation at the AlInAs-to-GaInAs interface.

After recipe optimization, the 450nm reflectance could be used as a characteristic finger-print of the formation of every single graded interface among the hundreds constituting a single QCL layers.

www.laytec.de/epicurve

BluGlass reports half-year financial results

In its interim report for fiscal first-half 2017 (to end-December 2016), BluGlass Ltd of Silverwater, Australia — which was spun off from the III-nitride department of Macquarie University in 2005 — has reported that revenue fell by \$198,367 (13.6%) to \$1,260,579. However, this was due to the lack of any government grants (which totalled \$192,479 in the prior half year).

The firm's principal activity during the half year was the further development and commercialization of remote-plasma chemical vapor deposition (RPCVD) technology for manufacturing epitaxially grown gallium nitride at low temperature on glass substrates. BluGlass is also engaged in research to develop other high-efficiency nitride devices.

Gross expenditure has risen by \$106,089 (3.3%), as employee benefits expense rose by 7.7% to \$1,352,667 (up from \$1,255,294). Patent and trademark expenses doubled from \$67,270 to \$145,688.

Consolidated loss was \$2,062,428, up 17.3% from \$1,757,972. However, in the half year, net assets rose from \$14,236,750 to \$20,177,030.

In fiscal first-half 2017, BluGlass achieved a number of key technical and commercial milestones that have brought the firm closer to its commercialization goals.

In September, BluGlass said that it had commissioned its upgraded RPCVD chamber (the smaller of BluGlass' two RPCVD systems) designed to help address the scalability and uniformity of RPCVD that is required for commercial demonstrations. The upgraded chamber was designed to build on and improve on past performance data as well as create a platform RPCVD design that can be easily scaled to larger deposition areas. Subsequently, at its annual general meeting (AGM) in November, BluGlass was able to show good initial thickness uniformity improvement demonstrated by the new deposition chamber. It has since made further improvements in thickness uniformity to a level that

satisfies requirements for industry demonstrations for 2" wafers.

In October, BluGlass said that it had completed the technology demonstration outlined in Phase I of its Exclusive Evaluation Agreement with LED maker Lumileds of San Jose, CA, USA. The two firms are now collaborating on Phase II of the evaluation, where Lumileds will further investigate the integration of BluGlass' RPCVD technology in its LED applications.

Also in October, BluGlass raised AUS\$5m in an institutional placement to support its three existing evaluation and collaboration agreements, and to enable it to explore additional strategic industry discussions and opportunities.

Following the AGM in November, George Venardos retired from the board after serving as non-executive director since December 2008 then chairman for the last six years. His replacement is Dr William Johnson (previously a non-executive director, joining the board in 2010). Johnson has experience of business development, mergers & acquisitions (M&A), IP commercialization and hands-on leadership in operations ranging from high-tech start-ups to Fortune 500 high technology firms, including as president & CEO of semiconductor processing equipment maker SPTS Technologies.

In November, BluGlass announced an order commitment from a new customer worth about \$600,000 for specialist epi (foundry) development (for delivery over 12 months). The UK-based customer is developing GaN technology targeting LEDs and other applications. BluGlass has placed additional emphasis in fiscal 2017 on growing its foundry business, which is introducing BluGlass to new and emerging applications including novel LED, μ LED, laser diode and power electronic applications.

Scaling the BLG-300 is also critical for other industry projects (IQE, Veeco and HC Semitek)

In November, BluGlass entered into a collaboration agreement with epi foundry and substrate maker IQE plc of Cardiff, Wales, UK to develop specific enabling technology for nitride films deposited by RPCVD on silicon wafers and on specially engineered cREO (rare earth oxide)-on-silicon substrates. "BluGlass' world-leading RPCVD technology is highly complementary to IQE's existing technology portfolio, and the collaboration is a key step in overcoming challenges inherent to epi-growth of cutting-edge materials," commented IQE vice president Dr Rodney Pelzel.

In December, BluGlass completed its share purchase plan, raising AUS\$3.1m (adding to October's \$5m institutional placement), positioning the firm to execute its commercialization plans.

Fiscal second-half 2017

The BLG-180 chamber has demonstrated improvement in thickness uniformity and, based on this design, the new and larger chamber for the BLG-300 was built to improve uniformity and address scaling of RPCVD technology. The new chamber recently arrived at BluGlass and is being prepared for installation.

The BluGlass technology team is plans to install it onto the larger RPCVD system, to ensure minimal disruption to BluGlass' partner evaluations, in particular the Lumileds Phase II project. BluGlass also expects the new BLG-300 chamber design to help with technical performance for the Lumileds project beyond simply scaling aspects, and it is assessing options for its implementation to assist with Lumileds' milestones and timelines.

Scaling the BLG-300 is also critical for other industry projects (IQE, Veeco and HC Semitek) to progress on commercial-size wafers.

BluGlass continues to explore new strategic opportunities, including collaborations, partnerships and expanding its foundry business within the optoelectronic value chain.

www.bluglass.com.au

Monocrystal grows sapphire shipments by 18% in 2016 ...but sapphire revenue falls 18% as average sales price drops by 23% for LED substrates and 38% for ingots

Monocrystal Inc of Stavropol, Russia (part of diversified industrial holding Energomera), which manufactures large-diameter sapphire substrates and cores for LED, optical product and RFIC applications (as well as screen printing metallization pastes for solar cells) says that its shipments into the sapphire segment in 2016 were up by 18% year-on-year, yielding a dominant share of 33% of the sapphire market for LED applications. However, sapphire revenue was \$56.8m, down 18% on 2015 due to the average sales price declining through 2016 by 23% for wafers for LEDs and by 38% for sapphire ingots.

Monocrystal says that it has secured several long-term orders totaling \$21m and become a serial supplier of polished wafers for three tier-1 Asian customers.



Full-year revenue from photo-voltaic (PV) paste operations totaled \$21.2m, up 5% year-on-year as a result of higher order amounts from customers. Consolidated shipment volume reached 2105 tons (a record for the business unit). Monocrystal was also qualified at three out of the top 10 solar cell makers and has begun serial shipments to them.

"2016 was another year of rapid growth for our share of the global market for sapphire components for electronic applications," notes CEO Oleg Kachalov. "For the first time in our history we have exceeded the 30% market share milestone, while providing our customers with the highest level of quality and demonstrating the fastest cost-reduction rates in the industry," he reckons. "One of the key factors in achieving this result was the increased percentage of large-diameter crystals in our production, which allowed us to cut down our manufacturing costs by more than 20%," Kachalov concludes.

www.monocrystal.com

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Noel expands and adds wafer-processing capabilities

Noel Technologies Inc of Campbell, CA, USA, a specialty foundry focused on process development and fabrication services, has expanded its wafer-fabrication facility in Silicon Valley by adding square footage and installing additional equipment that boost its production capacity by 25%. With additions including an i-line lithography system with 0.35µm resolution, a top-down critical dimension (CD) scanning electron microscope (SEM) and more plasma-enhanced chemical vapor deposition (PECVD) tools, the 20-year-old firm has increased its range of foundry serv-

ices for customers in the semiconductor, MEMS, bio-medical device, sensor and LED markets.

"We perform many wafer-fabrication services integral to the development of the newest micro- and nanoelectronic products," says founder & chief technical officer Leon Pearce. "As a manufacturing partner located right in Silicon Valley, we offer chip designers a local foundry solution to shorten their R&D cycles and reduce their time to production," he adds.

While large foundries provide fabrication services using standard CMOS processes, Noel specializes

in helping chip designers that work with non-CMOS materials and non-standard process flows. Specifically, the firm has decades of experience and capabilities in developing novel process flows involving III-V compound materials, gold, silver, transparent conductive oxides (TCOs) and emerging materials. In addition, all front-end wafer processing is performed in-house under the supervision of Noel's process engineering team, eliminating the need for customers to coordinate work flows among multiple suppliers.

[www.noeltech.com/
Process-Capabilities](http://www.noeltech.com/Process-Capabilities)

CVD Equipment adds VP of sales & marketing

CVD Equipment Corp of Central Islip, NY, USA (a designer and maker of chemical vapor deposition, gas control, and other equipment for developing and manufacturing materials and coatings) says that Emmanuel Lakios has been named to the newly created position of VP of sales & marketing.

Lakios has over 30 years of experience in the semiconductor, data storage and optical device industries and is the holder of several patents in the fields of process equipment and device structure.

From 2015 until earlier this year, Lakios was president & CEO at Sensor Electronic Technology Inc, overseeing its transition from R&D to a global commercial UV LED supplier. From 2003 to 2011 he was the executive VP of field operations and president & chief operating officer at Imago Scientific, bringing it from pre-revenue to a commercial leadership position in the 3D atomic scale tomography field. Lakios was previously at Veeco Instruments Inc from 1984 until 2003, where he held several positions, including president of the

Process Equipment Group and executive VP of field operations. He has been involved in several acquisitions and numerous product line launches. He received his BE in Mechanical Engineering with a focus on Material Science from SUNY Stony Brook in 1984.

"Manny's responsibilities will be to help grow our sales and distribution network and further our strategy for increasing CVD's overall growth through internal development and external acquisitions," says president & CEO Leonard Rosenbaum.

www.cvdequipment.com

DISCO establishes center for staff and customer equipment operation training in Taiwan branch

Tokyo-based equipment maker DISCO Corp is establishing the DHT Training Center at its branch office DISCO Hi-Tec Taiwan Co Ltd (DHT), dedicated to providing equipment operation training for both DISCO staff and purchasers of the firm's equipment.

Previously, DISCO equipment operation training (which requires technical knowledge) was performed on equipment installed at the customer's site or when equipment

owned by the DHT labs was not in use, so it was difficult to provide sufficient training to customers and DISCO employees.

By establishing an equipment operation training facility (with a floor area of about 50m², with a DFD6560 dicing saw and DWR1721 deionized water recycling unit installed, and grinder and laser saw to be added in the future), sufficient training services can be provided to customers, and the operation rate

of customers' equipment can be increased, reducing equipment downtime and increasing productivity, says the firm. Further, by improving its employees' level of knowledge on the equipment, DISCO reckons that it can provide higher-quality customer support and aim to be a trusted partner of customers. Training at the DHT Training Center was due to begin in January.

www.disco.co.jp

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Cambridge Nanotherm addresses thermal management challenge of CSP LEDs

Cambridge Nanotherm Ltd of Haverhill, Suffolk, UK, a producer of nanoceramic thermal management technology, says that its Nanotherm LC thermal management solution addresses the unique needs of chip-scale packaged (CSP) LEDs.

CSP LEDs have a number of benefits over traditional high-power LEDs (HP LEDs), giving module designers the ability to produce smaller, brighter and more cost-effective luminaires. Market research firm Yole Développement forecasts that CSPs will comprise 34% of the HP LED market by 2020.

However, CSPs also present a significant thermal challenge. Traditional HP LEDs have a ceramic submount onto which the LED die is mounted. This spreads the heat from the die before it reaches the printed-circuit board, helping to keep the junction temperature of the die within its approved operating temperature. CSPs do not use a submount. Instead the P and N contacts are metalized, enabling the die to be soldered directly onto the PCB — usually a metal-clad PCB (MCPCB). This approach reduces the cost and size of the finished LED package.

The downside is that removing the ceramic submount (and its heat-spreading abilities) makes CSPs an intense 'point source' of heat that most MCPCBs simply cannot handle. The challenge is conducting the concentrated thermal flux through the dielectric layer of the PCB and into the metal board where it can be spread and removed by the

heat-sink. If the heat is not removed quickly enough then there is a significant risk of the LED overheating and failing catastrophically. This situation is exacerbated by the ability to mount CSP LEDs extremely closely together — a benefit for shrinking module designs, but a major headache when it comes to thermal management as the intensity of the heat is increased significantly.

The key to understanding this challenge is the dielectric layer. MCPCBs are usually made of an epoxy resin mixed with ceramic to create a thermally conductive but electrically isolating barrier. However, there is a limit to how much ceramic can be added before the composite become friable, restricting the thermal conductivity of the layer.

Cambridge Nanotherm says that its approach to thermal management provides a unique solution to this challenge. A patented electrochemical oxidation (ECO) process converts the surface of an aluminium board into a super-thin alumina dielectric layer. This Nanoceramic alumina has a thermal conductivity of 7.2W/mK which, coupled with being just tens of microns thick, yields a composite thermal performance of 115W/mK (much higher than any competing MCPCB). This means that the heat from the CSP LEDs is conducted efficiently through the dielectric and into the aluminium board, ensuring that the LED junction temperature is kept at a stable temperature.

"CSPs, particularly Nichia's DMC LEDs, bring significant cost and manufacturability benefits to LED designers," says sales & marketing director Mike Edwards. "However, by removing the heat-spreading submount, they push the thermal challenge from the LED manufacturers to the module and luminaire designers who now need new and innovative ways to handle the heat," he adds.

"Epoxy-filled MCPCBs struggle to cope with the thermal profile of CSP designs, particularly when they are mounted close together on a module," Edwards continues. "Nanotherm's unique Nanoceramic MCPCBs overcome these limitations, enabling designers to build increasingly power dense modules," he claims. "This, coupled with our comprehensive manufacturing capabilities, offers designers the optimum route to realizing their CSP designs."

Cambridge Nanotherm also recently expanded its manufacturing capabilities to meet increasing demand for its thermal management technology. The firm says that, in keeping with its wider philosophy, it is pushing to make its technology as easy to implement as possible. Nanotherm has hence established partnerships with a wide network of PCB and thin-film manufacturers to offer a broad and comprehensive range of options for circuitization, quality, volume and standards.

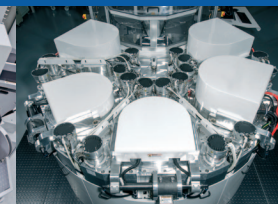
www.camnano.com/nanotherm-lc-solves-thermal-management-challenge-csp-leds

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HexaTech signs long-term AlN supply & IP licensing agreements with Osram

Osram to accelerate UV-C LED device development while HexaTech focuses on core competency of AlN substrates

HexaTech Inc of Morrisville, NC, USA — which manufactures aluminium nitride (AlN) substrates and long-life UV-C LEDs for disinfection applications, and is developing deep UV lasers for biological threat detection as well as high-voltage power semiconductor devices for smart grid and efficient power conversion — has signed two strategic agreements with Osram Opto Semiconductors GmbH of Regensburg, Germany. The agreements include a long-term supply commitment for HexaTech's AlN substrates, direct support of HexaTech's 2"-diameter substrate development program, as well as licensing of certain HexaTech intellectual property (IP).

As a commercial supplier of single-crystal AlN substrates, HexaTech says that it has devel-

oped a knowledge base for optoelectronic, high-power and radio-frequency applications based on its proprietary material, helping to activate a market pull for its underlying substrate technology.

"We view this collaborative partnership with Osram as truly a win-win for both companies," says CEO John Goehrke. "By licensing our technology, Osram is able to accelerate their UV-C LED device development based on HexaTech's

Through Osram's strategy of actively expanding our non-visible optoelectronic product portfolio into the UV-C wavelength range, we are poised to capitalize on this rapidly growing market segment

material, and we are able to focus on our core competency, supplying world-class AlN substrates," he adds.

"Through Osram's strategy of actively expanding our non-visible optoelectronic product portfolio into the UV-C wavelength range, we are poised to capitalize on this rapidly growing market segment," says Hans-Jürgen Lugauer, head of UV-LED research & development at Osram Opto. "Establishing a long-term strategic relationship with HexaTech, a recognized industry leader in the field of AlN, will allow us to develop highly efficient and reliable deep UV devices, positioning Osram as the dominant high-performance optoelectronic technology provider from the deep ultraviolet through infrared wavelengths."

www.hexatechinc.com/aln_wafer_sales.html

LG Innotek unveils first 70mW UV-C LED

Seoul-based LG Innotek (a subsidiary of South Korean electronics company LG Group) has developed what it claims is the first 70mW UV-C LED for sterilization applications (1.5 times higher than competing 45mW modules).

UV-C LEDs produce short-wavelength ultraviolet light in the range 200–280nm and can prevent the proliferation of bacteria by destroying their DNA, allowing them to be used for sterilization purposes. LG Innotek's new UV-C LED emits at 280nm.

Until now, UV-C LEDs have mainly been applied in small sanitary products because their low optical output power led to low sterilization performance. The power of LEDs for toothbrush sterilizers is 1mW and that for sterilizing the water tanks of humidifiers is 2mW.

Using its proprietary LED vertical

chip technology, LG Innotek has improved UV-C LED optical power to 70mW. While the new product measures just 6mm in both length and width, its sterilization performance is claimed to be the world's best.

LG Innotek says that it has overcome the UV output limit by using specialized LED chip technology. The epitaxial structure design and vertical chip technology for maximizing light extraction have boosted output, as well as ensuring reliability in quality by effectively expelling heat, it is claimed.

As the new UV-C LED is compact and has high sterilization performance, it can be applied to various fields such as water purifiers and air purifiers, since it allows the sterilization of flowing water and air. It can also be used in hardening equipment in the manufacturing

industry. As the UV output is strong, the performance of curing devices can be enhanced.

LG Innotek says that manufacturers of water purification, cleaning and curing devices can benefit from its stable supply of UV-C LEDs optimized for their respective applications, since the firm is equipped with a consistent production system that produces epitaxial wafers, chips, packages and modules.

According to market research firm Yole Developpement, the UV LED market is forecast to grow from \$130m in 2015 to \$270m in 2017.

Along with its 280nm UV-C LED, LG Innotek has a lineup of LEDs ranging from 365nm, 385nm, 395nm and 405nm UV-A LEDs for general industrial purposes to 305nm UV-B LEDs for bio and medical purposes.

www.lginnotek.com

Nikkiso and Formosa Plastic to form UV-LED JV Nikkiso Formosa to start production in Taiwan in 2018

Tokyo-based medical and industrial equipment maker Nikkiso Co Ltd, its subsidiary Nikkiso Giken Co Ltd and Taiwan-based Formosa Plastic Group (FPG) have agreed to form a joint venture Nikkiso Formosa Co Ltd in Touliu, Yunlin County, Taiwan (starting business in July) for manufacturing and selling deep ultraviolet light-emitting diode (UVC-LED) products (i.e. components made by Nikkiso Co Ltd, plus instruments and equipment incorporating them). Deep UV-LEDs are usable as a light source in applications including water disinfection, air disinfection and deodorization, resin/ink curing, and analytical and measurement instruments.

Nikkiso will have a 51% stake in

the JV and Formosa Plastic a 49% stake. With Formosa Plastic as the main investor, capital will be ¥4bn (about US\$35m) initially, rising later to ¥8bn. Nikkiso will contribute UV LED technology developed by Nikkiso Giken. The two firms will each hold half the board member seats (with three board members coming from Nikkiso Co Ltd).

Nikkiso has succeeded in developing and mass producing what is claimed to be the world's highest-performance deep UV-LEDs, and has also developed applications including water disinfection modules. The new JV aims to establish a fully integrated UV-LED factory, from epitaxial wafers through package and testing to the final

end-product.

Nikkiso reckons that the JV should allow for more rapid expansion into the deep UV-LED market, and provide high-performance and low-price deep UV-LEDs by combining Nikkiso's strengths in technology with Formosa Plastic's expertise in low-cost production (based on its experience of manufacturing visible-light LED components). The JV also aims to establish itself in deep UV-LED products by providing modules and systems closely aligned with the existing businesses of both companies. Production at the new factory should begin as early as 2018.

www.NikkisoUVLED.com

www2.fpg.com.tw

Crystal IS showcases UVC LEDs for disinfection and spectroscopic instrumentation at Photonics West

Crystal IS Inc of Green Island, NY, USA, an Asahi Kasei company that makes proprietary ultraviolet light-emitting diodes (UVC LEDs), showcased products for disinfection and spectroscopic applications at SPIE Photonics West 2017 in San Francisco (28 January – 2 February).

At the conference, Crystal IS is highlighting its new commercial product line targeting higher-power applications for UVC disinfection of water, air and surfaces. The firm's first-generation disinfection product

line Klaran offers germicidal output powers of 15-30mW, suiting healthcare, lab water and consumer product applications where health and human safety is of primary importance.

The Crystal IS booth will also feature three examples of customer use of UVC LEDs:

- Chelsea Technologies Group's UviLux, a highly sensitive fluorometer to monitor PAHs (polycyclic aromatic hydrocarbons) including phenanthrene;

- REACH Devices' RD4 detector, a UV, RI and conductivity monitor for preparative liquid chromatography and FPLC; and

- Marion Research's Aurorae detector, which is claimed to be the world's most compact, low-cost OEM detector.

In addition, Crystal IS is giving daily presentations on using UVC LEDs in disinfection applications and spectroscopic instrumentation.

www.cisuvc.com/products/klaran

www.cisuvc.com/photonics-west

Phoseon boosts power and performance for LED curing

Phoseon Technology of Hillsboro, OR, USA has released an updated FireLine FL400 LED curing solution, which increases the power of the LED unit by 25% (up to 24W/cm²).

The FireLine FL400 is designed for the printing, coatings and adhesive curing applications and is now available with increased performance. The solution is scalable to support custom length options, and offers

optical uniformity for consistent and reliable curing for the most demanding industrial printing applications.

The FL400 is part of the FireLine family — water-cooled UV LED curing lamps with uses in a wide variety of web/conveyor based UV curing applications. The FireLine architecture is designed to allow the scalable systems to be built up to 2m in length.

"Customers continue to ask for higher-performance solutions for increased throughput," says product marketing manager Joe Becker. "The more powerful FireLine FL400 offers customers a scalable, IP54-compliant solution with higher performance for jobs requiring high UV output."

www.phoseon.com/products/uv-curing-systems/fireline

FBH's new CV measurement method offers more specific approach to UV LED device optimization

Measuring p-side of stressed device independently from pn-junction and n-side indicates that stress activates magnesium acceptors

Aluminium gallium nitride (AlGaIn)-based light-emitting diodes (LEDs) with ultraviolet (UV) emission at wavelengths of 250–320nm are promising devices for applications such as water purification, gas sensing and UV curing. However, the lifetime of these UV LEDs is still limiting their applicability.

Within the Joint Lab GaN Optoelectronics of Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) of Berlin, Germany and the Institute of Solid State Physics at Technische Universität Berlin (TU Berlin), UV-B and UV-C LEDs with emission wavelengths of 310nm and 265nm have been developed. To enhance the lifetime, deep knowledge about the physical mechanisms behind the stress-induced degradation is needed. The UV-B and UV-C LEDs were therefore exposed to accelerated aging for 200 hours at a constant current density of 140A/cm² and different temperatures. It turned out that the reduction in the optical power is more pronounced and strongly temperature-dependent for UV-C LEDs compared with UV-B LEDs. To better understand this discrepancy, the LEDs were analyzed before and after stress by means of capacitance–voltage (CV) measurements.

This method allows access to the widths of space charge regions (SCR) within the LEDs. Comparing the capacitances before and after stress reveals the impact of the temperature during stress (see Figure 1). While the capacitance gets smaller for the investigated UV-C LEDs (which can be

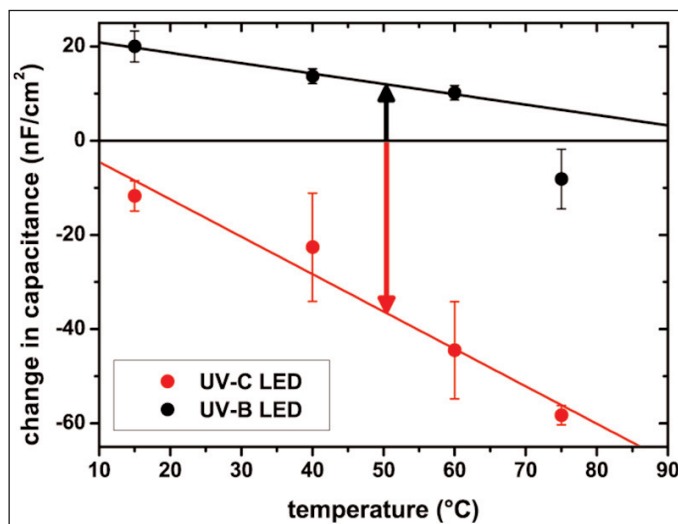


Figure 1: Change in measured device capacitance due to a 200hr constant current stress as a function of heat sink temperature during stress.

attributed to an enlargement of the SCR), the capacitance of the UV-B LEDs increased for stress temperatures $\leq 60^\circ\text{C}$. This opposite behavior indicates that at least two different degradation mechanisms are prominent in these devices.

Further investigation of the UV-B LEDs showed that the capacitance increases mostly at the beginning

of stress. This leads to the question of where exactly the changed SCR is located within the heterostructure. The researchers therefore developed a method for measuring the p-side of the stressed device alone. This allows the effects of the p-side to be separated from those of the pn-junction and the n-side of the heterostructure. The investigations show that the initial increase in capacitance can be attributed to changes in the p-side of the LED (see Figure 2). The stress is assumed to activate magnesium acceptors in the semiconductor.

The described method offers new possibilities for degradation studies in UV LEDs, say the researchers. In particular, the possibility of locating the changes in the LED structure should enable a more specific approach to device optimization.

The work was partially supported by the German Federal Ministry of

Education and Research (BMBF) through the consortia project 'Advanced UV for Life' under contracts 03ZZ0105A and 03ZZ0105B. Further support was given by the Federal Ministry for Economic Affairs and Energy (BMWi) through the project 'UV-Berlin' under contract 03EFCBE067 as well as by the Deutsche Forschungsgemeinschaft within the Collaborative Research Center 'Semiconductor NanoPhotonics' (CRC 787).

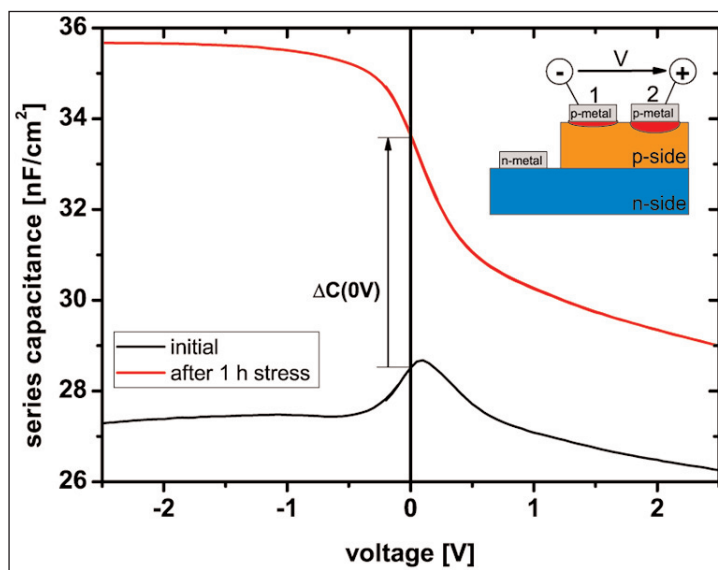


Figure 2: CV profiles of two p-contacts measured in series before (black) and after (red) stress of the LED-structure underneath one of these contacts.

<http://ieeexplore.ieee.org/document/7774995>
www.fbh-berlin.com



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US DoE awards new SBIR and STTR phase I grants

The US Department of Energy (DoE) Office of Science has awarded four Small Business Innovation Research (SBIR) grants and one Small Business Technology Transfer (STTR) grant for projects targeting critical advances in solid-state lighting (SSL) technology. The SBIR-STTR program seeks to increase the participation of small businesses in federally sponsored innovative and novel R&D.

The five fiscal year 2017 Phase I Release 1 grants will explore the technical merit and commercial potential of innovative concepts or technologies to help to achieving the price and performance goals described in the DOE's SSL R&D Plan.

Phase I recipients are:

- Pixelligent Technologies LLC of Baltimore, MD — for its application of a unique three-dimensional gradient index layer to improve organic LED (OLED) light extraction.
- Lumisyn LLC of Rochester, NY — for its development of unique nanocrystal-based silicone films with high quantum efficiencies and low optical scattering losses.
- OLEDWorks LLC of Rochester, NY — for development of a novel substrate and encapsulation process that should significantly reduce the cost of OLED lighting.
- SC Solutions Inc of Sunnyvale, CA — for developing an innovative control technology for improved within-wafer temperature uniformity in the metal-organic chemical vapor deposition (MOCVD) process used for manufacturing LEDs.

● MicroLink Device Inc (Niles, IL) — for improving the performance of phosphide-based red and amber LEDs by engineering the composition and combination of semiconductor materials.

Specifically, SC Solutions' SBIR project 'Radiation-Assisted MOCVD Heating for Improved Within-Wafer Temperature Uniformity in LED Manufacturing' seeks to demonstrate feasibility of control technology for improved within-wafer temperature uniformity in MOCVD that is most commonly used to produce commercial multi-quantum-well (MQW) LEDs. The proposed control technology promises to reduce the need for binning in LED manufacturing, which involves additional cost and complexity, including reduced wafer yield and less-than-ideal emission properties of phosphor-converted LEDs (pcLEDs). These challenges are believed to hinder more-widespread acceptance of LED products for energy-efficient building-illumination applications. SC Solutions will address this challenge by employing radiant heating from the top of the wafer with a heat flux profile shaped using a specially designed mask. The heater will be located beyond the susceptor edge within the MOCVD system. It will be controlled in conjunction with the susceptor heaters, using an integrated control architecture. The proposed approach is expected to reduce within-wafer non-uniformity by 90% or more.

MicroLink Devices' STTR project 'Al_xIn_{1-x}P LEDs with II-VI Cladding Layers for Efficient Red and Amber Emission' will involve teaming with the US National Renewable Energy Laboratory to improve the performance of phosphide-based red and amber LEDs by engineering their composition and alloy combinations to overcome fundamental loss mechanisms that are known to limit performance. The approach builds on the team's long-standing efforts using similar materials to advance high-efficiency multi-junction solar cell technologies. The project's main objective is to improve the performance of red and amber LEDs by implementing an 'Al_xIn_{1-x}P'-based active region in combination with an advantageous electron cladding layer based on a higher-bandgap II-VI semiconductor alloy. By demonstrating an innovative cross-cutting technology to design and fabricate high-efficiency, phosphide-based LEDs for eventual use in high-performance multi-LED SSL devices, this design approach is expected to mitigate both internal and external loss mechanisms in a significant way, increasing luminous efficacy in a stable and cost-effective manner. This is expected to be the most significant improvement in the efficiency of red and amber LEDs in decades, and should reduce market adoption risk by using existing device designs and manufacturing processes.

<http://science.energy.gov/sbir>

Flip Chip Opto releases 4800W 3-Pad flip-chip COB LED

Flip Chip Opto Inc of Fremont, CA, USA has launched the Apollo 4800, a flip-chip COB (chip-on-board) LED engine as part of its flagship Apollo high-power series based on patented 3-Pad flip-chip LED technology, which allows high-power single-source flip-chip COBs to exceed the industry limitation of 500W output while reducing junction temperature to 0.002°C/W.

The 4800 has maximum power of

4870W, achieving thermal resistance of 0.002°C/W and a luminous flux above 505,000lm, at a correlated colour temperature (CCT) of 5000K and color rendering index (CRI) of 80. High efficiency is also available at 2170W for a luminous flux 287,000lm.

The LED suits extreme applications such as military lighting, stadium lighting, broadcast lighting, and exploration spotlighting, and opens

up new applications that traditional lighting is unable to achieve.

The Apollo 4800 is also claimed to be unique due to its thermal properties and proprietary bonding technology, allowing designers to maximize lumens-per-dollar as well as reducing the form factor of the light fixture, fixture optics, and the number of fixtures needed.

www.fcopto.com

Seoul Semiconductor begins filament LED mass production

South Korean LED manufacturer Seoul Semiconductor (SSC) has announced the start of mass production of its LED chip-on-board package for use in LED filament bulbs.

"Based on its strong patents, Seoul Semiconductor will continue to increase its market share in the filament LED bulb market, which is a blue-ocean market estimated at \$1.3bn," says chief technology officer Ki-bum Nam.

Seoul Semiconductor says that its filament LEDs can realize high-quality light close to natural light through differentiated chip-on-board (COB) packaging technology and can produce light using omnidirectional emission technology, combining a small footprint with a wide beam angle. The color rendering index (CRI) is 80 or better, and different LEDs with a flux between 105 lumens and 210 lumens are available.

All feature a correlated color temperature (CCT) of 2700K, and can be used for spaces such as cafes and hotels or bedrooms and living rooms, making them an alternative to incandescent light bulbs that have been phased out in 2014.

Development of the technology began in the early 2000s, before there was a market for filament LEDs, but production was held until the market was ready for them.

Seoul Semiconductor says that it

now holds hundreds of patents for filament LEDs, spanning chip manufacturing, COB packaging, module and bulb

Development of the technology began in the early 2000s, before there was a market for filament LEDs, but production was held until the market was ready

manufacturing processes (all core technologies for manufacturing filament LED products) and that the portfolio provides strong IP protection for customers using Seoul Semiconductor's filament LEDs, the firm adds. "We are readying legal actions, as many of the LED bulbs released in the market have infringed our proprietary technologies," states a company official.

The global light bulb market is estimated at 7 billion units annually, of which 2.5 billion are light bulbs for various decoration purposes (a market being addressed by the filament LEDs). Their application in this market has begun and they can not only be applied to globe bulbs in their various forms but also to candle lamps in special shapes. These diverse applications are supported by two different lengths of the LEDs: 38mm and 50mm.

www.seoulsemicon.com

Samsung launches second-generation COB LED packages for spotlights & other directional lighting

South Korea's Samsung Electronics Co Ltd has launched its second generation of D-series chip-on-board (COB) LED packages. Featuring what is claimed to be the industry's highest light efficacy for COB LEDs, the second generation is suitable for directional lighting applications such as multi-faceted reflector (MR) bulbs, parabolic aluminized reflector (PAR) lamps, spotlights, downlights and high-bay lights.

At a correlated color temperature (CCT) of 5000K and color rendering index (CRI) of 80 (at 85°C), the D-series Generation 2 offers luminous efficacy of 160lm/W (up from the Gen 1's 150lm/W). The Gen 2 range adds to Samsung's COB lineup by providing more extensive lighting source options for spot lighting and most other directional lighting. The D-series Gen 2 also features about 50% lower thermal resistance than the first generation.



Samsung's new D-series Gen 2 COB LEDs.

In addition, all 11 different wattage options in the D-series Gen 2 range deliver high reliability and performance levels that meet DLC Premium standards (technical requirements for LED lighting solutions suggested by DesignLights Consortium). DLC standards are recognized in North America as a preferred means of evaluating LED lighting products in

terms of performance and quality.

The D-series Gen 2 is available for a wide range of CRIs from 70+ to 90+, and for 'Vivid' lighting, in providing color spectrums that have been optimized for retail markets (satisfying the need of many lighting designers to have richer, more vibrant colors).

www.samsung.com

Lumileds appoints former Micron Technology president Mark Adams as CEO

LED maker Lumileds of San Jose, CA, USA has appointed Mark Adams as chief executive officer. Most recently (from 2012 to 2016) Adams was president of Micron Technology Inc (a Fortune 200 global manufacturer of memory solutions).

"We will build upon Lumileds' robust innovation pipeline, technology leadership and strong customer base to drive Lumileds' future growth," says Adams.

Between 2008 and 2012, Adams



CEO Mark Adams.

was VP, world-wide sales at Micron. He also served in executive roles at Lexar Media Inc, Creative Labs Inc and NCR Corp.

He received his Bachelor of Arts degree in Economics in 1987 from Boston College and his MBA in 1995 from Harvard University. Adams currently sits on

the board of directors at Cadence Design Systems Inc and Seagate Technology plc.

Lumileds is a subsidiary of Royal Philips. Philips announced on 12 December that it signed an agreement to sell a majority 80.1% stake in Lumileds to funds managed by affiliates of Apollo Global Management LLC. The transaction is expected to be completed in first-half 2017, subject to customary closing conditions.

www.lumileds.com

Lumileds launches record-efficiency multi-die emitter LUXEON MX for outdoor fixtures

Lumileds has launched the LUXEON MX, a multi-die emitter that delivers what is said to be industry-leading efficiency and flux for outdoor fixtures and high-bay lighting applications.

The emitter's record 1200 lumen output (150lm/W luminous efficacy) at 85°C (at correlated color temperatures of 4000–6500K and a color rendering index of 70) enables a system efficiency of 120lm/W when driven at 700mA. "This is double the flux of comparable emitters in 120lm/W systems," claims LUXEON MX product manager Seth Danielson. "We have achieved this performance leap by optimizing the LED for improved efficiency at higher drive currents up to 1.5A with the 12V device," he adds.

Lumileds says that, with these



Lumileds' new LUXEON MX multi-die emitter.

developments, it has maximized emitter efficiency and lifetime. The LUXEON MX makes it possible for luminaire makers to meet the efficiency and quality requirements of the DesignLights Consortium (DLC) Premium V4.1 at 700mA and 85°C, it is reckoned. "By creating products eligible for the DLC

Qualified Products List, cities and municipalities can receive rebates on their LED street lighting projects, while also realizing the fast return on investment from using the most efficient emitters," says Danielson. Also, the LUXEON MX leverages a new, robust package that increases the projected lumen maintenance compared with the LUXEON M. The LUXEON MX is an instant upgrade to the LUXEON M, featuring identical footprint and optical characteristics.

The LUXEON MX multi-die emitter will be offered in a range of color temperatures (3000–6500K) and CRIs (70, 80 and 90) in convenient 3V, 6V and 12V configurations. Applications include roadway lighting, street lighting, stadium lighting and high-bay fixtures.

www.lumileds.com/LUXEONMX

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LESA's Lighting and Displays team at RPI and University of New Mexico awarded patent for inexpensive growth of large-area cubic GaN

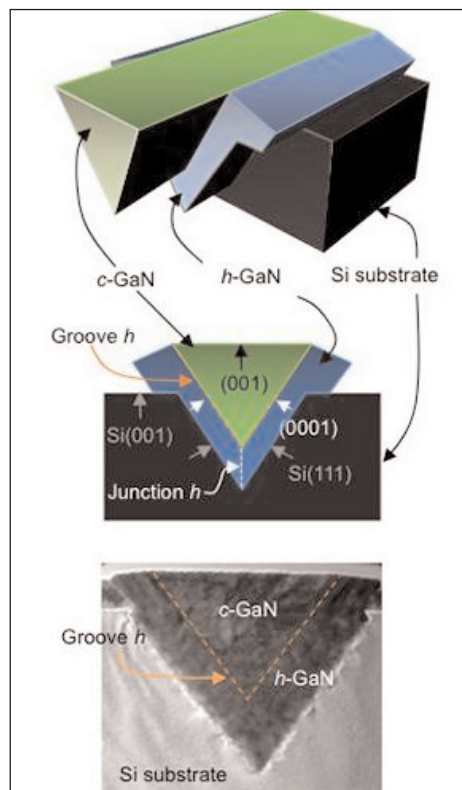
Nanoscale grooves yield geometrically driven phase segregation promoting growth of cubic phase at expense of hexagonal phase

A team of faculty and graduate students at the Center for Lighting Enabled Systems & Applications (LESA) of Rensselaer Polytechnic Institute (RPI) of Troy, NY, USA and at the University of New Mexico (UNM) have been awarded US patent no. 9,520,472 ('Growth of Cubic Crystalline Phase Structure on Silicon Substrates and Devices Comprising the Cubic Crystalline Phase'). Cubic gallium nitride (GaN) devices hold promise for addressing two long-standing issues that limit the performance of LEDs.

The research team and other investigators are working to develop LED manufacturing processes that will allow LEDs to shine brighter and in more colors. The material could be used in applications that include lighting for homes that would create brighter, more colorful, and efficient displays, as well as high-efficiency power electronics that are used to improve electric vehicles and renewable energy system performance.

According to the research team, LED performance is impacted by poor performance at longer emission wavelengths (the 'green gap' problem) and poor performance at higher operating current (efficiency droop). While GaN devices have excellent performance in the blue regions of the spectrum, these two technical problems limit the overall performance capability for future high-efficiency color-tunable lighting systems and advanced display technologies.

The patent was issued on 13 December to principal investigator Steven R.J. Brueck, distinguished professor emeritus with the UNM Department of Electrical & Computer Engineering (ECE) and UNM Center for High Technology Materials



LED manufacturing process enabling growth of cubic GaN on silicon.

(CHTM) faculty member and director emeritus; and inventors Sueng-Chang Lee (UNM) and a team from Rensselaer. The Rensselaer/LESA team includes Christian Wetzel, professor of physics, applied physics, and astronomy and co-inventor of the patent; along with Theeradetch Detchprohm, who received his Ph.D. from Japan's Nagoya University and served as a research associate professor in the Future Chips Constellation; and Christoph Stark, who received a Ph.D. in physics from Rensselaer and now works for a startup in Germany.

By using a non-polar facet of cubic GaN, the research team has demonstrated emission across the visible spectrum from the cubic InGaN/GaN material system that offers significant opportunities for

higher efficiency full-spectrum lighting and displays.

GaN crystals can be grown with either cubic or hexagonal (wurtzite) phases, but commercial GaN LEDs are based on hexagonal materials, typically grown on sapphire substrates. "The hexagonal phase typically forms most easily, as it is the lowest-energy crystallographic structure," says Wetzel. "Previous attempts to grow cubic GaN crystal structures have produced poor-quality, heavily defected mixed-phase materials," he adds.

"The patented UNM/RPI growth process uses inexpensive silicon wafers available in much larger sizes and lower defect densities than sapphire," says Brueck. "The silicon surface is first patterned with an array of nanoscale grooves that lead to a unique, geometrically driven phase segregation that separates the cubic phase and promotes its growth at the expense of the hexagonal phase GaN material," he adds. "Additional quantum well layers of InGaAs are added after the pure cubic phase GaN structure has been established to create the light-emitting material used to fabricate cubic LEDs."

The research at LESA exemplifies The New Polytechnic, an emerging paradigm for teaching, learning, and research at Rensselaer that emphasizes and supports collaboration across disciplines, sectors and regions to address global challenges by using the most advanced tools and technologies (many of which are developed at Rensselaer). Ultimately, LESA's vision is focused on creating digitized illumination for new applications in lighting, health-care, building management, horticulture, and advanced 5G wireless communications platforms.

<http://lesa.rpi.edu>

Cree reports higher-than-expected quarterly revenue growth of 8% and doubles profits

Fiscal 2017 free cash flow targeted raised from \$100m to \$120m

For fiscal second-quarter 2017 (to 25 December 2016), Cree Inc of Durham, NC, USA has reported revenue of \$401m, down 8% on \$435.8m a year ago but up 8% on \$371m last quarter (and well above the \$360–380m guidance).

Of this, discontinued operations contributed \$54m (exceeding the expected \$50m), rising further, by 8.2% on \$49.9m last quarter and by 28.6% on \$42m a year ago. In July 2016, Cree agreed for Germany's Infineon Technologies AG to buy its Wolfspeed business (which includes the Power & RF product lines that had historically been reported as a separate operating segment, plus the non-LED materials product line previously reported within the LED segment).

Continuing operations contributed \$347m, down 11.9% on \$393.8m a year ago but up 8% on \$321.3m last quarter (and exceeding the expected \$310–330m). Specifically, Lighting Product revenue (mainly LED Lighting systems and bulbs) was \$208.9m (60% of total revenue), down 18% on \$255m (65% of total revenue) a year ago but up 13.7% on \$183.8m (57% of total revenue) last quarter (rather than flat, as expected). LED Product revenue (chips and components) was \$138m (40% of total revenue), roughly level with \$137.5m (43% of total revenue) last quarter and \$138.8m (35% of total revenue) a year ago.

In fiscal Q2, Cree announced expanded lighting product offerings and improved performance in its LS surface ambient product family, its IG parking luminaires, and its Essentia by Cree family. In LEDs, the firm launched what is claimed to be the industry's most efficient horticulture LEDs and its new XHP 50.2 LED (claimed to deliver the highest lumen density in its class).

On a non-GAAP basis, gross margin has risen from 28.9% a year ago and 28.8% last quarter last quarter

to 32.7% (rather than being level quarter-to-quarter, as expected). Despite consumer lighting revenue declining, margins improved as Cree met its overall lighting targets. Gross margin for continuing operations rebounded further, from 27.7% last quarter to 32%, up on 28.2% a year ago. Specifically, Lighting Product margin has rebounded from 26.8% last quarter to 35.8%, up on 28.5% a year ago (improving for both commercial and consumer lighting). This sharp increase was counteracted slightly by LED Product margin falling further, from 30.9% a year ago and 30.4% last quarter to 29.2%.

Operating expenses (OpEx) for continuing operations have risen from \$80m last quarter to \$88m (above the target, due to contingent legal costs associated with settlement of the patent infringement and false advertising lawsuit against lighting company Feit Electric Company Inc of Pico Rivera, CA, USA).

Net income was \$29.9m (\$0.30 per diluted share), up slightly from \$28.5m (\$0.28 per diluted share) a year ago but doubling from \$15.2m (\$0.15 per diluted share) last quarter, and well above the expected \$13–19m (\$0.13–0.19 per diluted share). Correspondingly, income from continuing operations was \$19.9m (\$0.20 per diluted share), down from \$21.6m (\$0.21 per diluted share) a year ago but doubling from \$9.5m (\$0.09 per diluted share) last quarter and exceeding the

expected \$4–10m (\$0.04–0.10 per diluted share). Income from discontinued operations was \$10m (\$0.10 per diluted share), up from \$5.7m (\$0.06 per diluted share) last quarter, and exceeding the expected \$9m (\$0.09 per diluted share).

"Revenue and non-GAAP earnings were significantly above our targeted range due to the settlement of our patent infringement and false advertising lawsuit with Feit Electric," notes chairman & CEO Chuck Swoboda.

Spending on property, plant & equipment (PP&E) has been cut further, from \$31.9m a year ago and \$19.3m last quarter to \$15.9m, while patent spending of \$3.6m is up on \$2.3m last quarter. The total capital expenditure of \$20m was up slightly on \$21m last quarter (again including \$10m for Wolfspeed).

Cash flow from operations was \$101.6m, up from just \$18.1m last quarter. Free cash flow was hence \$82.2m, compared with –\$3.5m last quarter.

During the quarter, Cree spent \$63m to repurchase 2.7 million shares (making \$98m spent repurchasing 4.2 million shares in fiscal 2017 year-to-date).

Overall during the quarter, consolidated cash and investments hence rose by \$19m from \$402m to \$421m. At the end of the quarter, Cree had \$170m outstanding on its line of credit.

For fiscal third-quarter 2017 (ending 26 March), Cree targets combined revenue (including both continuing and discontinued operations) of \$340–370m. For discontinued operations (Wolfspeed), revenue is expected to be roughly level at \$55m. For continuing operations, revenue is expected to fall to \$285–315m, as growth in new commercial lighting products partially offsets seasonal slowness related to both weather and holidays. ►

Revenue and non-GAAP earnings were significantly above our targeted range due to the settlement of our patent infringement and false advertising lawsuit with Feit Electric

► This, combined with the consumer lighting revenue remaining level, will result in overall core lighting revenue falling a few percent from fiscal Q2. "We target our LED business to be 10% lower sequentially, which is slightly more than the typical seasonal decline due to the holiday timing impact [two major holidays in the quarter]," notes Swoboda.

Cree expects increased lighting gross margins to be the primary driver to improve operating margins over time. "We target the combination of higher-value new products and lower costs to drive improved core lighting gross margins," says Swoboda. However, this will be partially offset by LED margins falling slightly due to seasonally lower volumes and higher costs associated with the ramp up of new products.

Operating expenses from continuing operations are expected to be \$7m lower than fiscal Q2 due to lower legal spending on IP litigation and reduced brand marketing spending, partially offset by higher R&D spending for new LED product development.

Combined net income is expected to fall to \$10–18m (\$0.10–0.18 per diluted share), as income from

continuing operations falls to \$1–9m (\$0.01–0.09 per diluted share) while income from discontinued operations (Wolfspeed) is roughly steady at \$9m (\$0.09 per diluted share).

For full-year fiscal 2017, Cree continues to target Lighting and LED capital spending of \$55m to support continuing operations. "Until the sale of Wolfspeed is completed, we will continue to invest capital to support the Wolfspeed business," says chief financial officer Mike McDevitt. Cree targets Wolfspeed capital spending of \$15m for fiscal Q3 (up from \$10m in fiscal Q2). "Overall, we now target fiscal 2017 free cash flow of \$120m [up from the prior target of \$100m], which may change depending on the timing of the Wolfspeed sale," says McDevitt.

We continue to evaluate lighting growth opportunities through potential mergers & acquisitions. We are taking a very measured approach as we look for the right business to complement our current product portfolio

Regarding the LED business, the market "remains very competitive, and we continue to focus our technology on the applications where we can add the most value to the customer," says Swoboda. "We continue to work on some mid- to longer-term programs that are targeted to expand the LED business in both existing and new applications. One of the new applications that we have been pursuing is automotive lighting, where we believe our high-power LED technology can enable emerging exterior vehicle applications. We have been an LED chip supplier to automotive for two decades and target releasing our first new automotive-qualified XLamp LED components by the end of fiscal 2017," he adds.

"We continue to evaluate lighting growth opportunities through potential mergers & acquisitions," says Swoboda. "We are early in the process and taking a very measured approach as we look for the right business to complement our current product portfolio and enhance our channel relationships. We have the balance sheet to act when the right opportunity is available and we have the flexibility to be patient," he adds.

www.cree.com

Cree launches C1010 three-in-one RGB surface-mount LED for HD indoor video screens

Cree has launched the C1010 LED, a three-in-one RGB surface-mount device (SMD) LED that, it is said, enables high-definition LED screen manufacturers to create video displays that are sharper and more dynamic than previously possible. Product samples are available now with standard lead times.

Featuring what is claimed to be the best far-field pattern matching and the lowest power consumption in its class, the new LED delivers 40% better contrast ratio and a longer lifetime than competing LEDs, it is reckoned. The C1010 is also said to be the only high-density display LED with zero cross-

talk between pixels, eliminating the need for louvers that add cost and weight to displays.

"The robust C1010 opens up new applications for high-density displays and continues Cree's record of technology breakthroughs for display LEDs, including the first tilted-angle radiation pattern LEDs and the first waterproof SMD LEDs," says Dave Emerson, VP & general manager for Cree LEDs.

The C1010 has been proven to deliver more than double the lifetime of competing LEDs under accelerated high-temperature and high-humidity testing conditions, Cree claims. It also delivers a

luminous intensity of up to 140mcd at a drive current of 5mA in a compact ultra-black 1.0mm x 1.0mm package to maximize contrast under all viewing conditions.

"Cree's new C1010 LED will revolutionize the high-density LED display market," comments Aaron Wu, deputy general manager of LED display maker Shenzhen AOTO Electronics Co Ltd. "The C1010 creates a noticeably higher-quality image than any other small-pitch LEDs that we have evaluated and is backed by the best reliability data in the industry," he adds.

www.cree.com/hb/c1010

FLINGO EU project to develop new materials and processes to improve LED efficiency and durability

Osram Opto coordinating project with four partners from industry and research

Given the growing demands placed on the electrical, optical and thermal functionality of LEDs, increasing attention is being paid to the development of new material properties. To this end, sponsored by the German Federal Ministry for Education and Research (BMBF) throughout its intended duration until January 2020, the project FLINGO (Functional Inorganic Layers for Next Generation Optical Devices) has been established to develop new materials (layers, in particular) and processes to improve the efficiency and durability of LEDs.

As project coordinator, Osram Opto Semiconductors GmbH of Regensburg, Germany is working with universities, research institutes and companies to maintain and improve market leadership in innovative LED products. The FLINGO project is part of the M-ERA.NET EU initiative, an European Union-financed network set up to support the coordination of European research projects.

In FLINGO, researchers will investigate and combine different deposition methods for thin films such as atomic layer deposition (ALD),

spray pyrolysis and the sol-gel process for manufacturing high-quality LED light sources. Under the leadership of Dr David O'Brien of Osram Opto, the project partners will work on the entire bandwidth of new component properties — including extended lifetime, smaller electrical layer resistance and improved light extraction. These require new materials and innovative or adapted deposition processes. "The project objectives can only be achieved with the assistance of a broad-based consortium because they call for improvements, new developments and especially expert know-how across the entire value-added chain," says O'Brien.

Interdisciplinary expertise from five project partners

The members of the FLINGO project (in addition to Osram Opto) are: Uninova from the New University of Lisbon, Portugal; Finnish thin-film technology company Picosun Oy; the Fraunhofer Institute for Silicate Research ISC in Würzburg, Germany; and Vilnius University in Lithuania. Fraunhofer ISC provides support through its proficiency in the development of new inorganic layer

systems that are to be used as the matrix for sensitive converter materials. Uninova adds its expertise in the manufacture of highly transparent and highly conductive layers that are needed for the p-contact in the LEDs. Picosun is developing ALD processes and new materials to ensure conformal coating of even heavily structured surfaces. The Institute for Applied Research at Vilnius University provides specialist knowledge in the development and characterization of non-destructive material properties and will analyze the new layers and layer systems developed in the FLINGO project.

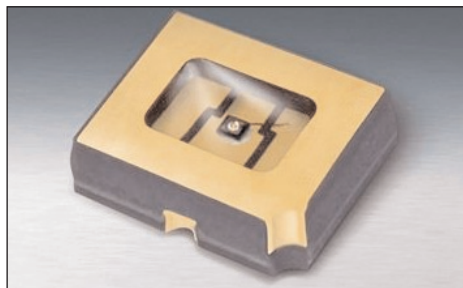
As an end user of the technologies developed in FLINGO, Osram Opto will ultimately transfer the new thin layers and layer systems to its LEDs to test them for their suitability for the mass market. "The results of the project should lead to highly efficient and durable white-light LEDs with possible applications in general lighting, for example," says O'Brien. "Our intention here is to improve our competitiveness and that of European industry."

www.m-era.net

Opto Diode launches 685nm deep red surface-mount LED

Opto Diode Corp of Camarillo, CA, USA (an ITW company) has launched a deep red, surface-mount device (SMD) light-emitting diode for biological analysis, health, science, medical and veterinary applications. OD-685C LED provides 2mW of radiant power at a forward current of 20mA, peak wavelength of 685nm, and radiant efficiency of 56%. Typical applications require radiometric measurement with tight spectral bandwidth.

The rugged new surface-mount device is fully operational within a



very wide temperature range from -65°C to $+125^{\circ}\text{C}$, making it suitable for use in harsh environmental conditions. The forward voltage is typically 1.8V with a maximum of 2.2V. The spectral bandwidth at 50% is

30nm. For higher optical power the OD-685C may be operated with total power dissipation at 110mW and continuous forward current at 50mA or with the peak forward current (at $10\mu\text{s}$ @ 300Hz) at 100mA.

Opto Diode's expanding product lines will include several surface-mount devices to be introduced in 2017. For added convenience and affordability, the OD-685C samples are available on tape and reel. The new deep red SMD LED is RoHS and REACH compliant.

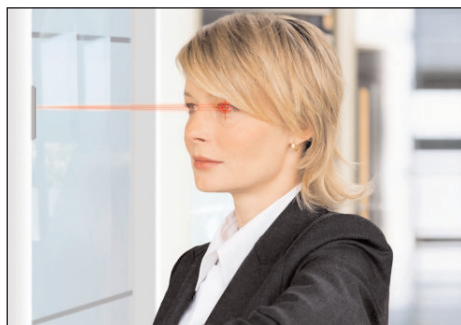
www.optodiode.com

Osram launches more evenly illuminating Oslux IR LED for iris scanners

At the 2017 Mobile World Congress (MWC) in Barcelona, Spain (27 February – 2 March), Osram Opto Semiconductors GmbH of Regensburg, Germany is presenting a new infrared LED (IRED) for iris scanners. The firm says that the SFH 4787S illuminates the eyes so evenly that the software identifying the iris pattern now hardly needs to correct artefacts. Like its predecessor, its direction of emission is slightly angled rather than vertical.

Iris recognition is among the most reliable biometric identification methods. Iris scanners illuminate the eyes with infrared light and a camera takes a photograph. Special software then uses this to detect the iris pattern, which is unique to each individual.

Two years ago, Osram Opto was first to market an infrared LED that brought this technology to smartphones and other mobile devices. This was followed by a version where the direction of emission is slightly angled rather than vertical, to align with the camera's field of view. This eliminates the usual mechanical



aids needed to tilt the entire LED, simplifying the design process.

Even illumination simplifies processing

This third-generation Osram IRED for iris recognition meets another need in this application: the brightness differences in the camera images should ideally only originate from the iris pattern and not be additionally caused by a gradient in the illumination, so that the software needs to correct fewer artefacts when determining the iris pattern. With the SFH 4787S, Osram has thus developed an emitter with a flat light, optimizing the reflector and lens to ensure virtually constant intensity across the emitted light beam.

Apart from this, the SFH 4787S is almost identical to the predecessor SFH 4786S. Both are based on the compact 3.5mm x 3.5mm x 1.6mm large Oslux package. A wavelength of 810nm delivers high-contrast images for all eye colors. The emission direction is tilted by 8°, while the emission angle is ±18°. The optical output of this highly efficient emitter is 720mW at a current of 1A, with a radiant intensity of 1000mW/sr.

Industrial applications gaining

The impetus to develop more compact and reliable iris scanners was driven by the need for dependable solutions to safeguard mobile devices from unauthorized access. The technology is now gradually making its way into other sectors. "Access control as a whole is becoming increasingly important, and iris recognition remains one of the most reliable methods here," says marketing manager Bianka Schnabel. "Following in the footsteps of consumer markets, we are now also seeing an upswing in interest from various industries."

www.osram.com

Leti presents 873x500-resolution, 10µm-pixel-pitch micro-LED displays at Photonics West

At SPIE Photonics West 2017 in San Francisco, micro/nanotechnology R&D center CEA-Leti of Grenoble, France presented a micro light-emitting diode (µLED) fabrication process for creating high-resolution arrays at 10µm pitch. That pixelization, and the 873 x 500 resolution that are enabled by the new process, exceed state-of-the-art technology, it is claimed.

Designed for micro-display applications such as augmented-reality (AR) or virtual-reality (VR) tools and wearable devices, the blue or green GaN/InGaN µLED arrays use Leti's proprietary self-aligned technology (key to achieving such a

small pixel pitch). A combination of several damascene metallization steps used to create a common cathode is also expected to provide good thermal dissipation and prevent voltage drops within the micro-LED matrix. Electro-optical measurements show record efficiency and brightness exceeding requirements for device integration.

"Leti's self-aligned process allows the creation of high-resolution µLED matrices with a reduced pixel pitch of 10µm and paves the way towards even smaller pitches for next-generation devices," says Ludovic Dupré, one of the paper's authors. "In addition, the use of the

damascene metallization process of the cathode, which also is a new process developed at Leti, is a breakthrough compared to previous demonstrations of µLED matrices. The common cathode indeed fills the whole volume between the µLEDs and provides metallic spreading of electrical current between them, as well as thermal dissipation," he adds. "These results are promising for integrating a µLED matrix in micro-display devices by hybridization on CMOS active matrices, and first prototypes are currently being tested."

<http://spie.org/photonics-west.xml>
www.leti.fr/en

Room-temperature single-photon emission demonstrated from defects in GaN films

Team now integrating sources with on-chip devices to develop commercial prototype

Demand for faster computers is growing rapidly and the rise of 'big data' demands that novel solutions are explored to deliver quicker results.

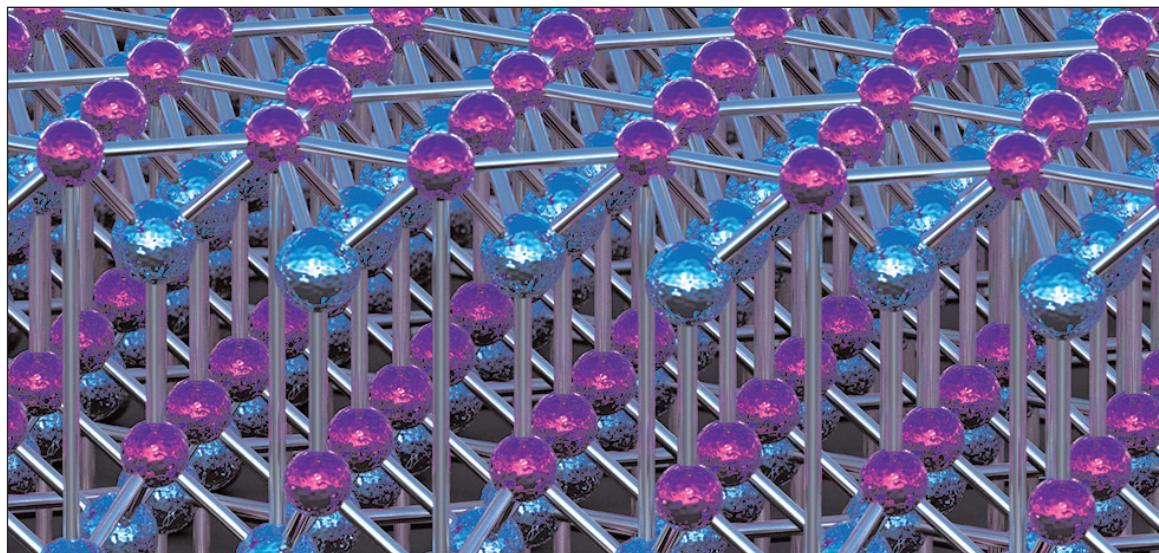
Weather prediction systems, computation modelling of protein structures and the ever-increasing need for safer communications of confidential data are examples of information that needs to be crunched

swiftly. Several platforms are in competition to realise quantum technologies, and among the most promising is one based on a generation of non-classical light sources.

The team of associate professor Igor Aharonovich of Australia's University of Technology Sydney (UTS) School of Mathematical and Physical Sciences (MAPS) and PhD student Amanuel Berhane — in collaboration with professor Dirk Englund and his group at the USA's Massachusetts Institute of Technology (MIT) — have demonstrated that this technology can be realized through commercially available gallium nitride ('Bright Room-Temperature Single-Photon Emission from Defects in Gallium Nitride' Advanced Materials; DOI: 10.1002/adma.201605092).

"Our technologies are based on ultra-bright light pulses that can carry the information at the speed of light, paving the way for quantum cryptography and optical quantum computing," says Aharonovich. "We're developing new solutions for secured communications and quantum information."

Berhane conducted the research that led to this latest discovery of GaN emitters early in 2016.



"Evaluating the properties of the new single-photon source in GaN against some of the criteria set for futuristic devices such as brightness and polarization, we concluded the emitters in GaN hold great potential," he says. The UTS team is focused on identifying and rendering

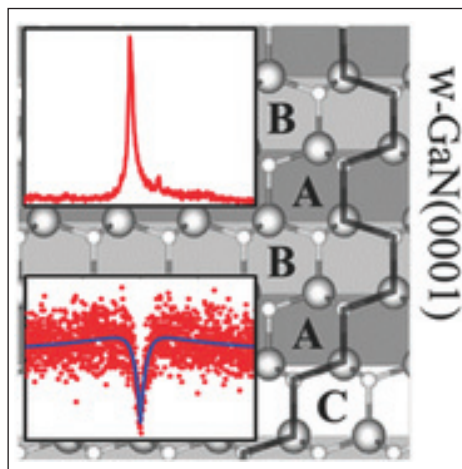
The team used experimental and numerical modelling to identify a unique arrangement of structural defects in gallium nitride as being the source of emission

semiconductor platforms that would make possible photon-based fast computing. "We work with technologically compatible materials, so the next step to build a quantum processor is becoming more and more viable," Berhane notes.

The team used experimental and numerical modelling to identify a unique arrangement of structural defects in GaN as being the source of emission, says co-author professor Milos Toth of UTS. "Our work demonstrates novel single-photon emission from gallium nitride films, a material that is already a viable platform for LEDs," he adds. "The emission has observed different films having varying thickness and structures."

The team is now focused on integrating these sources with on-chip devices to develop a commercial prototype. Most quantum technologies (such as quantum computers) are still largely in the research stage, with significant strides being made in lab demonstrations. This research demonstrates that use of those technologies is drawing closer, believes the team.

<http://onlinelibrary.wiley.com/doi/10.1002/adma.201605092/full>
www.uts.edu.au



SoraaLaser presents expanded LaserLight source technology at Strategies in Light

At the Strategies in Light conference in Anaheim, CA (28 February – 2 March), SoraaLaser of Goleta, CA, USA (which is commercializing visible laser light sources for display, automotive and specialty applications) presented its expanded light source technology, including LaserLight-SMDs, LaserLight MicroSpot modules with various beam-shaped illumination, LaserLight Fiber modules with dynamic illumination, and LaserLight Fiber modules with remote micro luminaires. These light sources are said to provide unique performance properties and advantages over LED, OLED, and legacy sources in specialty lighting applications.

SoraaLaser's visible laser light sources are based on its proprietary and patented semi-polar GaN laser diodes, combined with phosphor technology. The laser light sources provide novel properties compared with other light sources by combining the benefits of solid-state illumination (such as minimal power consumption and long lifetime) with the highly directional output that has been possible only with legacy technology.

Because the laser light is focused to a small spot on the phosphor and converted to white light, SoraaLaser says that its light sources deliver high luminance and enable safe, highly collimated white light output, superior optical control with miniature optics and reflectors, along with high-efficiency fiber-optic transport and glare-free waveguide delivery.

SoraaLaser is an independent spin-off from Soraa Inc of Fremont, CA, USA — which develops solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates — and was co-founded by the 2014 Nobel Laureate in Physics Dr Shuji Nakamura, Dr Steve Denbaars, Dr James Raring, and Dr Paul Rudy.

At Strategies in Light, SoraaLaser also presented during the session 'Laser Light Sources For Specialty Illumination Applications'.

In the last six months, the technology has received three recognitions:

- 2017 Sapphire Award Finalist, Illumineer of the Year;
 - inclusion in the 2016 IES Progress Report; and
 - 2017 PRISM Award Finalist from SPIE Photonics Media.
- www.soraalaser.com



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Walter Schottky Institute demonstrates first electrically pumped, single-mode, tunable VCSELs emitting cw up to 4 μ m

Buried tunnel junction with single-stage GaSb-based type-II quantum well active region extends VCSEL wavelength range to mid-IR

A group of researchers at the Walter Schottky Institute at Germany's Technische Universität München (TUM) has developed a buried tunnel junction VCSEL with a single-stage type-II active region to extend the wavelength coverage of electrically pumped vertical-cavity surface-emitting lasers (VCSELs).

One of the main applications of VCSELs is in gas sensing. Gases each have a unique set of energies they can absorb, derived from their molecular structure. These sets of absorption lines are akin to fingerprints, which enables unambiguous and sensitive detection with a suitable tunable laser such as a tunable VCSEL.

There are several important gases that are detectable with mid-infrared (mid-IR) light with wavelengths of 3–4 μ m, including methane, carbon dioxide and nitrogen dioxide. Application-grade VCSELs, however, aren't yet available for this wavelength range, but the increasing need for compact, portable and affordable gas sensors is spurring demand for energy-efficient semiconductor sources of mid-IR light.

Addressing this demand, the team of researchers set out to develop a concept to extend the wavelength coverage of VCSELs into this important regime (Ganpath Kumar Veerabathran et al, 'Room-temperature vertical-cavity surface-emitting lasers at 4 μ m with GaSb-based type-II quantum wells', *Appl. Phys. Lett.* 110, 071104 (2017)).

Typical VCSELs suffer in performance for the relatively long wavelengths of the mid-IR range, in part due to side effects of heating that disproportionately affect IR wavelengths. However, these effects are minimized by the buried tunnel junction configuration of the

VCSELs, where a material barrier is embedded between the standard p- and n-type materials. This structuring results in resistance-like behavior for the device and provides tunability of the optical properties in the desired range.

Once sensing systems become more affordable, there is great potential for deployment by industries such as the auto industry for emission monitoring and control, and these systems may even find uses within our homes

"The buried tunnel junction VCSEL concept has already yielded high-performance VCSELs within the entire 1.3–3 μ m wavelength range," says Ganpath K. Veerabathran, a doctoral student at the Walter Schottky Institute. "And so-called type-II 'W' quantum well active regions have been used successfully to make conventional edge-emitting semiconductor lasers with excellent performance within the 3–6 μ m wavelength range."

By combining the tunnel-junction VCSEL concept with these conventional edge-emitting laser designs, where the beam is emitted in parallel with the bottom surface, in this wavelength regime, the researchers created a buried tunnel junction VCSEL with a single-stage, type-II material active region to extend the wavelength coverage of electrically pumped VCSELs.

The development is reckoned to be the first known demonstration of electrically pumped, single-mode, tunable VCSELs emitting continuous wave up to 4 μ m. "It marks a

significant step from state-of-the-art devices emitting at 3 μ m in a continuous wave, and up to 3.4 μ m in pulsed mode, respectively," says Veerabathran. "Further, our demonstration at 4 μ m paves the way for application-grade VCSELs within the entire 3–4 μ m wavelength range, because the performance of these VCSELs generally improves at shorter wavelengths."

Although gas-sensing systems within this wavelength range are already available using other types of lasers, they are considered to be power hogs compared to VCSELs, note the researchers. They also tend to be cost-prohibitive, and are mainly used by industries to detect trace gases for safety and monitoring applications, they add.

"The 4 μ m VCSEL demonstrates that low-power, battery-operated, portable and inexpensive sensing systems are within reach," Veerabathran says. "Once sensing systems become more affordable, there is great potential for deployment by industries such as the auto industry for emission monitoring and control, and these systems may even find uses within our homes."

Next, the group will focus on making improvements "in terms of the maximum operation temperature and optical output power of the VCSELs," Veerabathran says. "In the future, it may be possible to extend this concept to make VCSELs emit further into the mid-infrared region beyond 4 μ m. This would be beneficial because the absorption strength of gases typically becomes orders of magnitude stronger, even for relatively small wavelength increases," he adds.

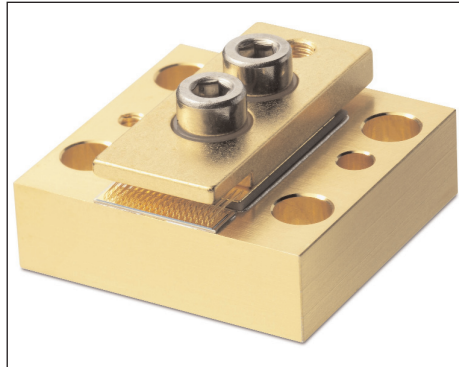
www.wsi.tum.de
<http://aip.scitation.org/doi/full/10.1063/1.4975813>

II-VI Laser Enterprise launches 170W passively cooled & 250W actively cooled laser bars for direct-diode lasers

The Zurich, Switzerland-based II-VI Laser Enterprise GmbH division of engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA (which provides high-power semiconductor laser components enabling fiber and direct-diode laser systems) has launched 170W passively cooled and 250W actively cooled laser bars.

Direct-diode lasers used in industrial sheet metal cutting, welding and additive manufacturing are achieving up to tens of kilowatts of output power using wavelength and polarization multiplexing of multiple high-power gallium arsenide (GaAs) laser bars. II-VI says that its new passively and actively cooled laser bars enable high efficiency coupling into optical fibers due to their mechanical flatness properties or 'low smile'. They also feature a critical and proprietary hard solder technology that is designed to withstand the high-power pulsed and on/off operation typical for direct-diode lasers.

"We continue to advance our high-power GaAs semiconductor



II-VI Laser Enterprise's new 170W passively cooled laser bar.

platform to extend our broad portfolio of seed lasers, pump lasers and laser bars that enable next-generation fiber and direct-diode lasers," says II-VI Laser Enterprise's general manager Karlheinz Gulden. "The use of direct-diode lasers in additive manufacturing to repair high-wear industrial tools is one of the more recent and exciting applications enabled by our new laser bars."

The 170W passively cooled and 250W actively cooled lasers bars are available over a wide wave-

length range of 790–1070nm to enable a variety of wavelength-multiplexed laser designs. Both products feature II-VI's proprietary E2 front-mirror passivation, preventing catastrophic optical damage (COD) to the laser diode facet even at extremely high output powers. II-VI also offers high-power laser optics, based on magneto rheological finishing and IBS coatings, for beam management and to fiber-couple direct-diode lasers.

II-VI Inc's capabilities were showcased at SPIE Photonics West 2017 in San Francisco (31 January — 2 February), highlighting the advances that the firm's material science and technology platforms have made possible for materials processing, industrial machine tools, biomedical instrumentation and military applications. II-VI is launching several new high-power semiconductor laser chips, modules and bars as well as high-power laser optics for next-generation CO₂, fiber and direct-diode lasers.

<http://spie.org/photonics-west.xml>
www.laserenterprise.com

II-VI Inc exhibits at Photonics West

At SPIE Photonics West 2017 in Moscone Center, San Francisco (31 January—2 February), II-VI Inc exhibited its portfolio of products, including high-power semiconductor lasers, laser optics, precision optics and beam delivery solutions, for laser-based materials processing equipment, metrology equipment in life sciences, semiconductor equipment, optical communications, 3D sensing and the military.

Specifically, II-VI Inc showcased its new 170W passively cooled and 250W actively cooled laser bars for direct-diode lasers, as well as the new 976nm wavelength-stabilized multimode pump laser modules, which can offer up to 20W of



II-VI Inc's new 976nm wavelength-stabilized 20W pump laser module.

output power for ultrafast fiber lasers.

Also, at the SPIE LASE conference, II-VI gave the following technical presentations:

- 'A cutting-edge solution for 1 μ m laser metal processing'; and
- 'Diode lasers for direct application by utilizing a trepanning optic for remote oscillation welding of aluminum and copper'.

In addition, II-VI Inc's president & CEO Chuck Mattera participated on the SPIE Executive Panel 'The seven biggest challenges executives will face in 2017'.

Later on the same day, during a gala awards ceremony at the San Francisco Marriott Marquis, Mattera presented at the PRISM Awards for Photonics Innovations, where he announced the winner in the Materials and Coatings category.

<http://spie.org/photonics-west.xml>
www.ii-vi-photonics.com

POET streamlines organization and makes key new appointments

Efficiency and productivity of commercial platform being maximized as part of integration of DenseLight acquisition

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 announced organizational changes to streamline the executive roles and operations of the consolidated organization, including a realignment of management responsibilities and key new appointments.

The acquisition on 11 May 2016 of Singapore-based DenseLight Semiconductor Pte Ltd was undertaken for strategic reasons including:

- to expand the POET's development facilities and capability; secure internal fab capacity; facilitate customer engagements across multiple product lines; and access established distribution channels.

As part of ongoing integration efforts over the past seven months, both POET and newly hired DenseLight executives have been conducting a strategic review of the organizational, functional and operational structure of the DenseLight fab. In support of management's effort to streamline the consolidated organization as well as further leverage its DenseLight subsidiary, POET has made the following appointments:

- Rajan Rajgopal as president & general manager of DenseLight, replacing Jerry Rodriguez who has resigned but will remain on DenseLight's board and continue to act as an advocate for POET. Rajgopal has previously had senior executive roles with firms such as Micron, GLOBALFOUNDRIES and Texas Instruments. He holds an MSEE degree from the University of Maine and a BSEE degree from the University of Texas at Austin.
- Soma Sankaran as DenseLight's VP of sales for the Asia-Pacific

region; current senior VP of sales & marketing Bryan Patmon will shift his primary focus to sales efforts in Europe and North America. Most recently, Sankaran led sales activity in the South Asia Pacific region for LED maker Cree Inc, where he identified and penetrated multiple new countries and implemented sustainable long-term growth strategies. Previously, he held sales as well as product and field engineering roles at Avago, Agilent and Hewlett Packard.

- Dr HaiQun Zheng as VP of DenseLight's Field Application Engineering organization (overseeing POET's critical applications engineering initiative). Zheng has 20 years of experience in optoelectronics research, engineering and sales, including new product introductions, production planning, inventory management as well as supply-chain management.

- Patrick Thong as DenseLight's VP of operations, reporting to Rajgopal. Thong has more than two decades of experience in semiconductor fab operations, including plant operations, new-product initiatives, technology development,

As part of the ongoing integration of our DenseLight subsidiary, we've continued to carefully evaluate the organizational, functional and operational elements of the business. We are significantly streamlining the consolidated organization in order to maximize the efficiency and productivity of our commercial platform

supply chain management, logistics as well as strategic sourcing. He has specific experience in end-to-end manufacturing — starting from new product introductions to pilot runs, and ultimately full-scale production and contract manufacturing.

Also, in support of consolidating operations and product development efforts and to achieve greater cost efficiencies, organizational changes have been taken to streamline POET's leadership team and conserve cash resources.

Chief operating officer Dr Subhash Deshmukh has resigned (effective 13 January) and assumes a new part-time role as special advisor to the CEO, driving and leading special projects for the firm.

Chief financial officer Thomas Mika will fill the position Deshmukh previously held on DenseLight's board. The resulting vacancy in the COO position is not expected to be filled, as the firm's staff in Singapore will perform the various facets of this role in coordination with Mika.

Also, POET has eliminated the post of corporate chief technology officer, held by Daniel Desimone (who is no longer with the firm). The role of CTO will be assumed by CEO Dr Suresh Venkatesan, who is familiar with and had already been overseeing POET's technological development and product roadmap.

"As part of the ongoing integration of our DenseLight subsidiary, we've continued to carefully evaluate the organizational, functional and operational elements of the business," says Venkatesan. "With these realignment actions, we are significantly streamlining the consolidated organization in order to maximize the efficiency and productivity of our commercial platform," he adds. "The individuals we've appointed bring tremendous depth of experience to POET. Collectively, they

meaningfully enhance our existing product development and sales efforts, while also helping to ensure that we fully capitalize on the value of our fab and POET's international operations."

Finally, as part of the announced realignment, POET is formally dissolving its Technology Roadmap Advisory Board (TRAB), which was originally established specifically to monitor its critical 'lab to fab' transition program. POET management believes that this oversight committee is no longer necessary following the addition of critical technologically centered staff through the acquisitions of both DenseLight and (in May 2016)

BB Photonics Inc (a designer of integrated photonic solutions for the data communications market), as well as with recently hired new executives. The TRAB's members will remain available to offer support and informal guidance to POET's internal management committees.

POET is formally dissolving its Technology Roadmap Advisory Board (TRAB), which was originally established specifically to monitor its critical 'lab to fab' transition program

Grant of options

POET also announced the granting of incentive stock options under its stock option plan to Thomas Mika (effective 16 January), consisting of the right to purchase up to 500,000 common shares. All of these options are exercisable at CAD\$0.385 per share. The options vest in stages over a period starting on 16 January 2018 and ending 16 January 2021. They were granted subject to provisions of the firm's stock option plan, which was approved by shareholders on 7 July 2016 and are subject to the TSX Venture Exchange policies and applicable securities laws.

www.poet-technologies.com

DenseLight expands narrow-linewidth laser range for test & measurement applications

At the Photonics West 2017 in San Francisco (31 January to 2 February), DenseLight Semiconductors (a subsidiary of POET Technologies Inc of San Jose, CA, USA that makes lasers for optical sensing applications) unveiled its next-generation Constellation Series of narrow-linewidth laser (NLWL) solutions for test & measurement applications. Introduced specifically to meet superior relative intensity noise (RIN) performance and ultra-narrow linewidths requirements, the new product family simplifies the overall design process for OEMs while shortening development time and accelerating time-to-market, claims the firm.

Designed specifically to provide low-noise capability with narrow linewidths (increasingly a requirement for optical sensing solutions spanning a number of end-market applications), the Constellation Series integrated light modules [CBF Series] offers narrow spectral linewidths (e.g. 10, 5 and 1kHz), excellent side-mode suppression ratio (SMSR), power stability and a very high wavelength stable laser output, claims the firm. These feature sets suit a wide range of high-precision remote sensing system

applications, including wind-farm LIDAR; meteorological atmospheric LIDAR; distributed acoustic sensing (DAS); perimeter intrusion detection systems (PIDS); distributed strain and temperature sensing using Brillouin optical time domain reflectometry (BOTDR); precision optical metrology & instrumentation; and high-resolution optical gas & chemical sensing.

"Our newest family of laser products delivers the most reliable laser performance with the lowest noise output," claims DenseLight's senior VP of sales & marketing Bryan Patmon. "We are greatly simplifying the process for customers to create and implement integrated systems and solutions with advanced capabilities."

The first Constellation Series product (CBF-9) is complete with a proprietary specialty laser module fixed into a newly designed hermetically sealed butterfly package, as well as an integrated laser driver and temperature controller. Premiering with a C-band laser, the CBF series will eventually be extended across a wide wavelength range, including the O, E, S, C and L bands. The new CBF platform can be customized for multiple use

and application options to meet customers' specific requirements.

Engineering samples are expected to be available in second-quarter 2017, with production beginning in second-half 2017.

A new family of derivative gain chips

DenseLight has also expanded its product portfolio of gain chips, based on proprietary indium phosphide (InP) active waveguide designs to provide high optical gain over a broad wavelength range and near-circular optical far-field profile. Gain chips are typically integrated in external cavity laser (ECL) systems as the laser gain source. The gain chip is delivered as chip or chip-on-submount, with high-reflectivity (HR) coating on the back facet and low-reflectivity anti-reflecting (AR) coating on the angled front facet. DenseLight says that its gain chip family will feature very stable operational characteristics as well as superior tuning capabilities. The gain chip product portfolio will offer ASE optical peak wavelength coverage spanning 1260–1650nm.

www.denselight.com
www.poet-technologies.com/constellation-series

Source Photonics expands investment in next-generation FTTx product technologies and operations

Firm to support access network upgrade cycle from EPON and GPON to 10GEPON and XG(S)PON

Optical communication component and module maker Source Photonics Inc of West Hills, CA, USA has expanded investments in its 10G passive optical network (PON) optical line terminal (OLT) and optical networking unit (ONU) product lines to support the upcoming fixed access network upgrade cycle from EPON and GPON to 10GEPON and XG(S)PON. The firm reckons that its investment at all levels of manufacturing, including laser chips and advanced optical modules will enable it to remain the highest-volume vertically integrated provider in the market.

Several industry participants have

publicly announced an exit from the FTTx transceiver market due to eroding margins and declining competitiveness, says Source Photonics. The firm, which initially entered the market supporting BPON in the early 2000s, will increase investments fivefold on last year to support the rapid growth of volumes expected during the 10G migration. It is concurrently investing in key technologies necessary to support future 25G and 100G migrations.

Leveraging its vertically integrated business model and lean manufacturing facilities, the firm's investments include capacity to support externally modulated laser (EML)

laser diode and optical sub-assembly volumes projected by customers and policy regulators. "Over the last two years, we successfully ramped our 100G product line to world-class levels of performance," says CEO Doug Wright. "We are expanding this operating infrastructure as we support early deployments of next-generation FTTx networks."

10GEPON OLT modules manufactured on the expanded lines are in production and currently available for order. XGPON and XGSPON OLT modules expected to be released later this year will leverage the same manufacturing assets.

www.sourcephotonics.com

Synopsys and PhoeniX present PIC design using OptSim Circuit and OptoDesigner

At SPIE Photonics West 2017 in Moscone Center, San Francisco (28 January – 2 February), the Optical Solutions Group of Synopsys Inc (which provides software, IP and services used to accelerate innovation in chips and electronic systems) and PhoeniX Software B.V. of Enschede, The Netherlands — a vendor of photonic design automa-

tion (PDA) software used to synthesize integrated photonic circuits — showcased software solutions enabling the design of accurate, easy-to-manufacture integrated photonic devices and systems.

On 1 February there was an Information Session open to all people interested in learning more about better integrated design flows,

allowing high-level photonic integrated circuit (PIC) design capture in Synopsys' schematic PIC simulation environment OptSim Circuit and final mask layout creation and verification in PhoeniX Software's OptoDesigner.

<http://spie.org/photonics-west.xml>

www.synopsys.com

www.phoenixbv.com

Firecomms appoints Americas field applications manager

Firecomms Ltd of Cork, Ireland and Tongxiang, China (which makes fiber-optic solutions and optical transceivers for communications networks) has appointed Dylan Loughnan as its new field applications engineering manager for the Americas.

As the firm's primary technical resource for the growing Americas market, Loughnan will support customers in the development of fiber-optic solutions. Customers — from a wide variety of markets including

industrial automation, transportation, medical imaging, renewable energy and home networking — will benefit from his expertise with the firm's portfolio of fiber optic transceivers and related solutions, the firm reckons.

"As a senior member of the engineering and technical staff, Dylan has been involved in all aspects of the development of Firecomms product roadmap as well as providing advanced technical support to our customers," comments

Lawrence Thorne, VP of sales & marketing, the Americas. "Having a strong technical resource close at hand will benefit our customers in this region."

Based in Boston, Loughnan has been with Firecomms for over four years, most recently as a senior product design engineer. He has an advanced physics degree from Cork Institute of Technology (CIT) with graduate research experience at Massachusetts Institute of Technology.

www.firecomms.com/products

Kaiaam recruits former PLM director at Lumentum/JDSU as VP of sales

Kaiaam Corp of Newark, CA, USA — a private company founded in 2009 commercializing hybrid photonic integrated circuit (PIC) technology for pluggable optical transceivers in data-centers — says that Sherwin Cabatic has joined it as VP of sales, leading the global sales team and reporting to president & CEO Dr Bardia Pezeshki.

“Kaiaam is continuing its rapid sales growth and customer base expansion,” says Pezeshki. “Sherwin brings a wealth of industry experience,



Sherwin Cabatic.

market knowledge, and relationships that are a great fit for our organization and the global markets we serve,” he adds. “The data-center optical interconnect space is incredibly dynamic, driven by strong fundamentals,” notes Cabatic. “Kaiaam is well positioned with the right

products, technology, and team.”

Cabatic has been in the industry for over 20 years, and has served in leadership roles at New Focus, Bookham, and Opnext; most recently coming from Lumentum/JDSU, where he was the PLM director for the datacom business. He has a BSME in Mechanical Engineering from Santa Clara University and an MS-MSE, Mechanical Engineering from Stanford University.

www.kaiaam.com

NeoPhotonics launches low-power-consumption 28GBaud EML with integrated driver for 100, 200 and 400G data-center and client-side applications

NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated optoelectronic modules and subsystems for high-speed communications networks) has launched a low-power-consumption 28GBaud externally modulated laser (EML) with an integrated driver, which is designed for client-side 4x25 NRZ 100G, 4x50 PAM4 200G and 8x50 PAM4 400G applications. The new EML joins NeoPhotonics’ family of EML lasers, which are currently shipping in high volume for 100G data-center and client-side applications.

Data-center operators and service providers are actively deploying client-side interface transceivers at 100Gbps and 200Gbps — and moving rapidly towards 400Gbps — leading to ever increasing demands for lower-power-consumption and smaller-form-factor components. NeoPhotonics’ existing suite of 28GBaud EML lasers offer a solution for 100G client interfaces and are shipping in high volume. In a typical 100G client application, a stand-alone driver is needed between the CMOS-

based CDR (clock & data recovery) IC and the EML to provide enough modulation voltage swing to the EML. The driver typically consumes around 1W of electrical power and occupies more than a square centimeter of board space inside the 100G transceiver.

NeoPhotonics’ new 28GBaud EML integrates a driver — which utilizes NeoPhotonics’ low-power linear gallium arsenide amplifier technology — with the 28GBaud EML at the chip-on-carrier (CoC) level. The CoC assembly fits into a four-channel transmitter optical sub-assembly (quad TOSA) designed for 100Gbps QSFP28 and CFP4 form factors, eliminating the need for a separate driver on the board. Users can then directly link the CMOS-based CDR IC to NeoPhotonics’ 28GBaud CMOS-drivable EML, and benefit from simplicity, low power consumption, and space savings. In PAM4 applications, the integrated linear driver makes the new CMOS-drivable 28GBaud EML an option for 200Gbps and 400Gbps applications due to the simple and direct connection to the PAM4/CDR IC.

“Our first-in-the-industry CMOS-

drivable 28GBaud EML simplifies 100G, 200G, and 400G transceiver designs, provides a reliable solution for an EML-based quad TOSA, and allows a 100G QSFP28 to meet the challenging target power consumption of 3.5W,” says chairman & CEO Tim Jenks. “This new product is based on our advanced hybrid photonic integration technology, and integrates our proven indium phosphide (InP) EML and gallium arsenide (GaAs) driver technologies together to achieve significant power and size reductions for the next-generation 100G, 200G and 400G data-center and client-side applications,” he adds.

NeoPhotonics’ CMOS-drivable EML is being designed into the firm’s next-generation client-side 100G, 200G and 400G transceivers and will be available to external customers in second-half 2017. The new EML, along with NeoPhotonics’ broad suite of products for line- and client-side 100G-and-beyond products, is being displayed in booth 3017 at the Optical Fiber Communication Conference & Exposition (OFC 2017) in Los Angeles (21–23 March).

www.ofcconference.org

Oclaro's quarterly revenue rise of 14% drives further records in gross margin and operating income

March-quarter to grow further, despite seasonal price cuts and sub-40G drop off

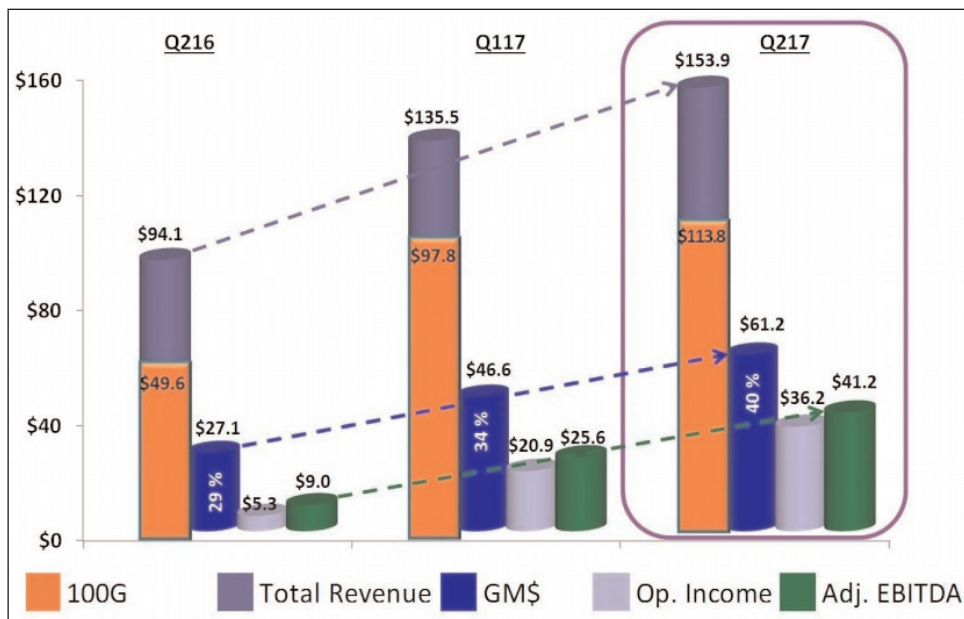
For fiscal second-quarter 2017 (to end-December 2016), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has reported revenue of \$153.9m, up 14% on the record \$135.5m last quarter and up 64% on \$94.1m a year ago.

Growth was driven by 100G-and-beyond product revenue of \$113.8m (74% of total sales), up by 16.6% on \$97.8m (72% of total revenue) last quarter and by 130% on \$49.5m (53% of total sales) a year ago, driven mainly by the ramp up in demand for the CFP2-ACO product.

For 40G-and-below products, revenue was \$40.1m (26% of revenue), down by 10% on \$44.6m (47% of revenue) a year ago but up by 6.4% on \$37.7m (28% of revenue) last quarter. Of this, 10G products grew strongly by almost \$5m from last quarter, driven by very strong demand for the firm's 10G tunable product portfolio, compensating for the drop-off in 40G product revenue.

By end-market, client-side (datacom) sales were \$69.8m (45% of total revenue), up by 2% on \$68.4m (50% of revenue) last quarter and by 37% on \$51m (54% of revenue) a year ago. Line-side (telecom) sales were \$84.1m (55% of total revenue), up by 25% on \$67.1m (50% of revenue) last quarter and by 95% on \$43.1m (46% of revenue) a year ago, after growing 25% sequentially, driven by operational execution on the 100G CFP2-ACO product line.

China continues to be very strong, growing 9% sequentially. Nevertheless, by region, China comprised 42% of total revenue (down slightly from 43% last quarter), Southeast Asia 26% (up from 23% last quarter),



the Americas 21% (up from 19%), and Europe, Middle East & Africa (EMEA) 10% (down from 13%).

"Our December quarter was very strong, with improvement in all our financial metrics," says CEO Greg Dougherty "In addition, we had record gross margin and operating income resulting from higher revenue, a richer product mix, and favorable foreign exchange rates," he adds.

On a non-GAAP basis, gross margin has risen further, from 28.8% a year ago and the record 34.4% last quarter to 39.8% (well above the 33–36% guidance), driven by a richer 100G and 10G product mix. Without the benefit of a favorable foreign-exchange related to the Yen, gross margin would have been 38%.

Operating expenses have fallen from \$25.8m (19% of sales) last quarter to \$25m (16% of sales), although OpEx benefited by \$1.1m from the weaker yen and pound.

Operating income has risen further, from \$5.3m (6% of sales) a year ago and the record \$20.9m (15% of sales) last quarter to \$36.2m (24% of sales), well above the

\$22–26m guidance.

Likewise, net income has risen further, from \$3.1m (\$0.03 per diluted share) a year ago and \$20m last quarter (\$0.14 per diluted share) to \$36.3m (\$0.21 per diluted share).

Adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) has risen further, from \$9m a year ago and \$25.6m last quarter to \$41.2m. Hence, after subtracting capital expenditure (CapEx) of \$17.2m (up from \$14.2m last quarter) and working capital (including prepaid expenses) of \$9.8m (up from \$6.8m), overall cash, cash equivalents, restricted cash and short-term investments hence rose during the quarter by \$14.2m from \$229.3m to \$243.5m.

For fiscal third-quarter 2017 (ending 1 April), Oclaro expects revenue to rise to \$156–164m, driven by healthy demand across multiple markets. This is despite the seasonal price negotiations (towards the more favorable end of the usual 10–15% reduction) and a projected drop in revenue of several million dollar from 10G and 40G product lines. Specifically, 40G-and-below product revenue should be in the

► mid-\$30m range, and is expected to drop by another few million dollars in fiscal Q4 as Oclaro ends the 40G line-card program (then remaining in the low- to mid-30s for the rest of the year, as 10G has a very long tail). Gross margin should fall to 36–39%. Operating income is expected to fall slightly to \$32–36m.

"At today's current exchange rate, we believe we can maintain operating expenses of 16–18% [as a proportion of revenue] for this year, with R&D of 9–10% and SG&A of 7–8% of revenue," says chief financial officer Pete Mangan.

Regarding CapEx for the remainder of fiscal 2017, Oclaro expects to invest \$40–50m to expand manufacturing capacity. In turn, an additional depreciation of about \$1m per quarter will start in the March quarter.

"Our technology leadership in the 100G-and-beyond, plus our tunable lasers, have us well-positioned for ongoing success," says CEO Greg Dougherty. "We continue to see strong demand for our products in the three market drivers that we've talked about during calendar year 2016: China, metro market and data-center applications," he adds. "We expect to see continuing strength in China as our 100G coherent port counts continue to grow and provincial network build-out increase. This translates into more growth for our narrow-linewidth tunable lasers, our lithium niobate modulators, and 100G client-side transceivers. Many of these products remain sold out. While we continue to experience sold-out conditions for our 100G client-side CFP transceivers during Q3, we do expect the shift to CFP2, CFP4 and QSFP28 transceivers to accelerate through the summer," Dougherty notes.

"We also continue to experience strong demand for our 10G tunable devices and modules. Here we're seeing a combination of a need for 10G metro applications, as well as the shift for using tunable transceivers such as the tunable SFP+ to replace fixed-wavelength modules.

In addition to all of this demand, we expect to see increasing CFP2-ACO activity in China throughout calendar year 2017," he adds.

"Finally, on China, the temporary export license for ZTE, which remains a greater-than-10% customer, is currently set to expire at the end of February. At this time, we do not expect to see interruptions in our ability to continue shipping product to ZTE," Dougherty notes.

"We expect demand for the CFP2-ACO in the metro market to stay strong and ramp through calendar year 2017. We are very well positioned with the two primary equipment suppliers to this market," believes Dougherty.

"We also continue to see very strong demand for the CFP2-ACO from both traditional equipment suppliers and new web 2.0 customers for data-center interconnect applications. We also expect to see this demand continue growing for 2017," he adds.

"Calendar 2017 will be year the 100G takes off for interconnection within the data center," he believes. "We continue to be sold out of capacity for QSFP28 LR4 and CWDM products for datacenters. We expect the market to be sold out or, at a minimum, remain very tight for at least all of the calendar year."

"The impact of datacenter architectures continues to broaden," notes Dougherty. "I am pleased with the increased penetration of core indium phosphide (InP) laser technology inside the datacenter, at

We expect demand for the CFP2-ACO in the metro market to stay strong and ramp through calendar year 2017. We also continue to see very strong demand for the CFP2-ACO from both traditional equipment suppliers and new web 2.0 customers for data-center interconnect applications

the edge of the datacenter, and between datacenters. Our proprietary building blocks such as indium phosphide tunable lasers, Mach-Zehnder modulators and directly or externally modulated high-speed lasers are proving to be key enablers to the massive and cost-effective scaling of the cloud infrastructure."

"Our multiple market drivers — China, the metro market and datacenters — continue to be healthy. We continue to have good visibility into the market demand in all three of these segments and we have several confirmed purchase orders that take us well into calendar year 2017," says Dougherty. "In addition, we've negotiated or are completing negotiations of several multi-year contracts or extensions contracts for some key product like the ACO that run as long as through calendar year 2018."

"We are now shipping beta units of our CFP8 PAM4 400G transceivers. The CFP8 utilizes our unique high-speed externally modulated laser (EML) technology. It is being shipped to enable design wins at network equipment manufacturers, where these transceivers will primarily be used in 400G system demonstrations and trials with leading service providers." Oclaro expects to ship qualified products in second-half calendar 2017.

"Given the strength of the markets that we are serving, combined with our technology leadership for 100G-and-beyond, we feel very good about our prospects not just for our Q3 as reflected in our guidance, but for the entire calendar year," says Dougherty. Oclaro hence expects to grow total revenue for full-year calendar 2017 by 25–30% compared with 2016. "We can maintain our gross margin in the upper 30–40% range," he believes. "This gross margin, when coupled with about 17% operating expenses, should leave us with the sustainable non-GAAP operating income as a percentage of sale in the high teens to low 20s."

www.oclaro.com

Lumentum's revenue grows 21% year-on-year to record \$265m, driven by 100G datacom growth of 537%

For fiscal second-quarter 2017 (to end-December 2016), optical and photonic product maker Lumentum Holdings Inc of Milpitas, CA, USA has reported record net revenue of \$265m, up 2.7% on \$258.1m last quarter and up 21% on \$218.3m a year ago, driven by strength in demand for 100G datacom, pump laser and submarine products.

Commercial Lasers revenue was \$28.4m (10.7% of total revenue), down 28.6% on \$39.8m last quarter and 12.6% on \$32.5m a year ago, driven by seasonal weakness in the micro-materials processing market, muted capital equipment spending in the semiconductor industry, and a major customer fiber-laser product transition (with fiber-laser revenue dropping from the record \$17.2m last quarter to just \$10.6m).

In contrast, Optical Communications revenue was \$236.6m (89.3% of total revenue), up 8.4% on \$218.3m last quarter and up 27.3% on \$185.8m a year ago, based on continued growth in datacom markets. Datacom revenue was \$68.1m, up 54.1% on \$44.2m last quarter and almost doubling from \$35m a year ago. In particular, by utilizing capacity added over the prior quarters, 100G datacom revenue grew 124% sequentially and 537% year-on-year to \$52m. "Despite the increased output for 100G datacom

product, our customers wanted more," says president & CEO Alan Lowe. Lower-speed datacom revenue continued to decline, to just 17% of datacom revenue. This growth was partially offset by Telecom revenue falling to \$160.1m, down 3.3% on \$165.6m last quarter, although up 16.1% on \$137.9m a year ago. Industrial & Consumer revenue (which includes 3D sensing revenue, as well as diode lasers for industrial applications) was \$8.4m, almost level with \$8.5m last quarter but down 34.9% on \$12.9m a year ago.

On a non-GAAP basis, gross margin has risen further, from 32.7% a year ago and 34.2% last quarter to a record 36.9%. This was driven by Optical Communications gross margin rising from 30.7% a year ago and 32.5% last quarter to 36.6%, due to the higher volume and the richer mix of new, higher-margin products including 100G datacom and WSS modules. In contrast, Commercial Lasers gross margin has fallen from 43.7% a year ago and 43.2% last quarter to 39.4% due to the impact of lower volume.

Operating expenses rose from \$55.5m (21.5% of revenue) last quarter to \$58.9m (22.2% of revenue). In particular, selling, general & administrative (SG&A) spending rose from \$21.7m to \$23.5m, while

R&D spending rose from \$33.8m to \$35.4m (due partly to increasing investment in 3D sensing).

Operating income rose further, from \$19.6m (operating margin of 9% of revenue) a year ago and \$32.7m (margin of 12.7%) last quarter to \$39m (record margin of 14.7%, exceeding guidance).

Net income was \$35.9m (\$0.57 per diluted share, exceeding guidance), up from \$30.7m (\$0.49 per diluted share) last quarter and \$19.1m (\$0.31 per diluted share) a year ago.

Capital expenditure (CapEx) is up from \$24m last quarter to \$35m. As well as expanding capacity for telecom and datacom products, Lumentum is adding equipment for emerging 3D sensing applications.

During the quarter, cash balance fell by \$10.9m from \$166.8m to \$155.9m, due to capacity expansion and timing of accounts receivable (AR) collections from customers.

For fiscal Q3/2017, Lumentum's net revenue should be flat to down at \$250–265m. "Seasonal factors will be more at play this year than they were last year (the start of a strong China ramp)," says Lowe. "Demand remained healthy, but sequential growth will likely be insufficient to overcome normal seasonality. Operating margin will fall to 12.5–14%. Diluted EPS will fall back to \$0.46–0.54 per share.

Lumentum unveils higher-output-power 200W ST2 pump laser

At SPIE Photonics West 2017 in San Francisco (31 January – 2 February), Lumentum showcased its new ST2 200W-output-power fiber-coupled pump laser module (available now in volume quantities) which also supports the 'build-your-own' kilowatt (kW) laser market.

"With its first generation of high-brightness pump lasers, Lumentum took a market leadership role in driving the 'build-your-own'

kW laser market ecosystem," says Dr Tomoko Ohtsuki, product line manager, Industrial Diode Lasers. "By designing in the ST2 200W pump laser, customers can easily scale their fiber laser powers to 2kW or higher, which is important due to the increasing adoption of multi-kilowatt lasers in machine tools where processing time and high-volume throughput are critical."

Powered by Lumentum's next-

generation diode laser chip, combined with optical and mechanical design innovations to achieve ultra-low optical loss and power management, the ST2 delivers 200W of power within 0.15 numerical aperture of a 135µm core fiber. The product has been rigorously tested for endurance and power stability to withstand prolonged use in manufacturing applications.

www.lumentum.com/en/products/diode-laser-9xx-nm-200w-ST2



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Emcore's quarterly revenue grows 18% to \$30.2m, driven by CATV

Transition of assembly from Langfang to automated facility in Beijing to be completed by end-March

For fiscal first-quarter 2017 (to 31 December 2016), 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 reported revenue of \$30.2m, up 17.9% on \$25.6m last quarter and up 34% on \$22.5m a year ago, and above the \$28–30m guidance.

“The cable TV market continues to drive revenue both for our DOCSIS 3.1 and RF-over-glass (RFOG) products,” notes chief financial officer Jikun Kim. “We continue to make solid financial progress during the quarter with strong top-line growth as the market continues to adopt the DOCSIS 3.1 solutions,” he adds. “We also recognized phenomenal growth on our SatCom & video and fiber-optic gyro product lines.” Emcore’s emerging chip products held steady in the quarter. Of fiscal Q1 revenue, cable TV comprised 80–85%, SatCom & video 5–10%, fiber-optic gyro 2.5–5%, and chip-level products 2.5–7.5%.

Within the cable TV market, Emcore continued to see strong sequential growth, with the business up about 19% on last quarter and 91% year-on-year. “The overall strength in the infrastructure side of cable television not only demonstrates the MSOs’ [multi-service operators’] commitment to deploying DOCSIS 3.1 fiber deep networks but also highlights Emcore’s leadership position within the space,” reckons president & CEO Jeff Rittichier.

On a non-GAAP basis, gross margin was 33.6%, down from the 35.6% gross margin last quarter (and down on the guidance of 34–36%). However, normalizing for the effects of \$350,000 in accelerated spending related to the Beijing manufacturing transition efforts,

gross margin would have been closer to 34.8%.

Operating expenses have risen from \$7.36m last quarter to \$7.78m, due to higher stock-based compensation expenses, annual performance bonus accruals, and year-end audit fees (raising selling, general & administrative expenses from \$4.96m to \$5.58m), offset by R&D investments being cut slightly from \$2.39m to \$2.2m. However, on a non-GAAP basis (adjusting for non-recurring items), operating expenses would have been level quarter to quarter.

Operating income has risen further, from \$2.5m (operating margin of 9.9% of revenue) last quarter to \$3.5m (operating margin of 11.5%). However, normalizing for the effects of the accelerated Beijing facility transition expenses, operating margin would have been closer to 12.7%, exceeding the 12.5% target. “With our improvement in non-GAAP operating margin to 11.5%, we are rapidly closing in on our target of 12.5% by the end of fiscal year 2017,” notes Rittichier.

Pre-tax income from continuing operations has risen further, from \$1.29m (\$0.05 per share) a year ago and \$2.59m (\$0.10 per share) last quarter to \$3.5m (\$0.13 per share).

“We demonstrated our improved manufacturing efficiency and operating leverage by growing non-GAAP pretax net income sequentially by approximately 35%,” says Rittichier.

We expect to end the fiscal second quarter with production almost completely shifted over to our new Emcore Asia facility, a key milestone in the evolution of Emcore

Capital expenditure (CapEx) has risen from \$1.3m last quarter to \$3.2m (remaining elevated due to the Beijing facility transition and the investments that Emcore is making in lasers). Depreciation & amortization was again about \$750,000. During the quarter, cash and cash equivalents fell from \$63.9m to \$62.2m.

Given the continued strength seen in the cable TV business, for fiscal second-quarter 2017 (to end-March) Emcore expects revenue of \$29–31m. “Fiscal Q2 has traditionally been a seasonally soft quarter due to weather limitations,” notes Rittichier. “Our roughly flat guidance is significantly better than planned.” Operating margin should be 9.5–11.5% (constrained by costs related to the Beijing facility transition being at a peak).

“We are still in the early innings of this network build-out, and are poised to benefit from our new products such as our LEML [linear externally modulated laser]-based solutions, which are being integrated across our product lines,” says Rittichier. “We remain optimistic about growth opportunities in this business, and expect to see strong upgrade spending for major and regional MSOs,” he adds.

“We look to expand our addressable market within the cable TV space with new products such as RF-over-glass. In our RFOG products, sales, marketing and engineering expense scaled down in lockstep with product margins,” says Rittichier. “We expect to see a bit heavier mix of the low end of our RFOG product in Q2, driving revenue and non-GAAP net income up in dollars, but at the expense of the gross margin line.”

Emcore’s 18-month transition to a hybrid EMS (electronics manufacturing services) model was nearly

► complete at the end of fiscal Q1. “We expect to end the fiscal second quarter with production almost completely shifted over [from the firm’s assembly operation in Langfang, China] to our new EA facility [Emcore Asia, the firm’s new, smaller automated facility near central Beijing], a key milestone in the evolution of Emcore,” says Rittichier. The new facility has now been audited by all major customers.

Within the SatCom and video markets, Emcore continues to see strong market share and close relationships with customers in legacy markets, while continuing to make progress on introducing new products for adjacent markets such as L-band link used by services such as Dish and DirecTV. “We are currently in the process of outsourcing our SatCom products to TAA [Trade Adjustment Assistance], which is essentially ‘Made in America’, an ITAR-compliant manufacturing

facility operated by our EMS partners,” says Rittichier. This transition was largely complete by the end of the fiscal first quarter. “We expect to see modest growth in the SatCom product line in fiscal 2017,” he adds.

“Our automation activities will have made us 180% more efficient on a cost of goods (COGS) per employee basis, while our outsourcing initiative continue to transform fixed expense to variable costs as we focus on processes where we can demonstrably add value over competing merchant electronic manufacturing facilities,” says Rittichier. These actions should lower Emcore’s breakeven revenue point by \$1–1.5m per quarter.

“The automation processes and cable TV module assembly that are responsible for the dramatic improvement in our commercial business were designed for dual use in our military program, allowing us to drive cost reduction and quality improvement in our US

manufacturing operation, even though the equipment was originally developed by our team in China,” notes Rittichier. “You should expect to see more of this automation development from us going forward, as we strive to make our US manufacturing operation capable of competing with offshore low-cost labor,” he adds.

“Moving on to the Chip market, we have begun production shipments of 10G parts at low volumes, and we are continuing our product development work to address the wireless and data-center markets, which we plan to enter toward the end of 2017,” says Rittichier.

“Emcore is working to become a broad supplier of chip-level products to the entire telecom industry, thereby optimizing our production mix between captive and merchant use, driving a higher blended margin for both our chip business and for the company overall.”

www.emcore.com

IDT to acquire GigPeak for \$250m

IDT adds GigPeak’s optical, RF and video transport technology

Integrated Device Technology Inc (IDT) of San Jose, CA, USA, which develops system-level mixed-signal solutions for the communications, computing, consumer, automotive and industrial markets, has agreed a tender offer to acquire GigPeak Inc of San Jose, CA, USA (formerly GigOptix) — which provides integrated circuits and software solutions for high-speed connectivity and high-quality video compression over the network and the cloud — for \$3.08 per share (\$250m in cash). This represents a premium of about 22% to GigPeak’s closing share price on 10 February.

The acquisition provides IDT with an optical interconnect product and technology business that is complementary to its position in real-time interconnect products.

GigPeak’s optical interface products are broadly used by companies in the communications, cloud data-center,

and military/aviation markets. IDT says that it will now provide seamless ultra-high-speed data connectivity products using electrical, RF and optical technologies.

“GigPeak is a recognized leader in high-performance optical, RF and video transport technology, and is a perfect fit for IDT. The products, technology and culture of GigPeak all complement and represent an acceleration of our current strategy,” comments IDT’s president & CEO Gregory Waters. “We gain an exceptional group of talented people and valuable intellectual property with the GigPeak team,” he adds.

“We find an exceptional culture, customers, business and technology compatibility with IDT,” comments GigPeak’s founder, chairman & CEO Dr Avi Katz. “Our leading product suite, which currently addresses the need for greater bandwidth across the network, will now have

the advantage of leveraging the scale of resources and broad distribution channels of IDT.”

The boards of directors of both GigPeak and IDT have unanimously approved the terms of the merger agreement, and GigPeak’s board will recommend that its stockholders accept the offer. Subject to customary conditions (including the tender of the majority of the outstanding GigPeak shares, the transaction — which is not dependent on a financing condition — is expected to close during second-quarter 2017, after which GigPeak will be delisted from the New York Stock Exchange and integrated into IDT.

The acquisition is projected to add \$16m in quarterly revenue at 70% non-GAAP gross margin, and to be immediately accretive to IDT’s earnings in the first full quarter following the transaction’s close.

www.gigpeak.com

First Solar awarded 140MW module supply contract for Australia's largest solar project

Cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA has been awarded the module supply contract for the 140MW_{DC} Sun Metals Solar Farm in North Queensland (QLD) which, once constructed, will be Australia's largest solar project and utilize more than 1,167,000 First Solar modules to produce about 270,000 megawatt-hours of energy in its first year of operation. Situated 15km south of Townsville, the project will supply electricity to the Sun Metals zinc refinery, which is a member of the metal processing technology firm Korea Zinc Group.

"Large-scale solar is fast becoming one of the most cost-effective sources of energy generation in Australia," says Jack Curtis, First Solar's regional manager for Asia Pacific. "This project represents the viability of the commercial and industrial

solar market in Australia, and the growing trend of major energy consumers owning and operating renewable energy assets."

First Solar claims that, with a track record across the solar value chain in Australia, it is the country's leading module supplier for large-scale solar projects. The firm says that its technology has a higher energy yield than crystalline silicon technology in Australia due to its lower temperature coefficient, linear shading response and superior spectral response. This is of particular importance in hot and humid climates such as Townsville, and over the

Large-scale solar is fast becoming one of the most cost-effective sources of energy generation in Australia

course of a project's operational life will translate to more energy output for Sun Metals.

Engineering, procurement & construction (EPC) of the project will be managed by RCR Tomlinson Ltd. "This is another milestone in our valued relationship with First Solar," says RCR's managing director & chief executive Paul Dalgleish. "RCR is a leader in the EPC delivery of large-scale solar farms, and the inclusion of First Solar's technology, with which we have extensive experience, will ensure the success of the project is maximized for all involved," he adds.

Construction is scheduled to begin in April. On completion, the project is expected to generate enough solar energy to displace about 248,000 metric tons of CO₂ annually (equivalent to taking nearly 66,000 cars off the road).

First Solar selected for 63MW solar project in Australia

Cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA says that Genex Power Ltd has achieved financial close for the Kidston Phase One Solar Project in Queensland, Australia.

First Solar will supply 63MW_{dc} of modules to the project, which will produce about 145,000 megawatt-hours of electricity in its first year of operation. The project is located next to the proposed Kidston Pumped Storage Project and, in an industry first, Genex Power will seek to integrate solar generation with a pumped hydroelectricity energy storage system.

"As Australia continues to diversify its renewable energy portfolio, this project is an excellent example of the potential of large-scale solar application and industry best practice," says Ewan Norton-Smith, First Solar's senior manager for business development in

Australia. "The combination of solar energy with pumped-storage hydroelectricity will allow for increasing penetration of renewable energy into the grid and will contribute to the stability of supply in the National Electricity Market," he adds. "Genex Power is at the forefront of this emerging industry and, with several compelling Australian projects on the horizon, we're proud to be supporting phase one of the project."

Situated 270km north-west of Townsville in far north Queensland, the project's first phase will use more than 540,000 First Solar modules. The firm claims that its technology has a higher energy yield in hot and humid climates due to its lower temperature coefficient and, over the course of a plant's operational life, will translate to substantial gains in power output. First Solar modules have been used in more large-

scale projects in Australia than any other PV manufacturer, the firm adds.

"The combination of First Solar's thin-film modules, single-axis tracking technology and the excellent local solar resource in Queensland will give our project the highest chance of achieving a record solar capacity factor in Australia," says Genex Power's managing director Michael Addison.

The electricity from the Kidston Phase One Solar Project will be sold via a power purchase agreement (PPA) supported by the Queensland Government. The project is also supported by AUS\$8.9m of Government funding through the Australian Renewable Energy Agency.

Construction of the project will be managed by UGL Engineering Pty Ltd and is on schedule to begin in first-half 2017.

www.firstsolar.com

First Solar to power 106.5MW of PV plants in France

French solar energy firm Photosol has selected the cadmium telluride (CdTe) thin-film photovoltaic (PV) modules of First Solar Inc of Tempe, AZ, USA to power 14 utility-scale solar power plants with a total capacity of 106.5MW_{DC}. Developed and owned by Photosol, the projects are part of the third procurement round initiated by France's Commission de Régulation de l'Énergie.

Located in central and southwest France, the plants will range from 4.5MW to 43MW in capacity. The largest will be in Burgundy. Jayme da Costa Energie (the French subsidiary of Portuguese engineering firm Jayme da Costa Group) is pro-

viding engineering, procurement & construction (EPC) for all the projects.

When completed, the plants are will supply almost 134,000MWh of electricity to the French electricity grid in their first year of operation (enough to power 23,000 average French households and to displace 5000 metric tons of carbon dioxide per year). The plants' collective environmental footprint will be lowered by about 67% due to their use of First Solar's modules, which offer the smallest carbon footprint, fastest energy payback time and lowest water use of all solar technologies, it is claimed.

The new projects bring Photosol's

total portfolio of PV plants, powered by First Solar modules, to almost 155MW. Upon completion, they will take First Solar's total installed capacity in Europe to about 4.5GW.

"The progressive French policy on reducing the carbon footprint of its solar energy program has set a new benchmark and serves as a precedent for other countries to follow," comments Stefan Degener, regional head of business development at First Solar. "It is a clear demonstration of how evaluating the environmental footprint can be effectively embedded in a competitive bidding process," he adds.

www.photosol.fr

First Solar and Prime Road complete 18MW of solar farms in Thailand

Bangkok-based investment group Prime Road Group Co Ltd (PRG, which develops, owns and operates renewable energy projects in Thailand and Japan) and First Solar have completed four solar farms totaling 18MW_{DC} of capacity in Thailand. Located across the Ayutthaya and Pathum Thani Provinces, the Prime Road Group Co-Op Project utilizes more than 158,500 First Solar modules to produce about 29,600 megawatt-hours (MWh) of electricity in the first year of operation. Developed under Thailand's Governmental Agency and Agricultural Cooperatives Program, the completion marks a milestone for the country as it continues to grow its installed solar PV capacity and target 30% renewable energy by 2036.

Thailand-based developer Prime Road Group has partnered with First Solar as module supplier and Bouygues-Thai Ltd — a subsidiary of the French Bouygues Group — as the engineering, procurement & construction (EPC) contractor for the delivery of the project. The project will produce enough energy annually to power 12,000 homes in Thailand and displace about 14,000 metric tons of CO₂ annually.



The Sena 1 solar installation is one of four solar farms included in a group of power generation assets completed across the Ayutthaya and Pathum Thani provinces in Thailand by Prime Road Group. First Solar supplied 18MW of PV modules.

"We have developed a broad range of renewable energy projects in Thailand and Japan, and the Prime Road Group Co-Op Project adds to our growing regional portfolio of high-quality solar farms developed, owned and operated by our group," says Prime Road Group's director Surachet Chaipatanont.

"First Solar's thin-film technology was selected for Prime Road Group Co-Op Project because of its superior energy performance attributes compared to traditional solar modules, making it suitable for the hot and humid conditions in

Thailand," he comments.

First Solar claims that its Series 4 PV modules deployed at the four sites are suited to the local environmental conditions in Southeast Asia, due to their superior temperature coefficient, better shading response, and better spectral response. This performance allows for optimal performance and, over the course of the project's operational life, will translate into significant gains in power output, he adds.

"Completion represents a significant installation of First Solar modules in Southeast Asia," says Robert Bartrop, First Solar's director of business development in Southeast Asia and China.

"First Solar's partnership with the Prime Road Group Co-Op Project reflects the value of First Solar technology in hot and humid climates such as Thailand, and we look forward to supporting future projects and the country's renewable energy targets," he adds.

Electricity from the Prime Road Group Co-Op Project will be sold via a 25-year power purchase agreement (PPA) with the Provincial Electricity Authority of Thailand at a rate of THB5.66 per kilowatt hour.

www.firstsolar.com

Ascent Solar secures \$20m in funding from strategic investor Hong Kong Boone Group

Ascent Solar Technologies Inc of Thornton, CO, USA, which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules integrated into off-grid applications and its EnerPlex series of consumer products, has entered into a securities purchase agreement for Hong Kong Boone Group Ltd to invest \$20m by purchasing the firm's newly designated Series K convertible preferred stock.

Priced at \$1000 per share, the Series K preferred stock will be convertible at the option of the investor into restricted common stock at a fixed conversion price of \$0.004 per share, representing a premium of about 74% to Ascent's per share closing bid price on the day prior to the agreement's signing.

The initial closing of the financing is expected to occur on or before 24 February, when Ascent Solar will issue a total of 1000 shares of Series K preferred stock to the investor in exchange for gross proceeds of \$1m. Ascent Solar will issue 4000 additional shares of Series K preferred stock in exchange for gross proceeds of \$4m in four closings scheduled to occur in March, April, May and June. A final closing is scheduled to occur in July, when the firm will issue 15,000 additional shares in exchange for gross pro-

ceeds of \$15m. The July closing will be conditioned on mutually satisfactory conditions regarding the use of the \$15m proceeds.

In the event that the investor defaults in closing on any tranche of the Series K preferred stock, Ascent Solar would be entitled to redeem 50% of the then outstanding shares at a price per preferred share equal to the \$0.01.

Ascent Solar is required to redeem for cash any outstanding shares of the Series K preferred stock at a price per share equal to \$1000 plus any accrued but unpaid dividends (if any) on the fifth anniversary of the date of the original issue of such shares. There are no dividends currently payable on this preferred stock, and will only incur dividends if Ascent Solar pays dividends to its common stock holders.

Hong Kong Boone Group is a multi-national industrial group of companies that specializes in industrial control system integration and hydraulic pressure systems. It is part of the Boone Group of Guangzhou City, China, which also specializes in the procurement, planning, installation and ongoing maintenance of on-grid solar farm projects in China.

"Boone Group has been involved in the renewable energy sector for

many years and we are deeply impressed with Ascent's lightweight and flexible thin-film CIGS technology, in particular their unique manufacturing process with the award-winning monolithically integrated technology," comments Boone Group's chairman & founder Song Liang. "China will undoubtedly be the world's largest solar market, but it is now predominantly limited to the installation of the rigid, fragile and heavy crystalline silicon-based panels," he adds. "Ascent's unparalleled PV module will have immense potential not only in China but the worldwide market, especially when Ascent can achieve the appropriate economies of scale," he believes. "We hope to help Ascent achieve the economies of scale which their technology can enable."

"The Boone Group understands that achieving scale is a significant prerequisite to the success of Ascent," comments Ascent Solar. "The funding will provide us with ongoing working capital as we continue to focus on the high-value specialty PV market," he adds. "The new investment reinforces our investor's belief in Ascent's strategy and the tremendous potential of the company's lightweight flexible CIGS solar panel."

www.AscentSolar.com

Solar-Tectic granted US patent for perovskite/crystalline germanium thin-film tandem solar cells

Solar-Tectic LLC of Briarcliff Manor, NY, USA says that a patent application for a germanium perovskite thin-film tandem solar cell has been allowed by the United States Patent and Trademark Office (USPTO). The patent (US 15/205,418) is 'Method of Making A Tandem Solar Cell Having a Germanium Perovskite/Germanium Thin-Film', for highly efficient and inexpensive solar cells, replacing the existing

silicon wafer technology that currently dominates the global market.

Perovskite materials have gained much attention as a solution to the long-standing problem of solar cell efficiency, says Solar-Tectic. There have been reports of perovskite/Ge tandem solar cells, but none on perovskite/crystalline Ge thin-film tandem solar cells. Crystalline thin-film Ge promises to be more efficient and less expensive than

silicon and germanium wafer technology due to low-temperature processing and less material use, notes the firm. An example of the perovskite layer is CsGeI₃.

The entire process is non-toxic, since germanium is non-toxic and tin is used to deposit the crystalline Ge thin-film material for the bottom layer in the tandem configuration, so there is no toxic lead.

www.solartecticllc.com

Manz receives €263m order for turnkey CIGS PV production lines with capacity of 350MW

CIGS PV commercialization deal with Chinese energy firms to establish R&D and equipment JVs

Manz AG of Reutlingen, Germany (a supplier of integrated production lines for solar cells and modules) has entered into a strategic cooperation on copper indium gallium diselenide (CIGS) thin-film technology with Shanghai Electric Group Co Ltd (one of China's largest equipment manufacturing conglomerates, and Manz's anchor investor) and power generation firm Shenhua Group Corporation Ltd (reckoned to be the world's largest coal supplier, which in 2015 adapted itself to China's strategic focus on clean energy development).

As part of the agreement, Manz has received two bulk orders collectively worth €263m: one for a 44MW-capacity R&D line from a newly established R&D joint venture, and one for a 306MW-capacity turnkey mass-production line (CIGSfab) for a newly established module joint venture of affiliated subsidiaries of Shenhua Group and Shanghai Electric. This CIGSfab, which is expected to be the largest CIGS production line in China and the second largest worldwide, will be built in Chongqing. Installation will begin in 2017 and finish in 2018.

However, this order is considered to be only a first step. The €263m will contribute to Manz's revenue and earnings during fiscal 2017 and 2018. Due to corresponding down-payment agreements, the orders will be realized cash flow positive.

"CIGS modules from Manz already offer the lowest electricity generation costs in comparison to the crystalline silicon technology," claims Manz's CEO & founder Dieter Manz.

"Today's agreements mark the breakthrough in our solar business."

To further commercialize and develop Manz's CIGS thin-film technology, the three partners — Shenhua, Shanghai Electric and Manz — have agreed to combine



their strengths in power generation, large-scale equipment manufacturing, and CIGS solar technology. Shenhua Group has teamed with Shanghai Electric to span expertise through the entire value chain of renewable power generation from CIGS solar modules. Due to its collaboration with ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung — or Center for Solar Energy and Hydrogen Research — Baden-Württemberg) of Stuttgart, Germany, Manz has exclusive access to CIGS thin-film solar cells on glass with record efficiency of 22.6%. Moreover, Manz already runs one of the world's largest CIGS R&D teams, in Schwäbisch Hall, Germany.

R&D joint venture

With the agreement, the firms have laid the foundation for an R&D joint venture dedicated to CIGS thin-film technology that aims to leverage CIGS' potential to further increase efficiency and reduce manufacturing costs. To accelerate R&D, supplementing Manz's existing R&D line in Schwäbisch Hall, the 44MW line will be delivered for installation at the JV in Beijing. Also, Manz's existing CIGS R&D entity Manz CIGS Technology GmbH will be acquired by the new R&D JV for €50m. In return, Manz will take a 15% stake in the JV in exchange for €25m. The remaining shares are held by affiliated subsidiaries of Shenhua Group and Shanghai Electric. The involved parties also agreed to

guarantee the site and jobs in Schwäbisch Hall for the next 5 years. Also as a result of this agreement, the annual €15–20m negative impact on Manz's earnings from running the site in Schwäbisch Hall will cease.

Equipment joint venture

Shanghai Electric, Shenhua Group and Manz will also establish an equipment joint venture that will exclusively begin sales activities for the CIGSfab in China, provide engineering services during upcoming projects, and support the ramp-up. Whereas the bulk orders for the 44MW R&D line as well as the 306MW production line have been placed at Manz directly, future orders from China will be placed at the equipment JV. Manz has a majority 56% stake, while Shanghai Electric and Shenhua Group hold the remaining shares. In the rest of the world, CIGSfabs will be sold solely by Manz. Regarding further commercialization, the equipment JV will also have access to future research results of the R&D JV as well as from the collaboration with ZSW through exclusive license rights agreements.

"Our long-standing perseverance as well as the high investments in the further development of our CIGS technology are paying off," believes Dieter Manz. "The past years have not always been easy, neither for our employees nor for our shareholders," he adds. "Manz now takes over a leading role with its fully integrated turnkey production line CIGSfab regarding the technological change from the labor- and material-intensive crystalline solar technology towards the resource-saving and efficient thin-film solar technology."

www.zsw-bw.de

www.manz.com

Back-reflector for gallium indium nitride arsenide solar cells

Researchers estimate that back-reflectors could lead to 28% increased short-circuit current under concentrator-type illumination.

Tampere University of Technology in Finland has developed a back-reflector structure for gallium indium nitride arsenide (GaInNAs) solar cells with a view to their incorporation in high-conversion-efficiency triple-junction structures [Timo Aho et al, Appl. Phys. Lett., vol109, p251104, 2016]. The team estimates that their back-reflectors could lead to 28% increased short-circuit current (J_{sc}) under concentrator-type illumination.

There are difficulties in providing GaInNAs layers with low enough background doping. This limits the thickness of the absorber layer. By applying a reflector to the back surface of the structure one can effectively double the photon path length in the absorber region for higher-efficiency energy extraction.

The researchers see potential application in space and concentrator photovoltaic systems with high power-to-mass ratio, radiation durability, and high efficiency. GaInNAs with around 4% nitrogen content is seen as being suitable for harvesting longer-wavelength (1400nm) photons with energy around 0.9eV. In multi-junction structures, higher-energy photons are filtered out by the upper layers of the device.

Since charge is conserved, currents in multi-junction structures must be equal throughout the cell. The team comments: "The results enable current-matching for GaInNAs materials with a high amount of N corresponding to bandgaps below 0.9eV, ultimately allowing the development of lattice-matched solar cells with more than three junctions." They also report low contact resistivity and that none of the samples exhibited notable peeling of metals in adhesion tests. The researchers add: "Moreover, no discernible diffusion of the metals into the semiconductor was observed after thermal annealing at 200°C."

The solar cells were fabricated from material grown by molecular beam epitaxy (MBE) — see Figure 1. Four mirror structures were compared with metals deposited by electron-beam evaporation (Table 1). The main mirror type was an unannealed combination of silver/copper/nickel/gold (Ag/Cu/Ni/Au) with varying thicknesses (including zero). The Ag, Cu and Au components give almost ideal reflectivity

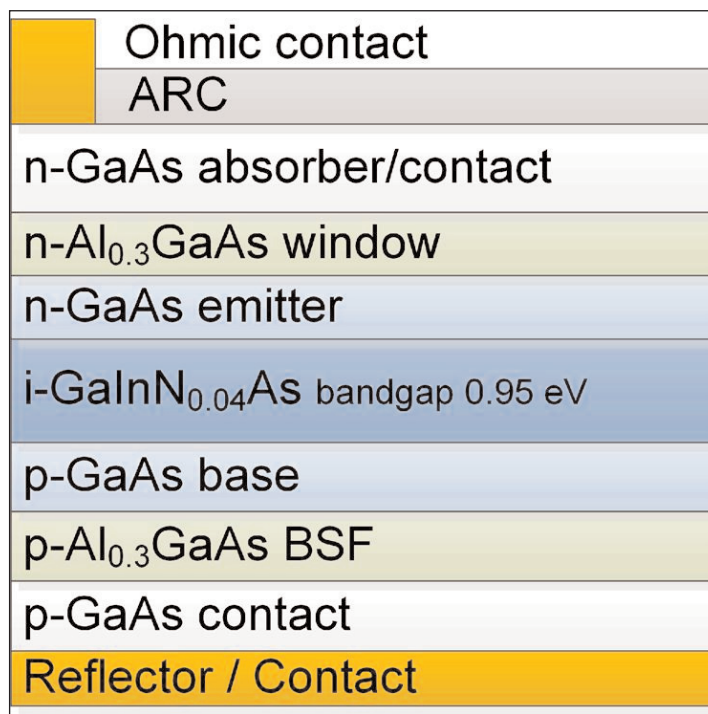


Figure 1. Generic test structure of back-surface reflector cell. Light enters from n-GaAs side.

for wavelengths longer than 800nm. A benchmark cell replaced the mirror layers with an annealed titanium/gold (Ti/Au) ohmic contact.

The Ag was used both as a reflector and diffusion barrier, aiming to stop Cu from mixing with and poisoning the semiconductor material and reducing open-circuit voltages. In addition to reflecting light, the Cu acted as a high-conductivity current spreader. The Ni was used as an adhesive layer between the Cu and Au. The final

Table 1. Mirror structures.

| Mirror | Structure | Thicknesses |
|------------|-------------|----------------------|
| 50nm Ag/Cu | Ag/Cu/Ni/Au | 50nm/100nm/10nm/50nm |
| 30nm Ag/Cu | Ag/Cu/Ni/Au | 30nm/100nm/10nm/50nm |
| 10nm Ag/Cu | Ag/Cu/Ni/Au | 10nm/100nm/10nm/50nm |
| Cu | Cu/Ni/Au | 100nm/10nm/50nm |
| Au | Au | 100nm |
| Ti/Au | Ti/Au | 50nm/100nm |

Au layer protected the mirror and acted as a bonding surface.

The top ohmic contact consisted of indium, while the light entered through a titanium dioxide/silicon dioxide bilayer anti-reflective coating (ARC).

The external quantum efficiency (EQE, Figure 2) was improved by using Ag/Cu, Cu or Au mirrors (~ 0.9 peak) over that of using a Ti/Au ohmic bottom contact (~ 0.7 peak). This was based on a 52% improvement in reflectivity near the band edge, comparing 10nm Ag/Cu with Ti/Au. The Ag/Cu mirrors gave similar performance. The Au reflector had performance intermediate between the Ag/Cu and Ti/Au structures. Also, thermal annealing of the 10nm Ag/Cu mirror at 200°C for 90 seconds did not significantly affect the EQE, indicating some latitude in processing thermal budget.

The short-circuit current (Table 1) was deduced from the EQE measurements under atmospheric mass AM1.5 (sun zenith angle 48.2°) and AM0 (space) simulated conditions. The AM1.5 simulated spectrum was also separated into those suitable for flat-panel (AM1.5G) and concentrator ('direct', AM1.5D) systems. The model assumed a thick GaAs filter on top of the solar cell.

The researchers comment: "The solar cell with the 30nm Ag/Cu reflector exhibited a J_{sc} value of $\sim 14\text{mA}/\text{cm}^2$ at AM1.5D ($1000\text{W}/\text{m}^2$), which is 28% higher compared to the reference solar cell with the Ti/Au reflector. These values are similar to the current that can be generated by GaInP/GaAs top cells, which is $\sim 14\text{mA}/\text{cm}^2$ at AM1.5D ($1000\text{W}/\text{m}^2$)."

The team further expects a 10-percentage-points higher conversion efficiency for an Ag/Cu reflector bottom cell compared with Ti/Au in an optimized GaInP/GaAs/GaInAs triple-junction solar cell under $\sim 1000\times\text{AM1.5D}$ illumination. This would raise conversion efficiencies from around 35% to 45%. ■

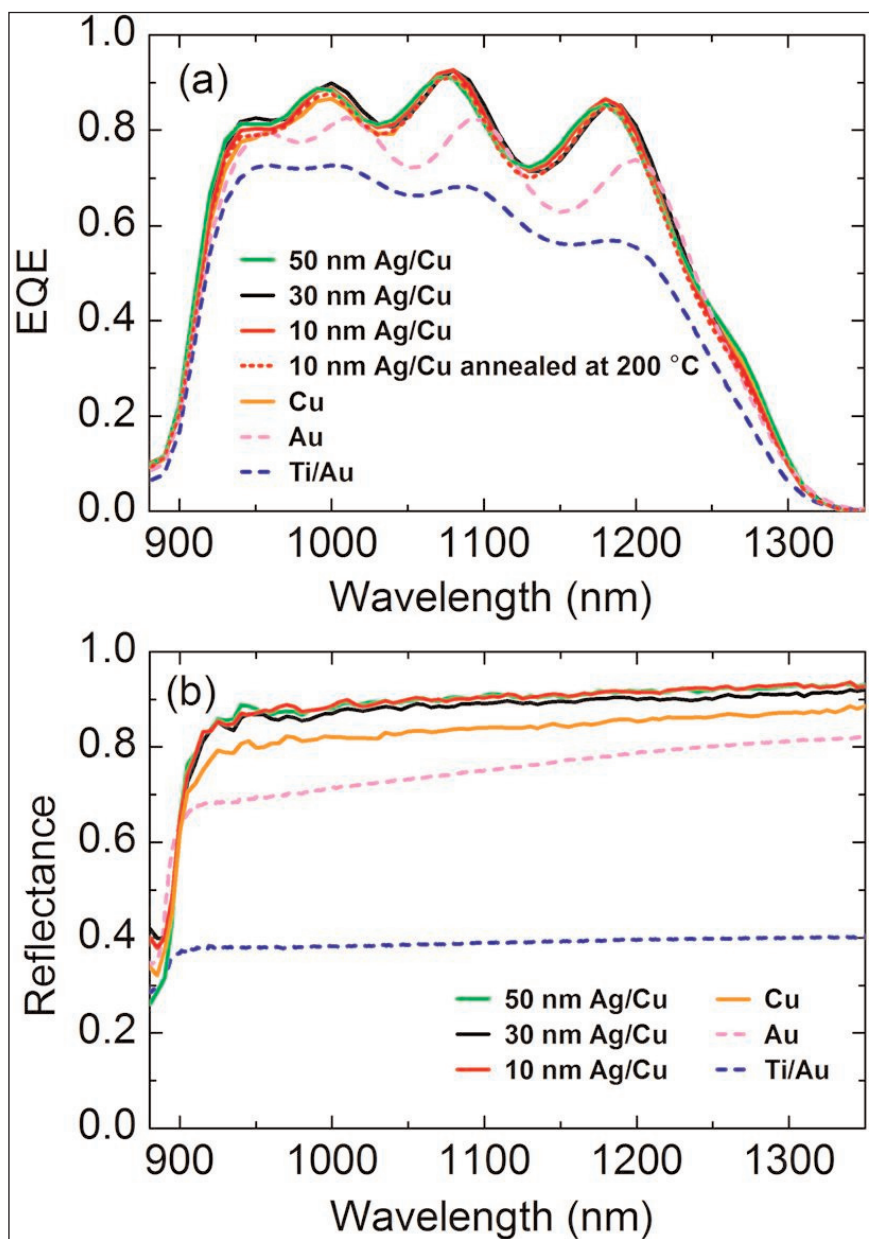


Figure 2. (a) EQE of GaInNAs solar cells with various back-surface reflectors and (b) reflectance of double-side-polished semi-insulating GaAs samples with back-surface reflectors and without ARC.

<http://dx.doi.org/10.1063/1.4972850>

Author: Mike Cooke

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Avalanche photodiode with photomultiplier-like performance

Researchers use periodically stacked structures of gallium nitride and aluminium nitride to claim record gain.

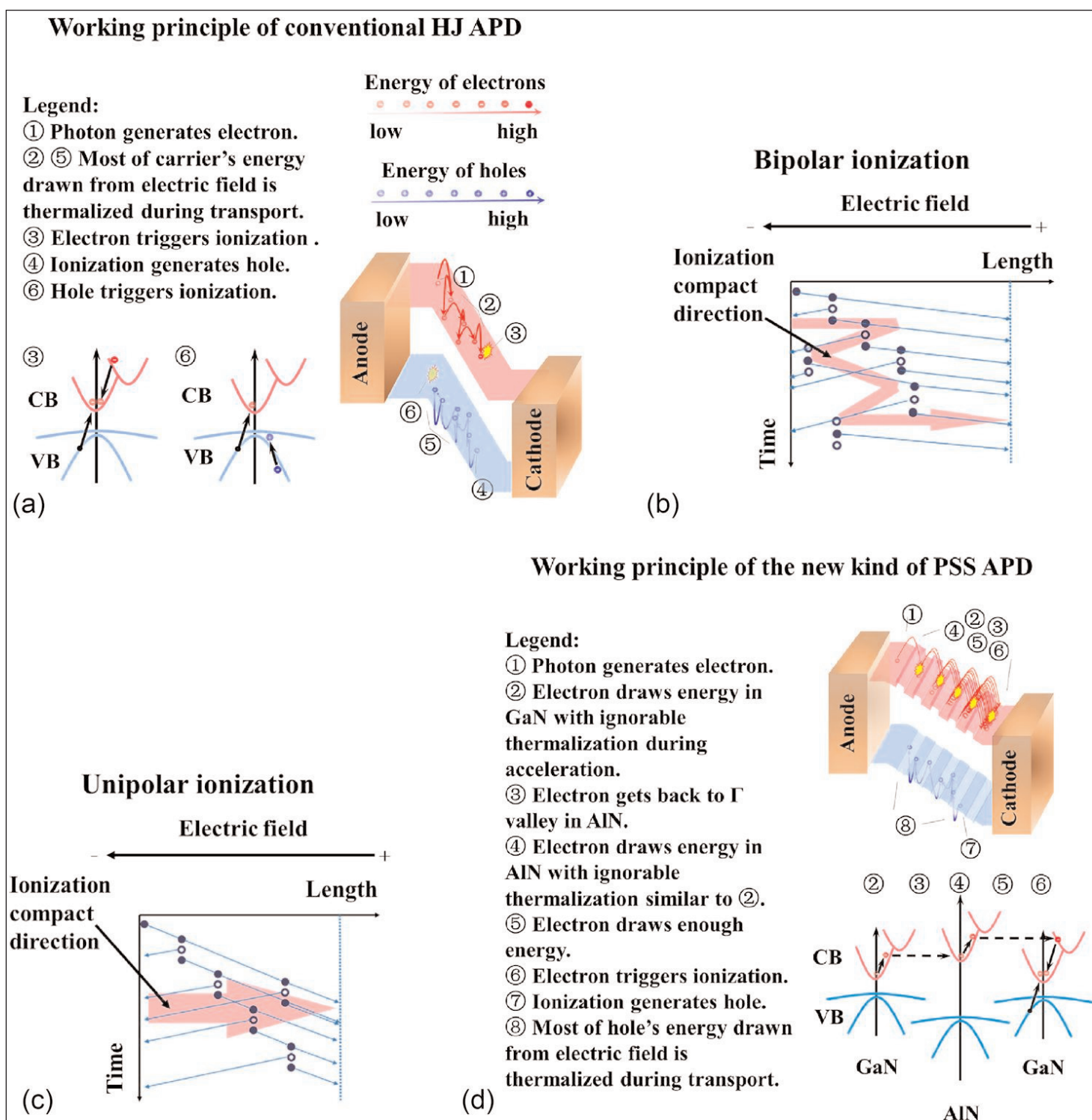


Figure 1. Motivations of design: (a) carrier transport in conventional heterojunction APDs under electric field, (b) bipolar ionization proceeding along two opposite directions and (c) unipolar ionization proceeding along single direction. (d) Carrier transport in GaN/AlN PSS APDs.

Researchers in China and France have developed photomultiplier tube (PMT)-type performance from avalanche photodiodes (APDs) that implement periodically stacked structures (PSSs) of gallium nitride (GaN) and aluminium nitride (AlN) [Jiyuan Zheng et al, *Appl. Phys. Lett.*, vol109, p241105, 2016]. The PSS APD had a record high gain of order 10^4 with noise factor as low as 500 and ionization coefficient of 0.05, according to the researchers. The highest gain for silicon APDs in linear mode is about 100.

The team at China's Tsinghua University, CNRS-CRHEA (Centre de Recherche sur L'Hétéro-Epitaxie et ses Applications-Centre National de la Recherche Scientifique) in France and Institute of Semiconductors, Chinese Academy of Sciences in China used Monte Carlo simulations to develop the APD. By employing the PSS technique, the team hoped to avoid inter-valley scattering that reduces the performance of conventional APDs.

The PSS technique (Figure 1) enhanced the multiplication effect for electrons, but not for holes. This made the APDs unidirectional in terms of response to

incoming photons and the resulting avalanche electrons. Suppression of hole avalanche reduced the potential for breakdown events.

PMTs are a vacuum tube technology used to measure low lighting conditions, including in single-photon experiments. Researchers would like to replace bulky, fragile PMTs with compact, robust solid-state devices based on semiconductors.

A prototype structure with alternate $20 \times 10 \text{ nm}/10 \text{ nm}$ layers of GaN/AlN were fabricated into PSS APDs. The structure was grown by molecular beam epitaxy (MBE) on AlN/sapphire templates supplied by Suzhou Nanowin Science and Technology Co Ltd. After depositing 50 nm of AlN on the AlN template, the p-i-p-i-n structure was grown with separated absorption (I-GaN and multiplication (I-AlN/GaN) layers (Figure 2).

A double mesa structure with inner diameter of $25 \mu\text{m}$ and outer diameter of $35 \mu\text{m}$ was etched by inductively coupled plasma. The light absorption occurs through the top of the inner mesa. Further fabrication included plasma-enhanced chemical vapor deposition (PECVD) of silicon dioxide and ohmic contact formation — p-type nickel/gold and n-type chromium/gold. ▶

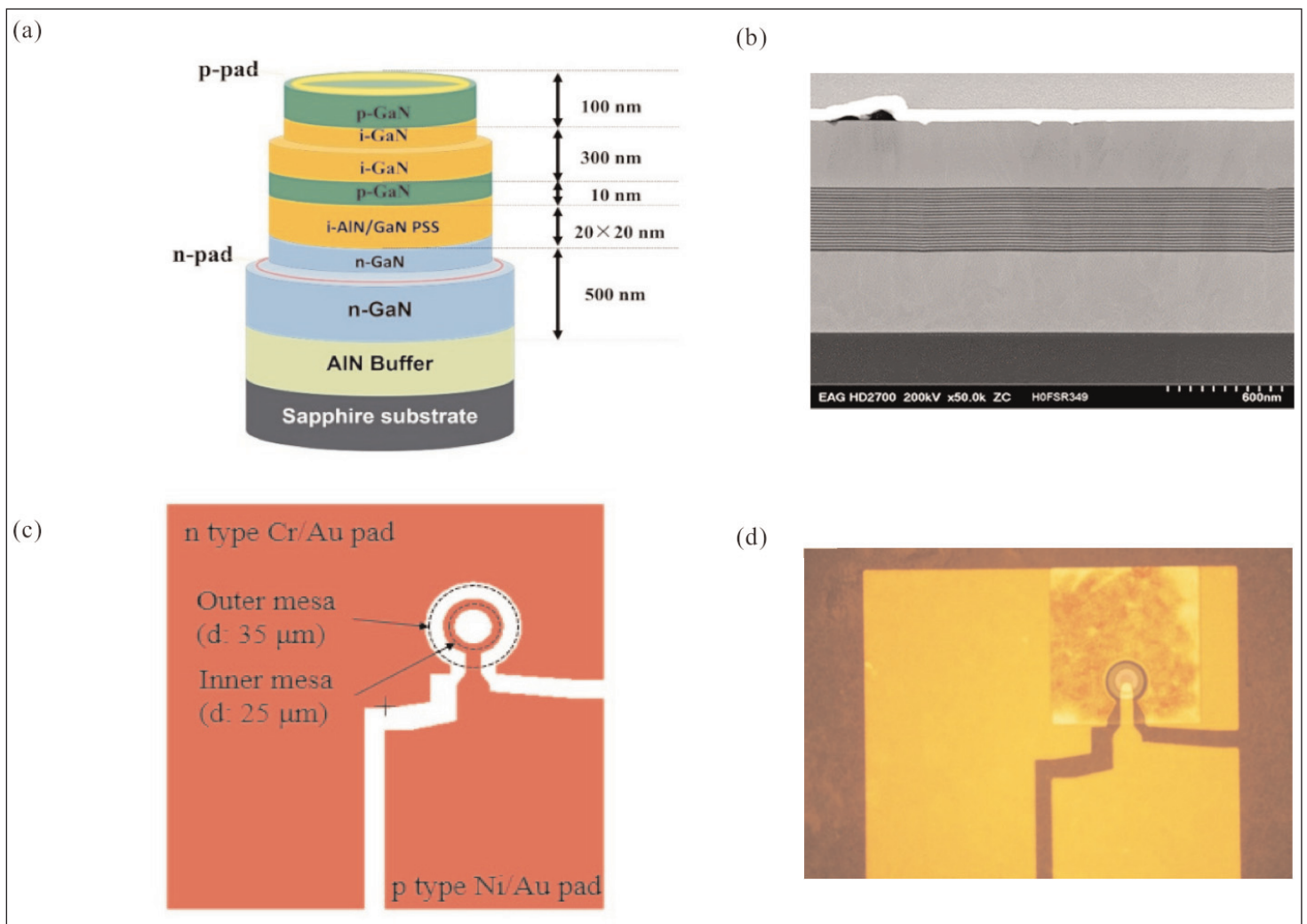


Figure 2. Design & fabrication of GaN/AlN PSS APD: (a) epi-structures, (b) cross-sectional transmission electron micrograph of epitaxy layers, (c) device processing design. (d) Top-view micrograph of practical device.

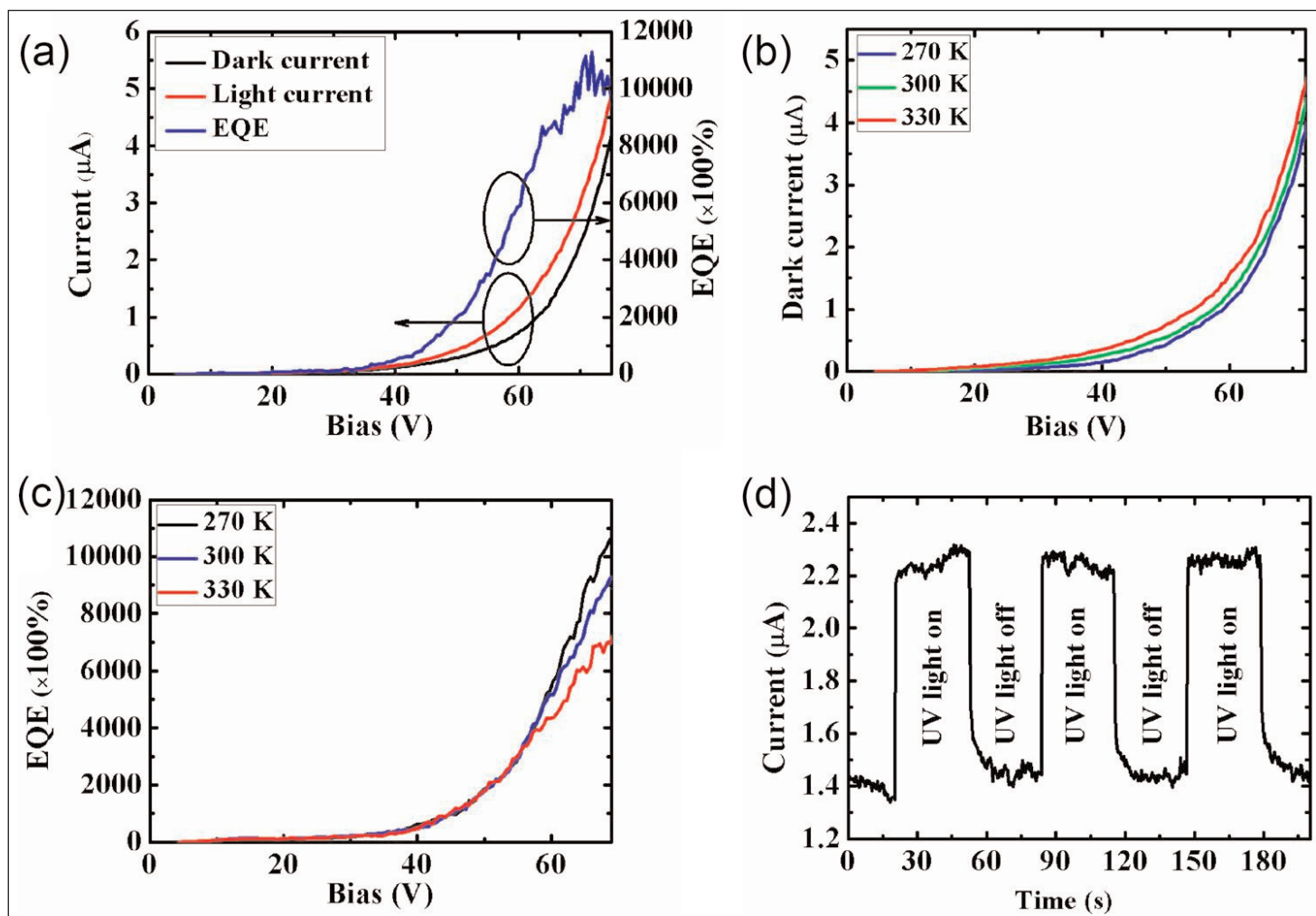


Figure 3. (a) Current-voltage and EQE-voltage curves; (b) revers-biased dark current curves tested under different temperatures. (c) Temperature dependence of EQE-V curves. (d) Device under constant bias responding to ultraviolet 325nm laser light switching on and off.

Electrode pads were gold.

The external quantum efficiency (EQE) of the devices increased with bias voltage, unlike traditional APDs (Figure 3). The saturation of EQE occurred around 10^4 , representing 14 $2\times$ multiplication stages. The probability for electron-triggered ionization is estimated at 70% per period. This is close to the 80% predicted by Monte Carlo simulation.

The researchers believe higher gain could be achieved by increasing the number of GaN/AlN stacks in the

PSS region.

By using III-nitride alloys with different electronic band structures, the researchers believe that devices with various working wavelengths ranging from infrared to ultraviolet could be realized using inter-band or inter-subband transitions. They also see electronic amplifiers being developed based on the same carrier multiplication mechanism. ■

<http://dx.doi.org/10.1063/1.4972397>

Author: Mike Cooke

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Light transmission from co-integrated laser and modulator on silicon

III-V distributed Bragg reflector laser and silicon Mach-Zehnder modulator produce 25Gb/s signals.

Researchers in France have co-integrated a 1.3 μm III-V laser source with a silicon-based Mach-Zehnder modulator (MZM) [Thomas Ferrotti et al, Optics Express, vol24, p30379, 2016]. Combining semiconductor laser diode technology with silicon photonics would fill the gap for transmitters in the silicon photonics toolbox.

The hybrid III-V/silicon photonics devices were able to transmit information at 25 Gigabits/second at wavelengths of 1303.5nm and 1315.8nm with a 2.5V peak-to-peak signal. The researchers at Université

Table 1. III-V epitaxy layer structure.

| Layer | Material | PL wavelength (μm) | Thickness (nm) | Doping ($/\text{cm}^3$) |
|--------------------|----------|---------------------------------|----------------|---------------------------|
| p-doped contact | InGaAs | 1.65 | 200 | 2×10^{19} |
| Transition | InGaAsP | 1.1 | 50 | 5×10^{18} |
| p-doped cladding | InP | 0.92 | 2000 | 2 to 0.5×10^{18} |
| SCH | InGaAsP | 1.1 | 100 | Undoped |
| Barriers (x7) | InGaAsP | 1.1 | 10 | Undoped |
| Wells (x8) | InGaAsP | 1.29 | 8 | Undoped |
| SCH | InGaAsP | 1.1 | 100 | Undoped |
| n-doped contact | InP | 0.92 | 110 | 3×10^{18} |
| Super-lattice(x2) | InGaAsP | 1.1 | 7.5 | 3×10^{18} |
| Super-lattice (x2) | InP | 0.92 | 7.5 | 3×10^{18} |
| Bonding interface | InP | 0.92 | 10 | Undoped |

Grenoble Alpes, STMicroelectronics and Université de Lyon see their devices as being compatible with the

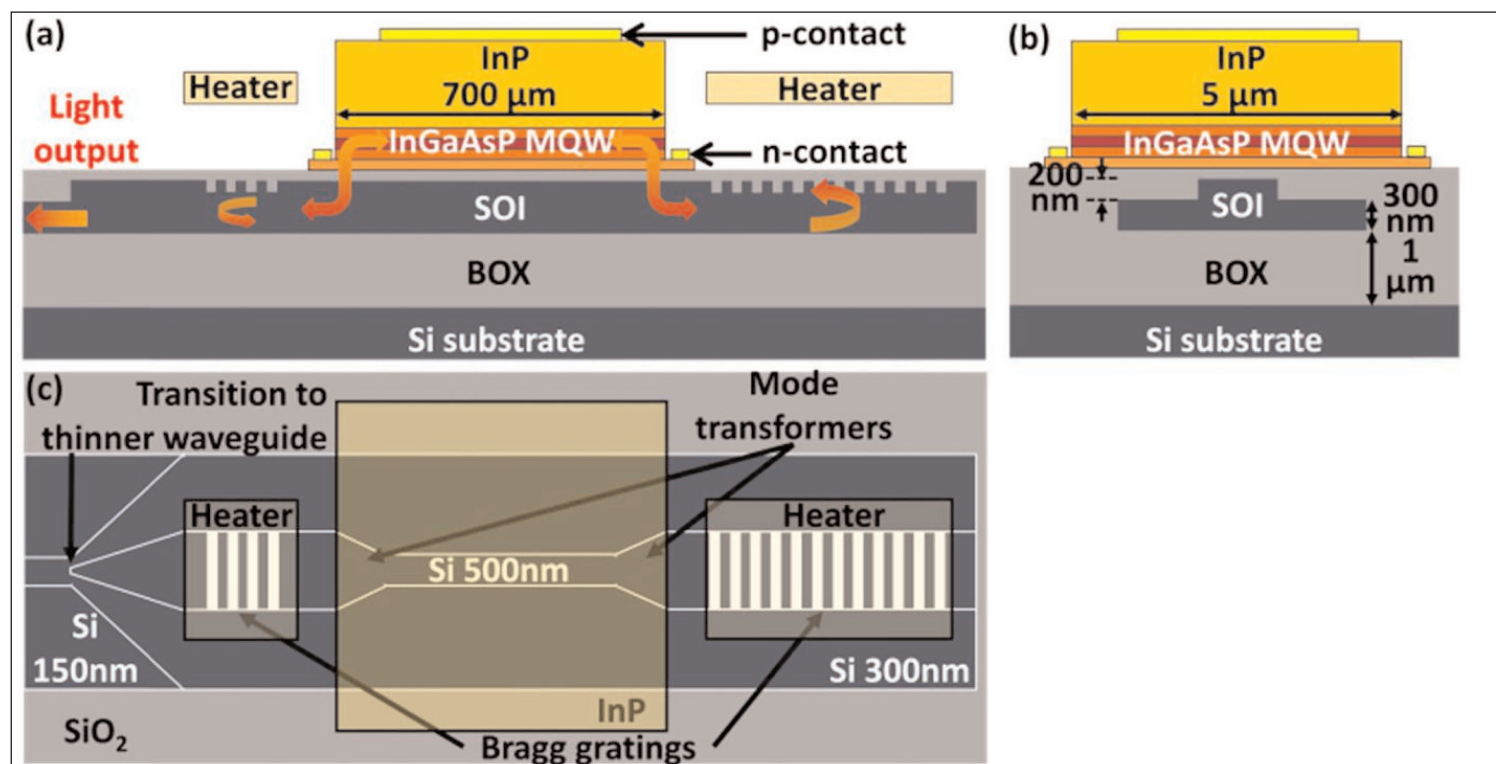


Figure 1. Longitudinal (a), transversal (b) and top (c) schematic views of laser (not to scale!).

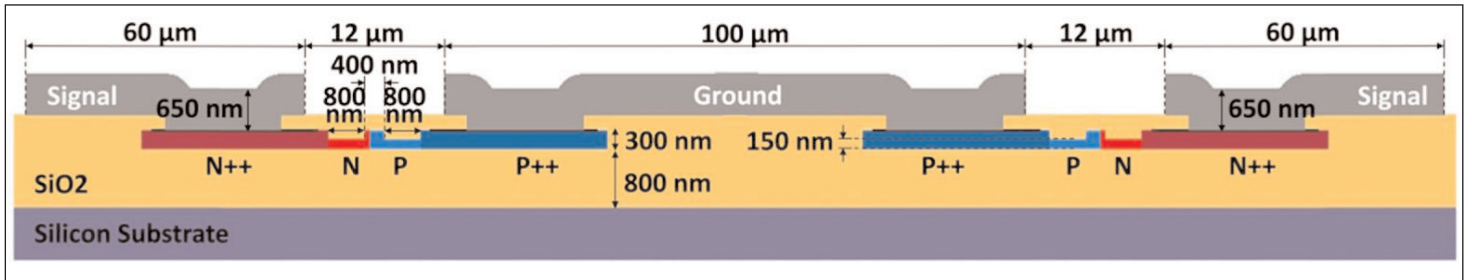


Figure 2. Transversal view of silicon MZM.

wavelength-multiplexing requirements of the 100GBASE-LR4 and other communications standards.

The 1.3 μm laser diode active region consisted of indium gallium arsenide phosphide (InGaAsP) multiple quantum wells and barriers surrounded by p- and n-type indium phosphide (InP) — see Table 1. The III-V material for the laser diode measured 700 μm x5 μm x2.7 μm .

The light that was produced was coupled into the silicon-on-insulator rib waveguide system (Figure 1) through tapered mode transformer regions that led into distributed Bragg reflectors (DBRs) that partially trapped light in a laser cavity. At the back end of the cavity the DBR was highly reflective. The DBR at the laser output end was less reflective, allowing for coupling into the rest of the device.

Nickel-iron heaters over the DBRs allowed fine tuning of the laser light by increasing the refractive index of the silicon material. The DBR periods provide coarser tuning.

The silicon MZM section used the plasma dispersion effect, where changes in free carrier density alter the real and imaginary parts of the refractive index. The carrier density was controlled by an implanted vertical p-n junction (Figure 2). The effect of hole carriers has more effect than electrons on the real part of the refractive index around 1.3 μm .

The modulation was achieved through interference effects between light split and guided down two separate paths, as in Mach-Zehnder interferometry.

The hybrid laser and MZM were combined (Figure 3) to create a signal transmitter. The phase of the radiation carried by the two arms of the MZM was controlled by a further heater section to give quadrature difference for the selected wavelength.

The structures were produced on 8-inch (200mm) SOI wafers supplied by SOITEC. The oxide layer

was 1 μm thick. The silicon top layer was 500nm. The handle wafer was high-resistance silicon.

The III-V material was grown on 2-inch (50mm) InP and room-temperature bonded to the SOI wafer. Both surfaces of the bond were activated with oxygen plasma. Post-bond annealing was carried out at 300 $^{\circ}\text{C}$ for 2 hours. The InP substrate of the III-V material was removed by hydrochloric acid wet etch.

The SOI/III-V was 'downsized' to 3 inches to allow "processing in a standard III-V platform". The researchers hope to avoid this downsizing in future work.

The laser thresholds were 48mA. The maximum power for single-mode output was up to 52 μW with a grating period of 197nm. The MZM length was 2mm, giving an extinction ratio of 2.9dB. With a grating period of 195nm, the threshold was the same, but the maximum output power was 37 μW . The 195nm DBR device had a 4mm-long MZM with a larger extinction ratio of 4.7dB.

With currents beyond 100mA and 150mA for the 195nm and 197nm DBR devices, respectively, the emissions became multi-mode. Heating the DBR regions allowed a maximum shift in wavelength of 8.5nm for both devices. The heating efficiency was hampered by a thick layer of silicon nitride between the heaters and the DBRs. ■

<http://dx.doi.org/10.1364/OE.24.030379>

Author: Mike Cooke

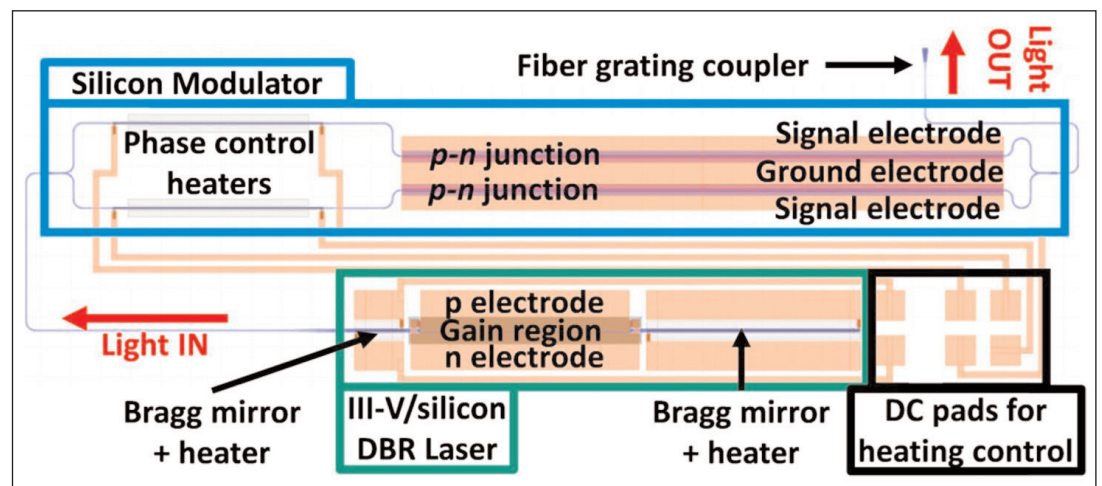


Figure 3. Layout view of complete transmitter integrating hybrid III-V/silicon DBR laser and silicon MZM (2mm-long).

Interface engineering for green indium gallium nitride laser diodes

Thermal treatment results in low threshold current density of 1.85kA/cm² under continuous-wave operation at room temperature.

University of Chinese Academy of Sciences has developed an interface engineering thermal treatment of indium gallium nitride (InGaN) quantum well active regions in green laser diode (LD) structures [Aiqin Tian et al, Optics Express, vol25, p415, 2017]. The resulting laser diodes had a low threshold current density of 1.85kA/cm² under continuous-wave operation at room temperature.

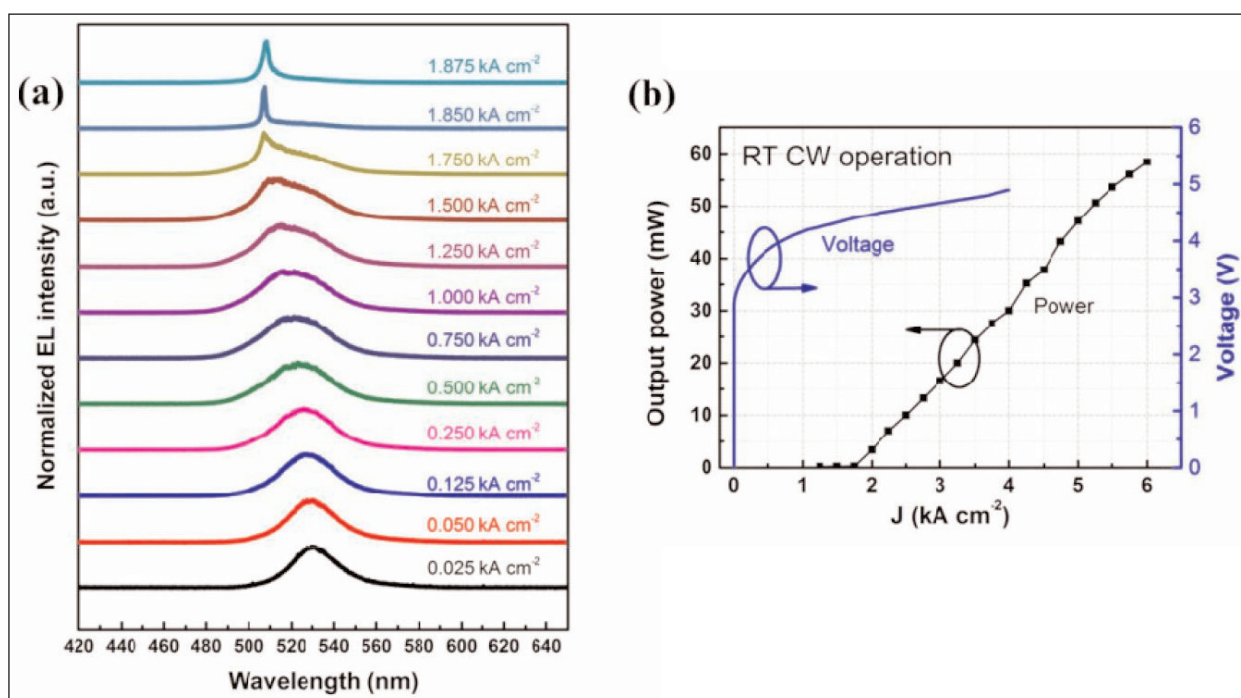
Green laser diodes should lead to more compact projectors and other display technologies based on laser light. At present, green light for such applications tends to use non-linear optics to frequency shift light produced at other wavelengths, increasing device sizes and reducing power efficiency.

The green laser diode structures were grown by metal-organic chemical vapor deposition (MOCVD) — see Figure 1. The material quality of the wells was improved by thermal ramping from 700°C to 850°C over 240 seconds and holding for 30 seconds before

| | |
|-------------------|----------------------------------|
| Contact | p ⁺ -GaN |
| Cladding | p-AlGaIn/GaN superlattice |
| Electron blocking | p-AlGaIn |
| Waveguide | InGaIn |
| Quantum wells | 2x(InGaIn/GaN) |
| Waveguide | InGaIn |
| Cladding | n-AlGaIn |
| Contact | n-GaN |
| Substrate | GaN/sapphire or freestanding GaN |

Figure 1. Epitaxial structure.

Figure 3. (a) Emission spectra at different current density. (b) Power-current-voltage curve of typical green laser diode under continuous-wave operation at room temperature.



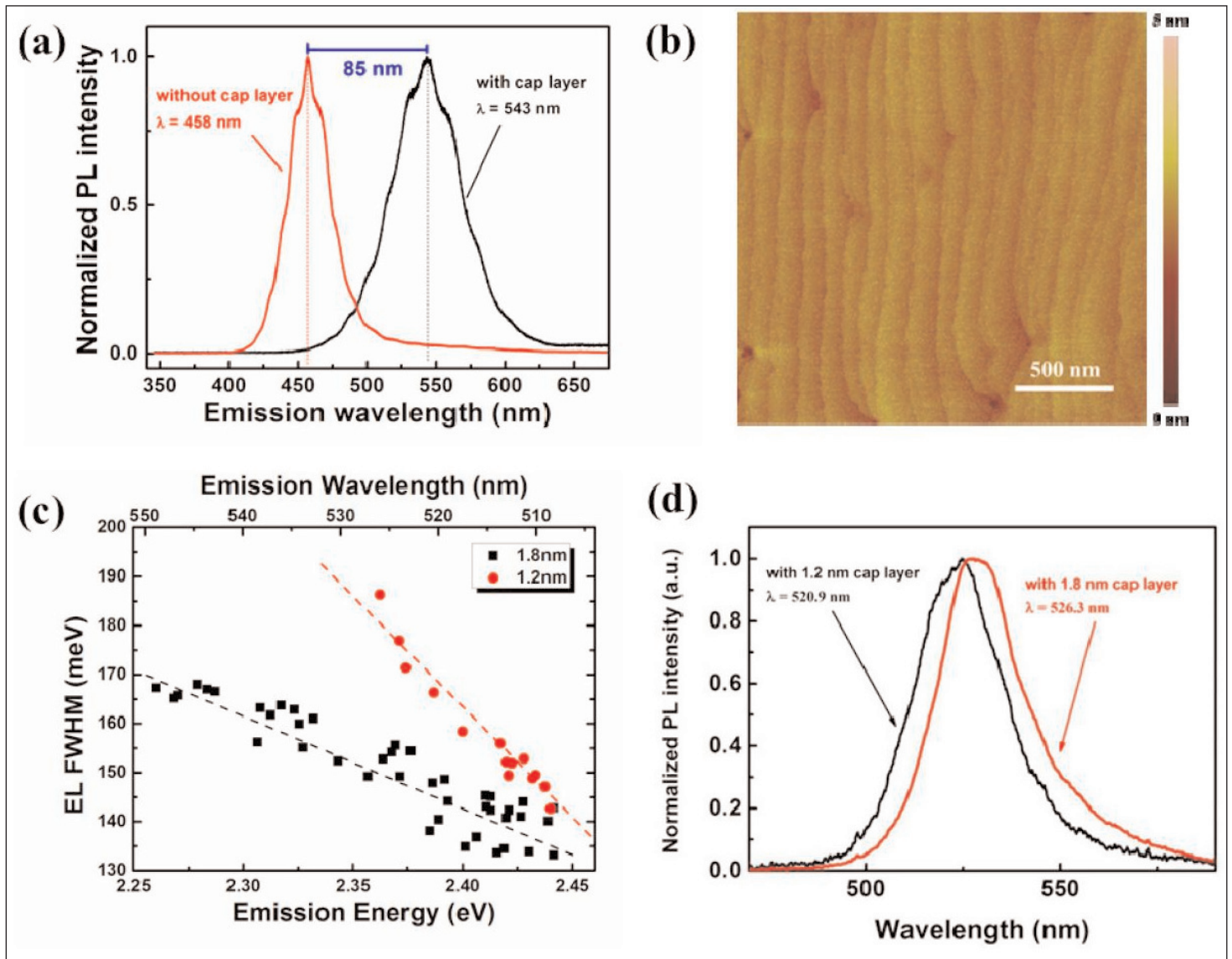


Figure 2. (a) Photoluminescence (PL) spectra of green InGaN/GaN QWs with and without GaN cap layer, (b) atomic force microscope (AFM) images of 15nm quantum barrier layers on GaN/sapphire template, (c) electroluminescence full-width at half maximum (FWHM) dependent on emission energy of laser diode groups with 1.2nm and 1.8nm GaN cap layer, (d) PL spectra of green InGaN/GaN QW with 1.2nm and 1.8nm GaN cap layer.

growing the 15nm GaN barrier at 850°C. The indium layer was protected from loss of indium during the thermal treatment by a 1.8nm GaN cap layer grown at 700°C.

The thermal treatment suppressed trench defects and removed indium clusters that arise from severe segregation effects usually seen in the high-indium-content InGaN needed for green light emission (Figure 2).

Thermal treatment suppressed trench defects and removed indium clusters that arise from severe segregation effects usually seen in the high-In-content InGaN needed. The treatment process was developed using material grown on GaN/sapphire templates and free-standing GaN

The treatment process was developed using material grown on GaN/sapphire templates and free-standing GaN. Electroluminescence and cathodoluminescence studies showed that the indium clusters were formed both at and away from dislocations.

The laser diodes used material deposited on free-standing GaN. Laser diodes with 10µm ridge-waveguide width and 800µm cavity length had a threshold current density of 1.85kA/cm² under continuous-wave operation at room temperature (Figure 3). A low voltage of 4V at threshold is attributed to suppressed carbon impurity in magnesium-doped AlGaIn cladding layer. At 6kA/cm² injection the output power was 58mW. The green laser wavelength was around 508nm. ■

<http://dx.doi.org/10.1364/OE.25.000415>

Author: Mike Cooke

Gallium nitride thin-film transistors produced in 200°C process

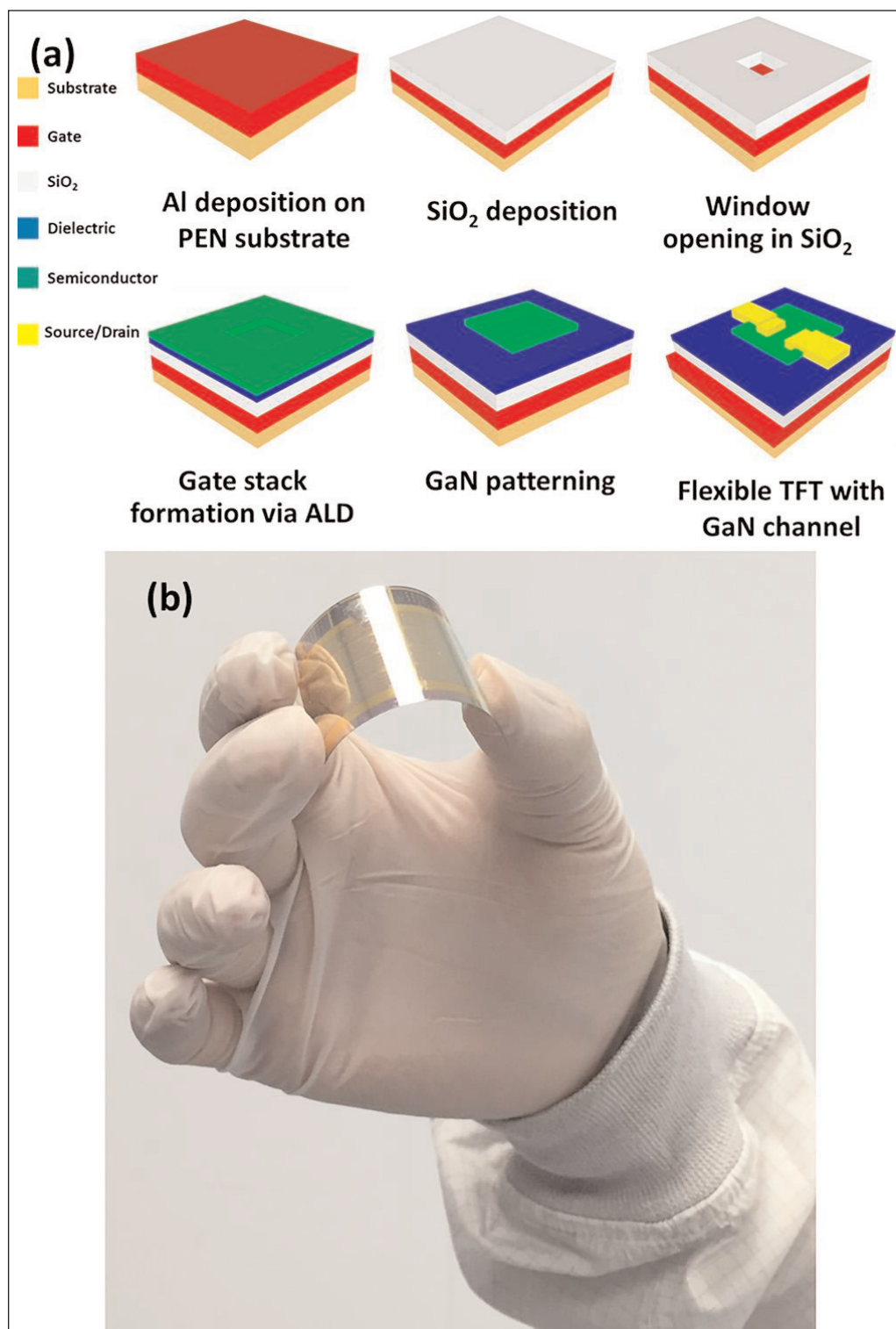
Researchers claim record low-temperature thermal budget.

Bilkent University in Turkey has developed a low-temperature process to create gallium nitride (GaN) back-gated thin-film transistors (TFTs) on flexible and rigid substrates [S. Bolat et al, Appl. Phys. Lett., vol109, p233504, 2016]. The team reports that the “overall fabrication thermal budget is below 200°C, the lowest reported for the GaN-based transistors so far.”

The Bilkent team points to potential applications of flexible devices for health monitoring, wearable electronics, and displays. Alternatives to the rigid TFT circuits used in most displays suffer from the need for high-temperature deposition/annealing steps. Organic and metal oxide devices are impacted by reliability issues. Although reliability in metal oxides such as zinc oxide can be improved with encapsulation, this adds to production complexity and cost.

Normally, GaN is deposited at high temperature around 1000°C, but other techniques such as atomic layer deposition have been developed with much improved thermal budget. “Up to now, the nitride-based electronic

Figure 1. (a) Schematic of device fabrication steps on flexible substrate, and (b) photograph of flexible substrate with series of bottom-gated TFTs with GaN channels flexed in author’s hand.



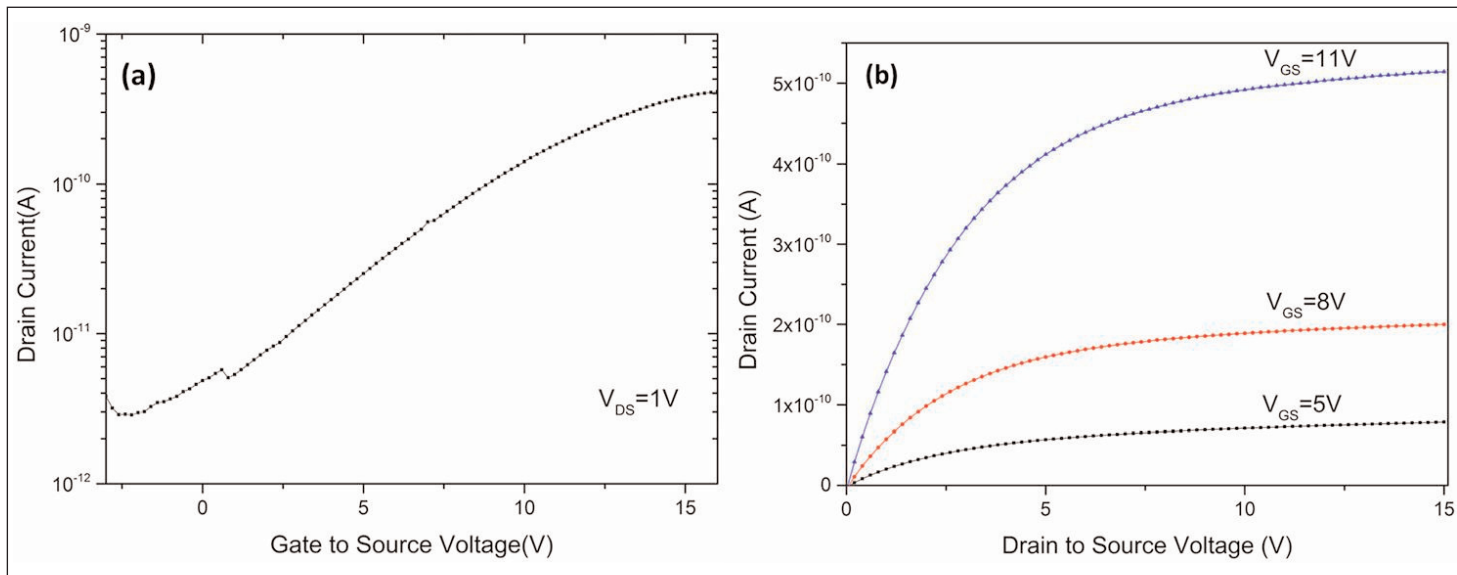


Figure 2. (a) Transfer and (b) output characteristics of GaN TFTs on flexible substrates.

and optoelectronic devices have been realized on flexible substrates only via the transferring method, which carries the potential risk of decreasing the yield of the devices, which therefore prevents the commercialization of the proposed devices," the team writes.

The Bilkent University researchers say that they have beaten their own record for lowest-temperature GaN electronic devices. The present results are not exactly high performance, but the team hopes that III-nitride-based flexible electronics could follow from further materials and process optimization.

The researchers produced GaN TFTs (Figure 1) on rigid p-type silicon and flexible polyethylene naphthalate (PEN). Hollow-cathode plasma-assisted atomic layer deposition (ALD) at 200°C was used to create 77nm aluminium oxide (Al_2O_3) and 11nm GaN layers on a silicon dioxide layer in which patterned windows were cut to define the devices. The 200nm silicon dioxide was created by electron-beam evaporation.

The silicon dioxide was applied directly to cleaned rigid silicon substrates. For PEN substrates, a 100nm aluminium layer formed a back-gate structure on which the silicon dioxide was applied. In the rigid-substrate devices, the back gate was formed by p-silicon.

The devices consisted of square gates with 50 μm length and width. Device isolation was by dry etch. The source/drain contact metals were titanium/gold.

The devices on rigid substrates achieved on/off current ratios

of 2×10^3 with "clear saturation in their output characteristics". The threshold voltage was +0.25V. The effective mobility was $0.005 \text{cm}^2/\text{V}\cdot\text{s}$ with 10V gate potential and 1V drain bias. The low mobility is blamed on "the nanocrystalline and defective nature of the ALD-based GaN thin films".

On flexible substrate, the TFT managed a reduced on/off ratio of 7×10^2 , while giving a higher threshold voltage of +2.5V (Figure 2). The researchers comment: "The difference in the threshold voltage can be attributed to the higher oxygen concentration in the as-deposited GaN thin films on flexible substrates (10% oxygen) compared to rigid substrates (2–3% oxygen), which is confirmed with the x-ray photo-spectroscopy measurements."

The higher oxygen content results in the formation of Ga_2O_3 in the GaN thin film; "therefore the devices on the flexible substrate demonstrate a higher threshold voltage and lower on-to-off current ratio," the researchers write.

The effective mobility on flexible substrate was $0.0012 \text{cm}^2/\text{V}\cdot\text{s}$ with 8V gate potential and 1V drain bias.

Gate-bias stability of the flexible TFTs under 10V stress with source and drain grounded for varying periods was tested. The 10V gate bias represented an electric field of 1.3MV/cm in the gate oxide. The threshold voltage shift after 1000 seconds was 0.14V (~5%). This compares with ZnO-based TFTs that have a shift of 11V under the same conditions.

The researchers comment: "This result is significantly important in the sense that no encapsulation or annealing, which are commonly applied methods to electrically stabilize the TFTs with semiconducting metal oxide channels, are needed to stabilize the devices." ■

<http://dx.doi.org/10.1063/1.4971837>

Author: Mike Cooke

This result is significantly important in the sense that no encapsulation or annealing, which are commonly applied methods to electrically stabilize the TFTs with semiconducting metal oxide channels, are needed to stabilize the devices

Non-polar aluminium gallium nitride from two-way pulsed precursor flow

Improving crystal quality of a-plane material with Al content of more than 60%.

Researchers at Southeast University and Changshu Institute of Technology in China have improved the crystal quality of a-plane aluminium gallium nitride (AlGaN) with Al content more than 60% grown by metal-organic chemical vapor deposition (MOCVD) on r-plane sapphire [Jianguo Zhao et al, Appl. Phys. Express, vol10, p011002, 2017]. The team used a technique that used separate pulses of nitrogen and aluminium precursors to avoid parasitic chemical reactions that reduce aluminium incorporation in the crystal structure.

High-Al-content AlGaN is used to create deep ultraviolet light-emitting diodes (DUV LEDs) with wavelengths shorter than 300nm. Such devices are being developed for killing dangerous micro-organisms in water and air for disinfection/purification purposes.

Presently the efficiency of DUV LEDs is pitifully low — of the order of a few percent. One source of inefficiency is that standard growth techniques result in c-plane material with electric fields from charge polarization effects that reduce electron-hole overlap, hindering recombination into photons. The problem is commonly referred to as the quantum-confined Stark effect. It can be reduced or eliminated by using non-polar or semi-polar III-nitride semiconductor heterostructures. The a-plane (11 $\bar{2}$ 0) is an example of a non-polar crystal structure orientation.

Other inefficiencies for c-plane devices are added by optical anisotropy and energy band structure effects. However, the growth of a-plane material is challenged by a large lattice-mismatch with r-plane sapphire,

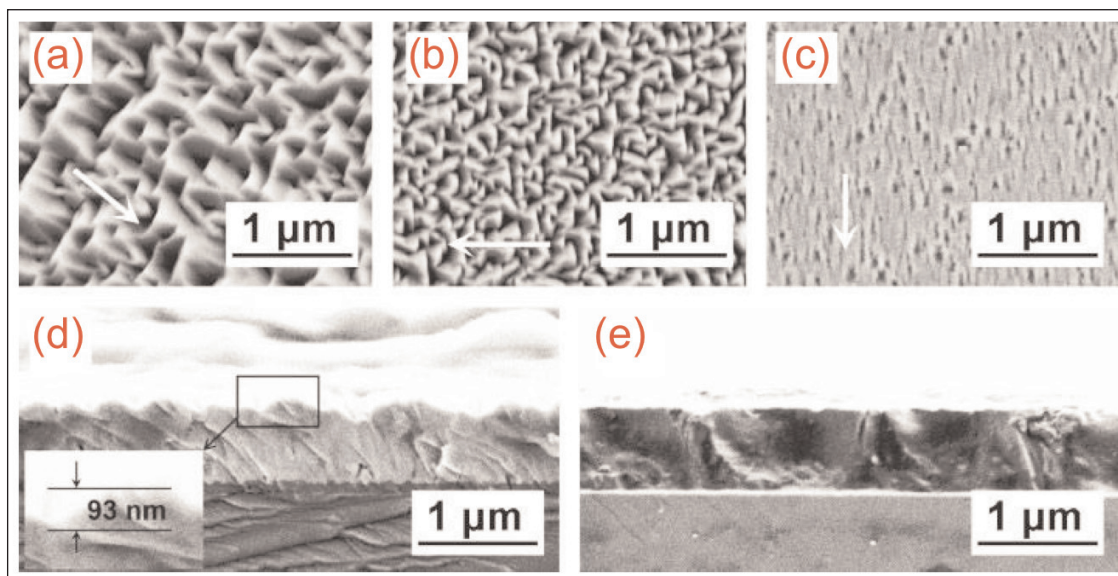


Figure 1. Top-view surface SEM micrographs for samples (a) A, (b) B and (c) C with white arrows pointing in c-direction; and cross-sectional SEM micrographs for samples (d) A and (e) C.

basal stacking fault tendencies, and the strong anisotropy of such epilayers.

The a-plane (11 $\bar{2}$ 0) AlGaN growth was carried out at 40Torr low pressure. The respective precursors for Al, Ga, silicon and nitrogen were trimethylaluminum (TMAI), trimethylgallium (TMGa), silane (SiH₄), and ammonia (NH₃).

The growth sequence on r-plane (2 $\bar{2}$ 04) sapphire was surface contamination removal at 1060°C in hydrogen, 20nm 600°C AlN nucleation, 1100°C AlN buffer, and 800nm AlGaN epitaxial layer. The buffer was grown either continuously or in pulse-flow mode. Various AlGaN layer growth processes were tested: continuous (sample A), pulsed-flow (B), and two-way pulsed-flow (C).

The sample B method involved pulses in the ammonia flow only, for both the AlN buffer and AlGaN epilayer. Sample C was grown with pulses of ammonia and TMAI organized to suppress parasitic gas-phase reactions between these components. At the same time, the TMGa flow was continuous. The precursor pulses in all cases lasted 6 seconds.

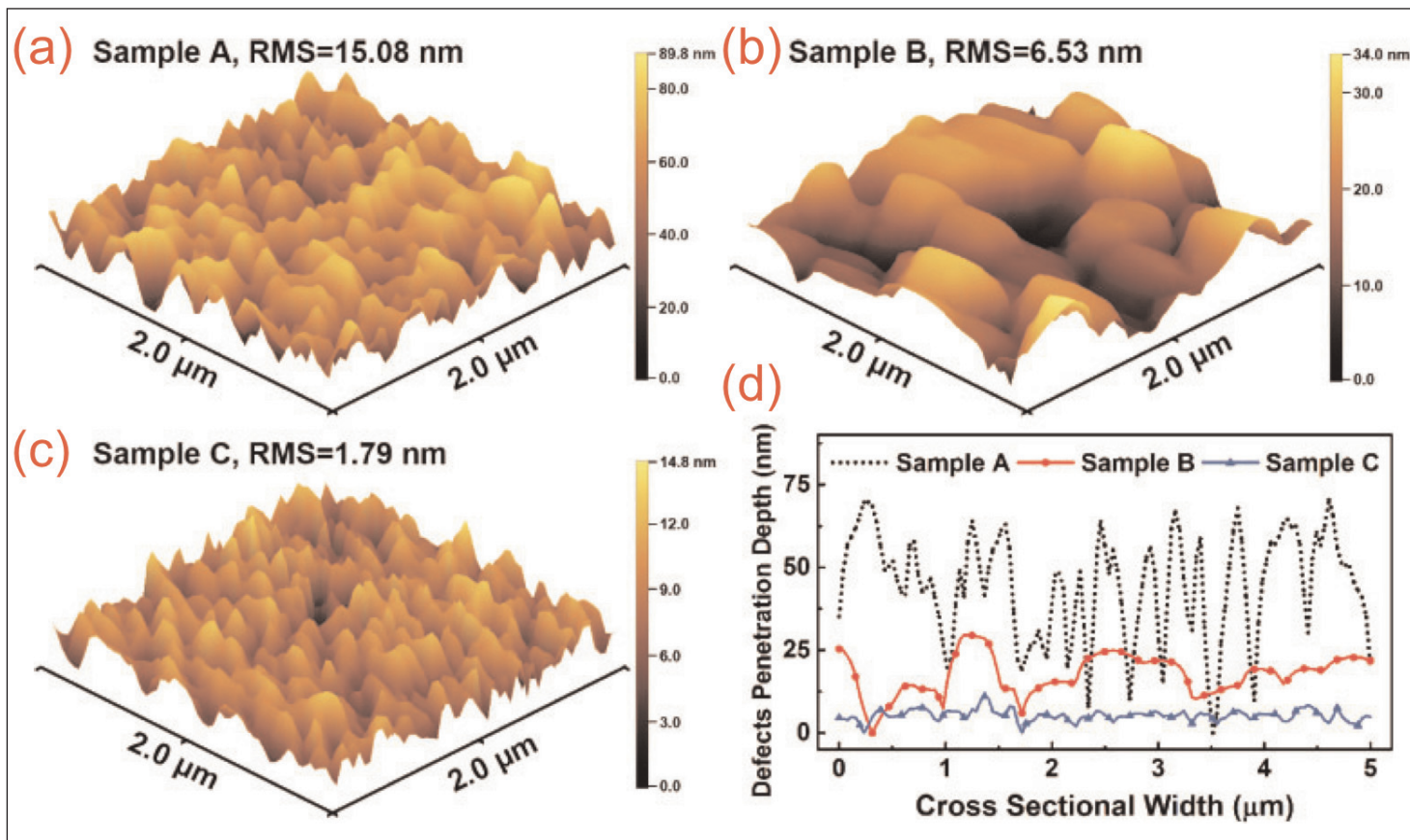


Figure 2. AFM three-dimensional view images and RMS values measured within detection area of $2\mu\text{m}\times 2\mu\text{m}$ for samples (a) A, (b) B and (c) C; and (d) AFM cross-sectional graphs for samples A (black dotted line), B (solid red line), and C (solid blue line).

X-ray analysis suggested that the Al content of the AlGaN epilayers was 60%, 66% and 68% for samples A to C, respectively. The researchers attribute the higher Al content in samples B and C to suppression of the parasitic gas-phase reactions between ammonia and TMAI, enhancing Al incorporation.

Scanning electron microscope inspection of the surface showed that sample C had much reduced roughness with large defect-free areas compared with the other samples. The researchers comment: "In fact, both large and small pyramidal defects coalesced very well, and the penetration depth of the defects into the epilayer was found to be very shallow for sample C, resulting in an apparent reduction in defect density, as demonstrated by the top-view surface and cross-section SEM micrographs" (Figure 1). The team adds: "This improvement in crystalline quality for the non-polar

This improvement in light transmission characteristics was attributed to the smoothed surface morphology and the improved crystalline quality for the sample grown using the innovative two-way pulsed-flow technology... Smaller RMS values and lower defect densities correlate with less absorption

a-plane AlGaN epi-layer is the result of the introduction of the innovative two-way pulsed-flow growth technology, which can be explained based on the fact that there is more time for the Al adatoms to migrate to their appropriate lattice sites under an Al-rich growth condition."

Atomic force microscope (AFM) scans also showed reduced root-mean-square (RMS) roughness for sample C (Figure 2). In $10\mu\text{m}\times 10\mu\text{m}$ scans the RMS roughness values corresponding to samples A to C were, in order, 15.37nm, 6.94nm and 2.02nm.

Sample C also showed increased transmittance of light, especially when the wavelength was longer than 400nm. The peak enhancement was 36.4% in the 200–400nm range. The researchers comment: "This improvement in light transmission characteristics was attributed to the smoothed surface morphology and the improved crystalline quality for the sample grown using the innovative two-way pulsed-flow technology. It is well known that smaller RMS values and lower defect densities correlate with less absorption, which is of critical importance for enhancing the light extraction efficiency of DUV-LEDs."

The higher Al content of sample C resulted in an absorption edge 8nm shorter in wavelength (higher energy bandgap) than sample A. ■

<https://doi.org/10.7567/APEX.10.011002>

Author: Mike Cooke

Metal-organic vapor phase epitaxy of nitrogen-polar gallium nitride

Researchers in China have used a reformed-flow-rate-modulation technique to improve crystal quality for N-polar GaN.

Southeast University and Changshu Institute of Technology, both of China, have jointly developed a metal-organic vapor phase epitaxy (MOVPE) process for nitrogen-polar (N-polar) gallium nitride (GaN) with improved crystal quality [Heng Zhang et al, *Jpn. J. Appl. Phys.*, vol56, p015501, 2017]. The researchers call the technique 'reformed-flow-rate-modulation epitaxy', which was performed to create the nucleation layer.

N-polar GaN is usually produced by molecular beam epitaxy (MBE) methods, but MOVPE is the preferred manufacturing technology. MOVPE usually results in Ga-polar GaN.

The N-polar orientation of the crystal structure could be used to improve features of light-emitting structures, such as creating electron-blocking layers with reduced barriers to hole injection using charge-polarization engineering. The technology could also be used to increase options for high-frequency and high-power electronics, where charge polarization is used to create two-dimensional electron gases (2DEG).

The MOVPE was carried out on (0001) sapphire at low pressure (70Torr) with trimethylgallium (TMG) and ammonia (NH₃) precursors in hydrogen carrier gas. The process began with the removal of surface contamination at 1060°C and a 30-second nitridation in NH₃ at 980°C.

The reformed flow-rate modulation nucleation layer consisted of material grown from 12-second pulses of TMG flow separated by various gaps. Ammonia was supplied continuously throughout the growth. Conventional flow-rate modulation alternates precursors, but GaN tends to decompose in the absence of NH₃.

The grown layers consisted of 1070°C 500nm N-polar GaN on top of 600°C 20nm low-temperature (LT) GaN nucleation. The N-polarity of the resulting material was confirmed by potassium hydroxide etching, which preferentially consumes N-polarity material compared with Ga-polarity.

The x-ray rocking curve (XRC) full-width at half maximum (FWHM) was least for an interruption time of 4 seconds between the 12-second pulses of TMG during

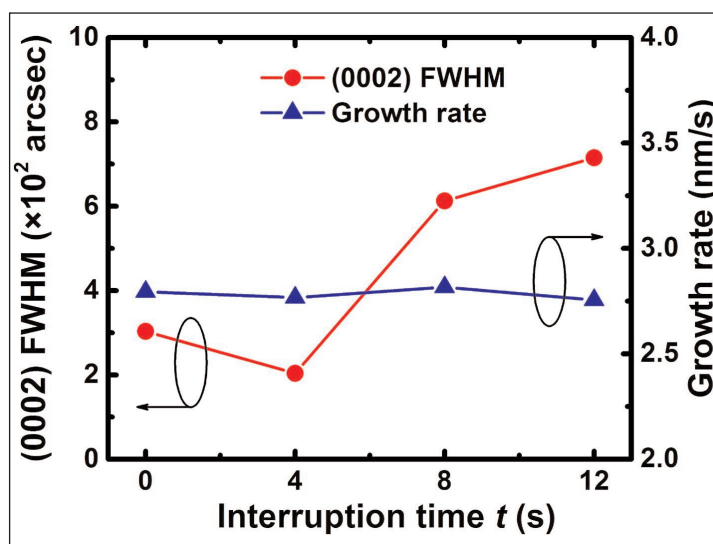


Figure 1. FWHM of XRCs and growth rates as function of TMG-supplying interruption time for N-polar GaN epitaxial layers with LT-GaN nucleation layers grown by reformed flow-rate-modulation technology.

nucleation growth (Figure 1). Low FWHM values indicate better crystal quality. The different nucleation growth processes had little effect on the total growth time for the N-polar GaN material.

Room-temperature photoluminescence intensity achieved the same optimum of 4-second interruption time (Figure 2). Also, the ratio of band-edge (BE \sim 364nm) over 'blue-band' (BB \sim 470nm) emission was highest with 4-seconds-interruption growth.

The researchers comment; "Since the migration length of the Ga atom is quite long on the surface of (0001)-plane GaN, and the Ga atom usually does not have sufficient time to sit at the lattice site where it should be, the formation of the native Ga vacancy in GaN epitaxial layer was considered to be responsible for the BB emission."

There were few 'yellow-band' (\sim 580nm) emissions, which are often associated with threading dislocations and carbon impurities.

The threading dislocation (TD) density derived from the XRC FWHM measurements was also lowest with

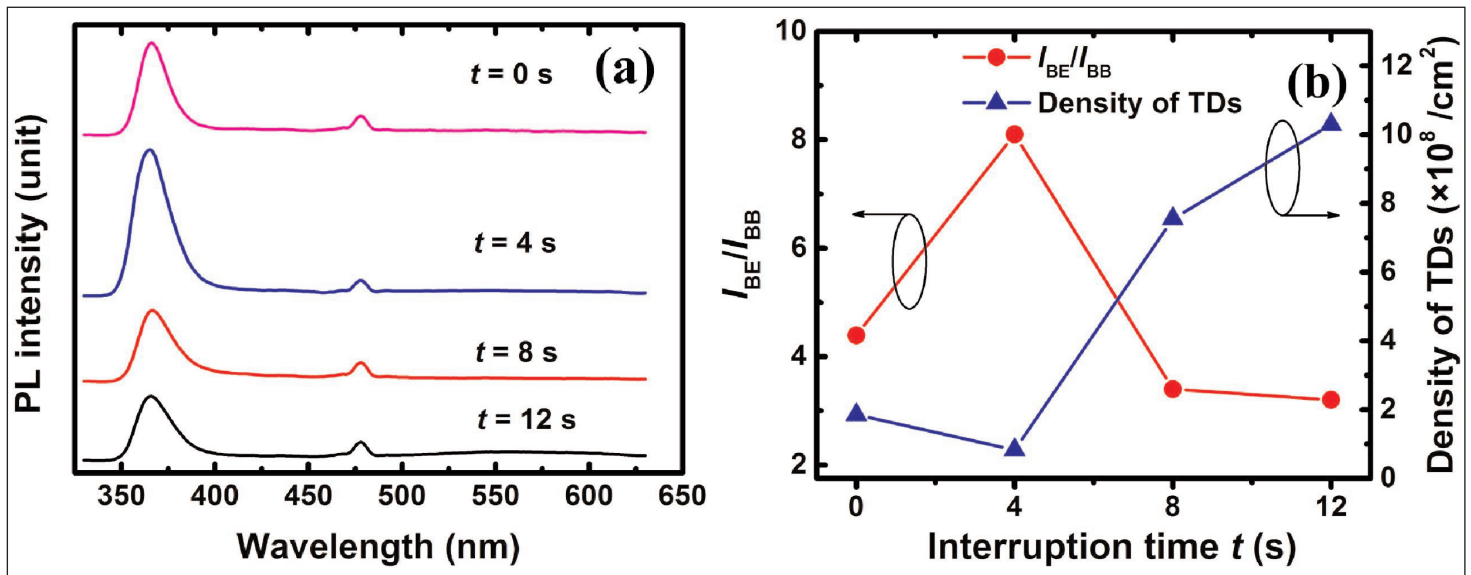


Figure 2. Room-temperature photoluminescence spectra (a), and ratio of intensities, I_{BE}/I_{BB} and density of TDs as function of TMG-supplying interruption time.

4 seconds interruption between pulses. The story was repeated in Hall measurements, with the lowest intrinsic electron concentration ($\sim 4 \times 10^{18} / \text{cm}^3$) and highest mobility ($\sim 90 \text{ cm}^2 / \text{V-s}$) occurring in the 4-second sample.

High background carrier concentrations are associated with unintentionally doped oxygen and carbon impurities and acceptor states around TDs. The researchers suggest that the low intrinsic electron concentration was due to the reduction in TDs in the 4-second sample. "Besides, with the successful suppression of the incorporation of oxygen and carbon impurities, the mobility of sheet carriers can be enhanced with the reformed flow-rate-modulation technology owing to a lower ionized impurity scattering," they add.

Atomic force microscopy on the nucleation layer showed a steady increase in root-mean-square (RMS)

roughness from no interruption (0.25nm) to 12-seconds (7.89nm). The 4-second sample had a roughness of 0.48nm.

The researchers comment: "With continuous supply of NH_3 in our reformed flow-rate-modulation epitaxial growth process, the effects of the decomposition and re-deposition are more notable, leading to a rougher surface morphology. The facts above imply that, just like the role of patterned sapphire substrate (PSS), the shape and dimension of LT-GaN nucleation islands are of crucial importance for achieving high-crystalline-quality N-polar GaN epitaxial layer, and the optimal RMS value for the LT-GaN nucleation island height is 0.48nm." ■

<https://doi.org/10.7567/JJAP.56.015501>

Author: Mike Cooke

CS ManTech 2017

Indian Wells, California, 22–25 May

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Korea's UNIST fabricates thinnest oxide semiconductor

Deposition of monolayer hexagonal ZnO on graphene promises highly transparent and flexible opto devices

A new study, affiliated with South Korea's Ulsan National Institute of Science and Technology (UNIST), has introduced a novel method for fabricating what is claimed to be world's thinnest oxide semiconductor — two-dimensional zinc oxide (ZnO) just one atom thick. This may open up new possibilities for thin, transparent and flexible electronic devices, such as ultra-small sensors, it is reckoned (Hyo-Ki Hong et al., 'Atomic Scale Study on Growth and Heteroepitaxy of ZnO Monolayer on Graphene', *Nano Letters* (2017) 17 (1) p120).

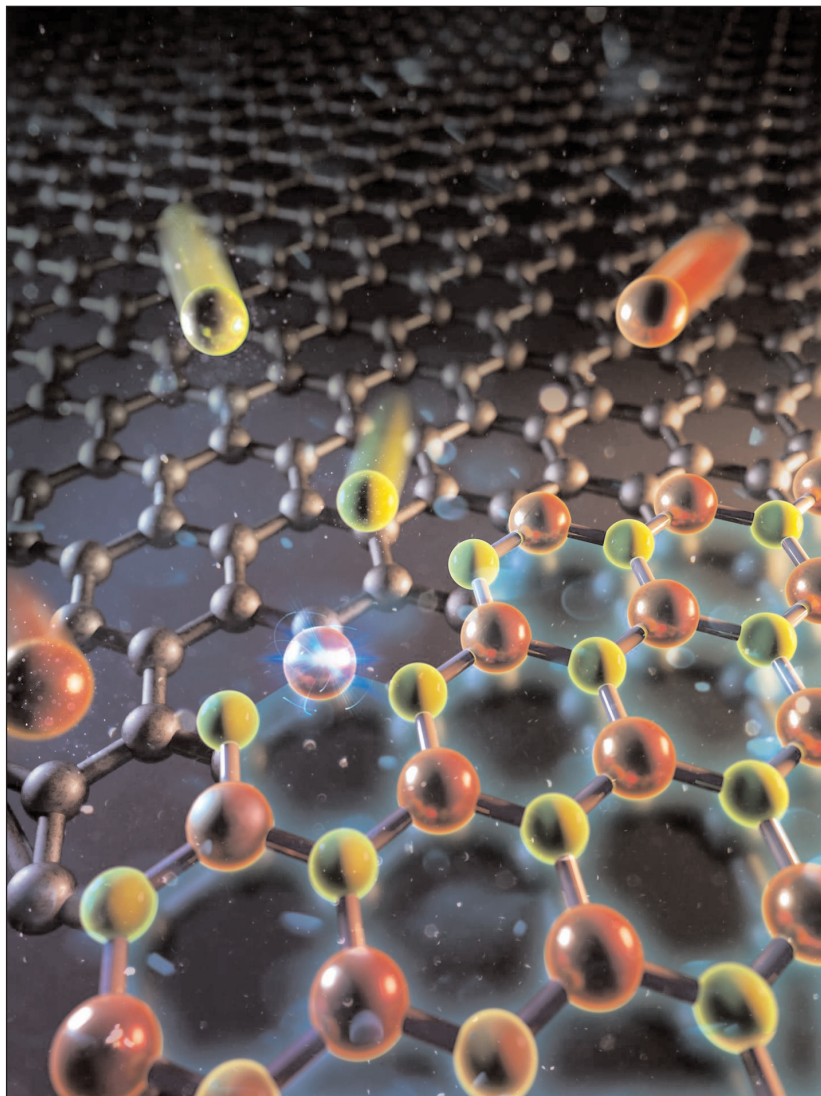
The new ultra-thin oxide semiconductor was created by a team led by professor Zonghoon Lee of Materials Science and Engineering at UNIST.

The material is formed by directly growing a single-atom-thick ZnO layer on graphene, using atomic layer deposition (ALD). It is also said to be the thinnest heteroepitaxial layer of semiconducting oxide on monolayer graphene.

"Flexible, high-performance devices are indispensable for conventional wearable electronics," says Lee. "With this new material, we can achieve truly high-performance flexible devices."

As existing silicon fabrication processes become finer, the performance becomes a much more critical issue, and there has been much research on next-generation semiconductors to replace silicon, notes the team. Graphene has superior conductivity properties, but it cannot be used directly as an alternative to silicon in electronics because it has no energy bandgap. In graphene, however, electrons move randomly at a constant speed, regardless of their energy, and they cannot be stopped.

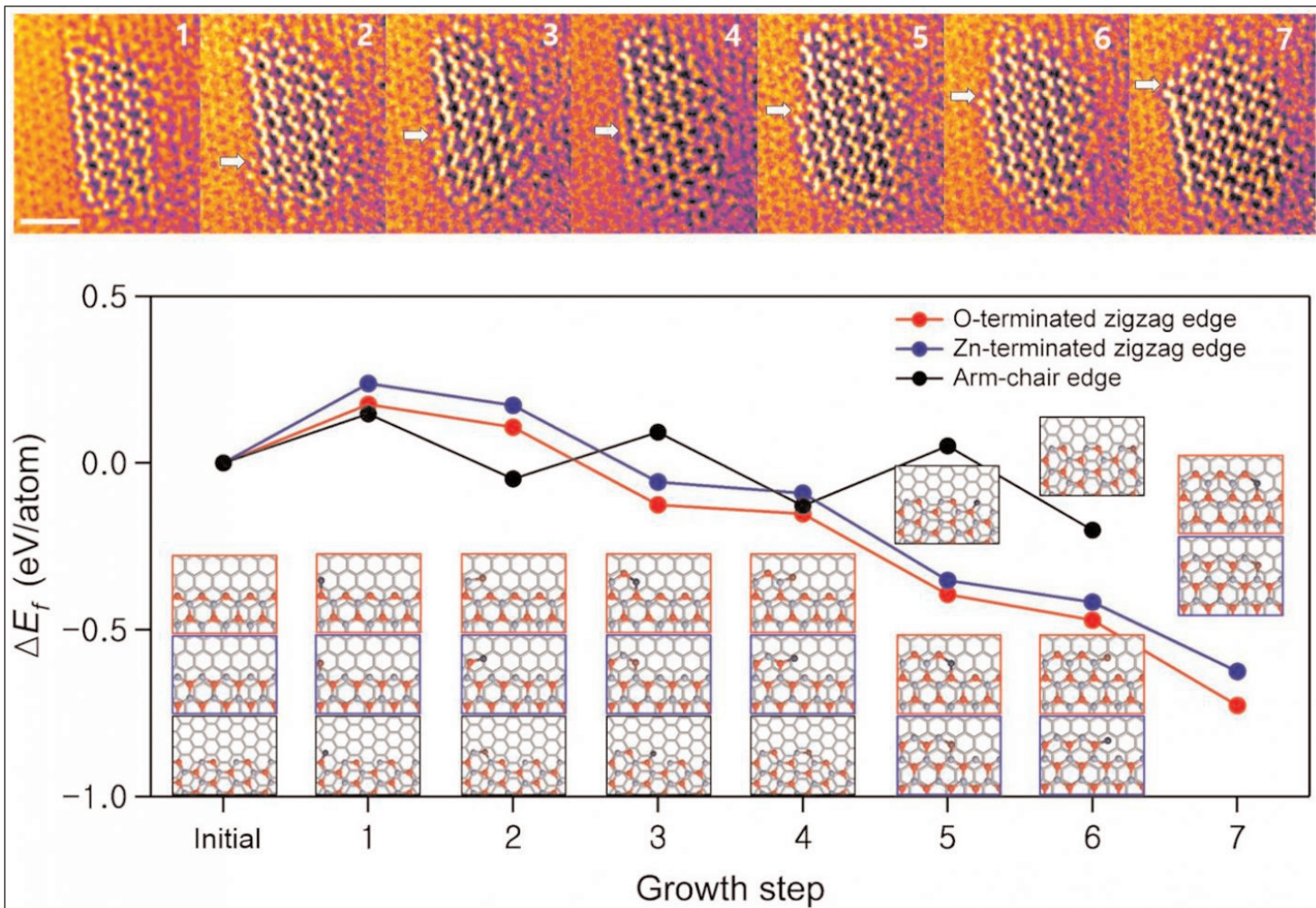
To solve this, the research team decided to demonstrate atom-by-atom growth of zinc and oxygen at the preferential zigzag edge of a ZnO monolayer on graphene through in-situ observation. They then experimentally determine that the thinnest ZnO monolayer has a wide bandgap (up to 4.0eV), due to quantum confinement and a graphene-like 'hyper-honeycomb' structure, as well as high optical transparency. Existing oxide semiconductors have a relatively large bandgap, in the range of 2.9–3.5eV. The greater the bandgap energy, the lower the leakage current and excess noise.



Growth of ZnO on graphene layer, consisting of interconnected hexagons of carbon atoms. Zinc atom shown as red spheres; oxygen atom as green spheres. (Credit: UNIST.)

"This is the first time to actually observe the in-situ formation of hexagonal structure of ZnO," says the paper's first author, Hyo-Ki Hong of Materials Science and Engineering. "Through this process, we could understand the process and principle of 2D ZnO semiconductor production," he adds.

"The heteroepitaxial stack of the thinnest 2D oxide semiconductors on graphene has potential for future optoelectronic device applications associated with high optical transparency and flexibility," notes Lee. "This



Lateral growth of ZnO monolayer along the zigzag edges. Credit: UNIST.

study can lead to a new class of 2D heterostructures, including semiconducting oxides formed by highly controlled epitaxial growth through a deposition route."

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Atomic scaling of future electronic materials to lower dimensions

Mike Cooke reports on increasing interest in graphene, nanotubes and other planar and linear structures at the IEDM conference in San Francisco.

As microelectronics scales down to atomic scales, engineers and scientists must increasingly deal with phenomena that are better described in terms of two-, one- and even zero-dimensional models. The loop joining experiment, theory and models provide the language needed for coordinating and creating applications. There is much interest at the moment in potential electronic applications of two-dimensional (2D) materials that are formed from strong intra-plane bonds and weaker inter-plane adhesion. This was reflected at the recent IEEE International Electron Devices Meeting (IEDM 2016) in San Francisco last December.

Researchers have used '2D' structures in III-V compound semiconductors for some time, in the form of quantum wells with charge carriers confined to thin nanometer-scale layers. In complementary metal-oxide-semiconductor (CMOS) transistors the channel consists of a thin 'inversion layer' under the gate. However, new materials like graphene, along with transition-metal dichalcogenides (TMDs) and hexagonal boron nitride (BN), allow the confinement to be squeezed by a factor of ten to the atomic scale.

Since the development is relatively new, several presentations and almost all of session 14 concentrated on theory and modeling. However, we focus here on experimental achievements.

Graphene

The Indian Institute of Science claims record low resistance for chemical vapor deposition (CVD) graphene contacts with metal at room temperature [session 5.3]. The researchers used various techniques to massage the chemical bonds by engineering the carbon atomic orbitals from the sp^2 - to sp -hybridized form. The sp^n hybridization description is commonly used in carbon (quantum) chemistry — sp^3 gives the diamond structure and sp^2 gives graphene/graphite. The sp -type bond is seen in the linear acetylene structure HC-CH with a triple bond between the carbons.

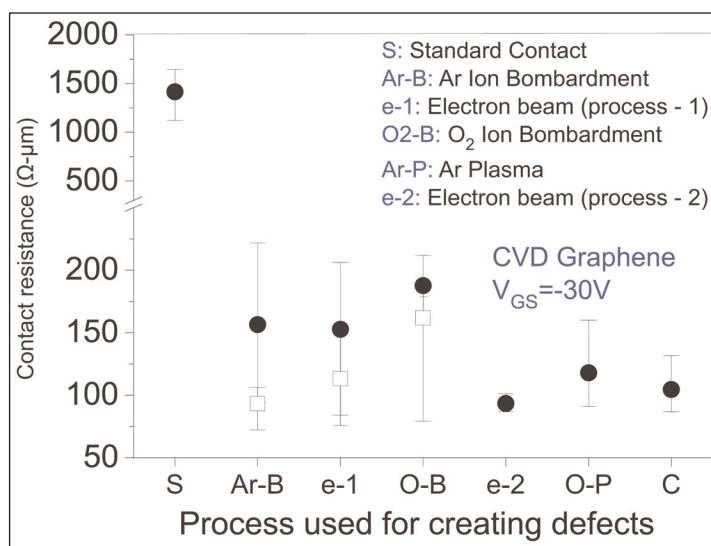


Figure 1. Metal-graphene contact resistance of standard versus engineered contacts from different processes.

The sp hybridized carbon orbitals form a more conducting bond with metal. Graphene edges contain sp hybridized carbon atoms. The experimental realization of sp hybridization was achieved by increasing the edges of the graphene.

Three techniques were tried to give graphene with increased sp hybridization: plasma/ion bombardment with oxygen or argon, electron-beam, and increasing the edge perimeter through lithography of comb patterns. The plasma/ion and electron-beam techniques increase sp hybridization through introducing defects in the graphene structure.

All the methods were found to reduce contact resistance — $78\Omega\text{-}\mu\text{m}$ for oxygen plasma, $84\Omega\text{-}\mu\text{m}$ for electron-beam treatments (see Figure 1). These achievements are claimed as record lows for metal-graphene contacts. The $84\Omega\text{-}\mu\text{m}$ value is claimed as "138% and 28% better than best reported till date while using CVD and epitaxial graphene, respectively."

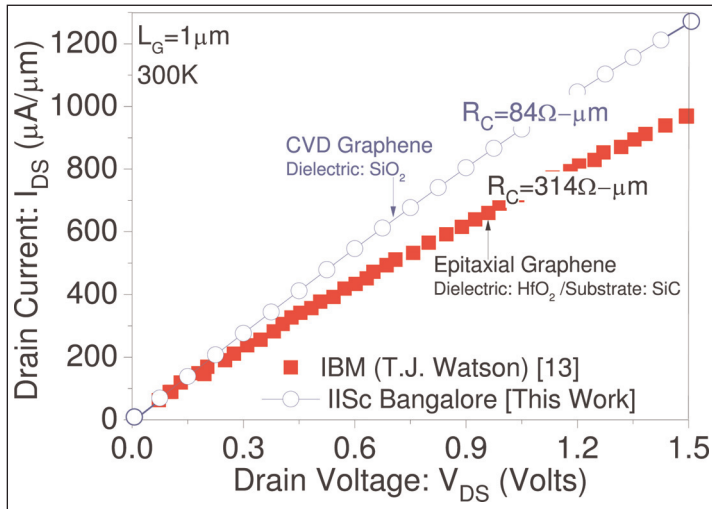


Figure 2. Transistor output characteristics of CVD graphene on SiO_2 FET with engineered contact compared with the best reported in literature for epitaxial graphene on SiC substrate.

The researchers also report that their contact engineering has led to CVD graphene transistors offering record high performance (Figure 2), “better than the best reported till date” for epitaxial graphene on silicon carbide.

Stanford University and Lam Research Corp have used graphene grown on copper (Cu) wiring to reduce electro-migration that can degrade performance of advanced integrated circuit interconnects [session 9.5]. The process was carried out below 400°C to meet back-end-of-line (BEOL) thermal budgets in CMOS manufacturing.

The test structures consisted of sputtered tantalum (Ta) and Cu on silicon dioxide on silicon (SiO_2/Si) substrate (Figure 3). The 5nm tantalum was used as an adhesion layer. After patterning, the graphene was applied by CVD. Plasma-enhanced CVD silicon nitride (SiN_x) provided a capping layer.

The researchers report that the graphene/Cu composite exhibited 2x lower resistivity, 1.4x higher breakdown current density and 40x longer electro-migration (EM) lifetime than as-deposited Cu. The EM performance at 150°C with $20\text{MA}/\text{cm}^2$ stress was also 10x better than 2nm cobalt tungsten phosphide (CoWP) on copper.

An industry-standard 3nm CoWP layer had comparable EM characteristics to the graphene coating.

With SiN_x capping, a temperature of 200°C and $36\text{MA}/\text{cm}^2$ was used to shorten the time to EM failure. The SiN_x

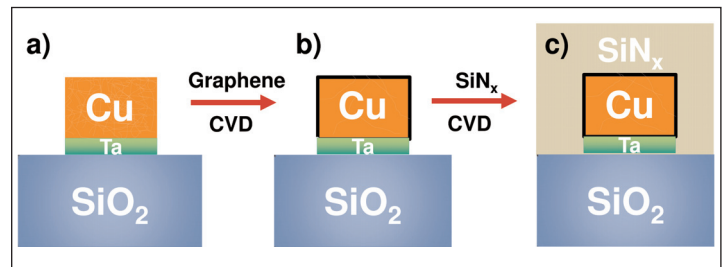


Figure 3. Cross-sectional view of process steps for fabricating test structure. (a) Ta/Cu is sputtered onto SiO_2/Si substrate followed by metal lift-off. (b) Graphene is grown directly on patterned Cu wires by CVD below 400°C . (c) Structure is then capped with SiN_x as protection layer against oxidation under high-temperature stress testing.

improved the performance of CoWP layers on Cu more than for the graphene, and the mean time to failure (MTTF) of graphene layers was 1.3x less than for 3nm CoWP.

The breakdown current density was $65\text{MA}/\text{cm}^2$, compared with $52\text{MA}/\text{cm}^2$ for wires capped with amorphous carbon or CoWP and $48\text{MA}/\text{cm}^2$ for the Cu as-deposited.

Fujitsu Laboratories Ltd presented gas sensors based on graphene-gate transistors [session 18.2]. The absorption of molecules on the graphene alters the work function and hence the transistor threshold voltage.

The devices were based on $0.6\mu\text{m}$ silicon MOS field-effect transistors (FETs), but with 13.5nm graphene replacing the usual polysilicon gate electrode (Figure 4). The graphene came from CVD on Cu.

The device was particularly sensitive to ammonia (NH_3) and nitrogen dioxide (NO_2), but not sulfur dioxide, hydrogen sulfide or acetaldehyde (Figure 5). NO_2 is an air pollutant that arises from motor vehicle emissions and smoking, causing inflammation of airways and asthma.

The team reports: “We have actually found that this sensor can have a sensitivity more than one magnitude higher than that of resistivity-based graphene gas sensors and commercially available gas sensors.”

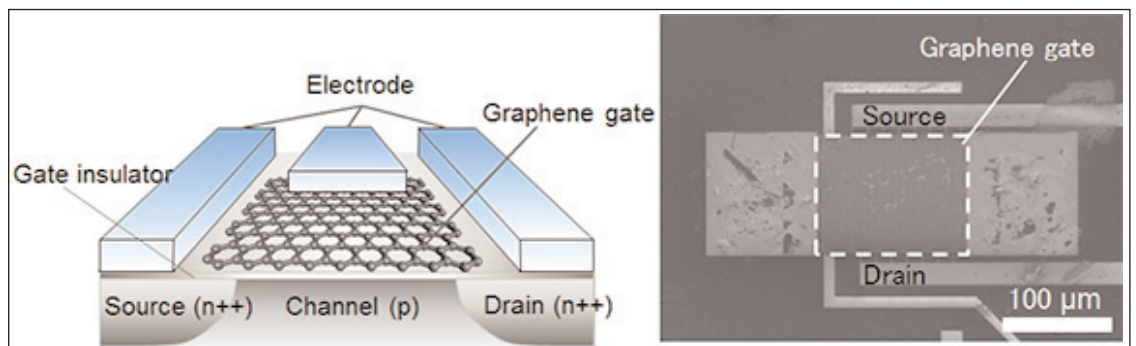


Figure 4. Schematic and scanning electron microscope (SEM) images of graphene-gate transistor sensor.

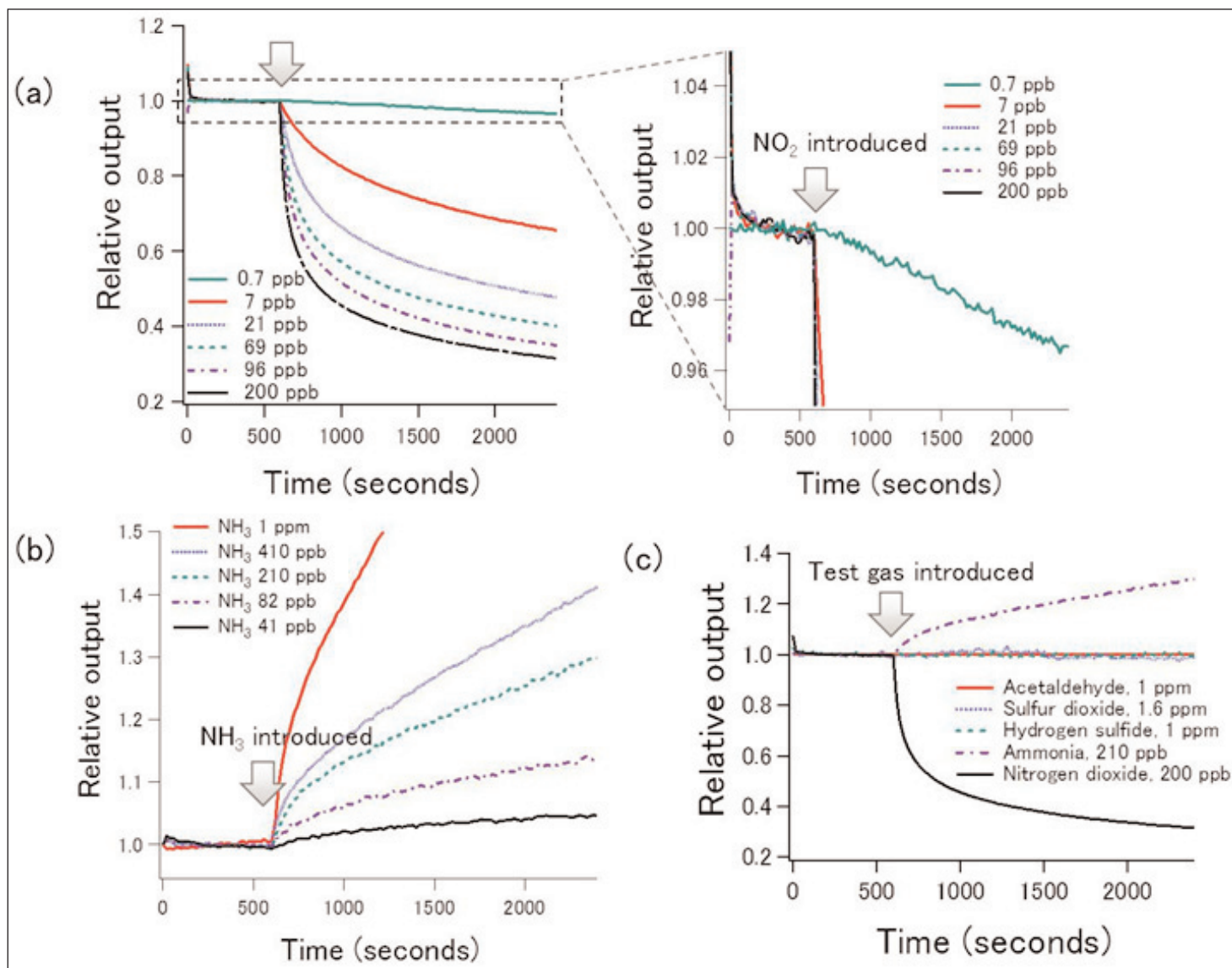


Figure 5. (a) Responsiveness of graphene-gate transistor sensor to NO₂ with magnification. (b) Response to NH₃. (c) Response to other gases.

- ▶ A Fujitsu press release adds: "This technology's sensitivity to NO₂ is an order of magnitude greater than conventional resistivity-based graphene sensors, at less than 1ppb, and the commercially available electrochemical sensors, which have sensitivity of over tens of ppb."

NH₃ sensitivity was of the order of tens of parts per billion (ppb). "The responses to NO₂ and NH₃ are in the opposite directions, corresponding to p-doping by NO₂ and n-doping by NH₃," the team reports.

"This sensor could be used in a compact device that could measure NO₂ anywhere, in real time, at the environmental benchmark level of sensitivity of 40–60ppb, which is an index of air pollution," Fujitsu adds.

Although the device was sluggish to return to its original performance when exposed to pure carrier gas (nitrogen), the researchers believe that heating the sensor could speed re-setting. "In practice, this sensor should be used at relatively high operation temperature, which is a strategy often employed in commercial sensors."

Fujitsu has already developed a sensor for NH₃ based on copper bromide p-type semiconductor material that, combined with the graphene sensor for NO₂, could result in "a highly sensitive and portable sensor that can be used as conveniently as a thermometer to measure gases in human breath for early detection of lifestyle diseases".

Nanotubes

IBM T.J. Watson Research Center presented end-bonded contacts to carbon nanotubes (CNTs) created through a low-temperature process [session 5.1]. The contacts were used to fabricate both p- and n-channel field-effect transistors (P-/N-FETs).

CMOS inverters based on CNTs with end-bonded contacts are claimed as demonstrating the smallest contact size thus far for such circuits. The team hopes that the technology could pave the way to realizing CNT-based scalable CMOS technology.

The semiconducting CNTs were deposited on a 10nm

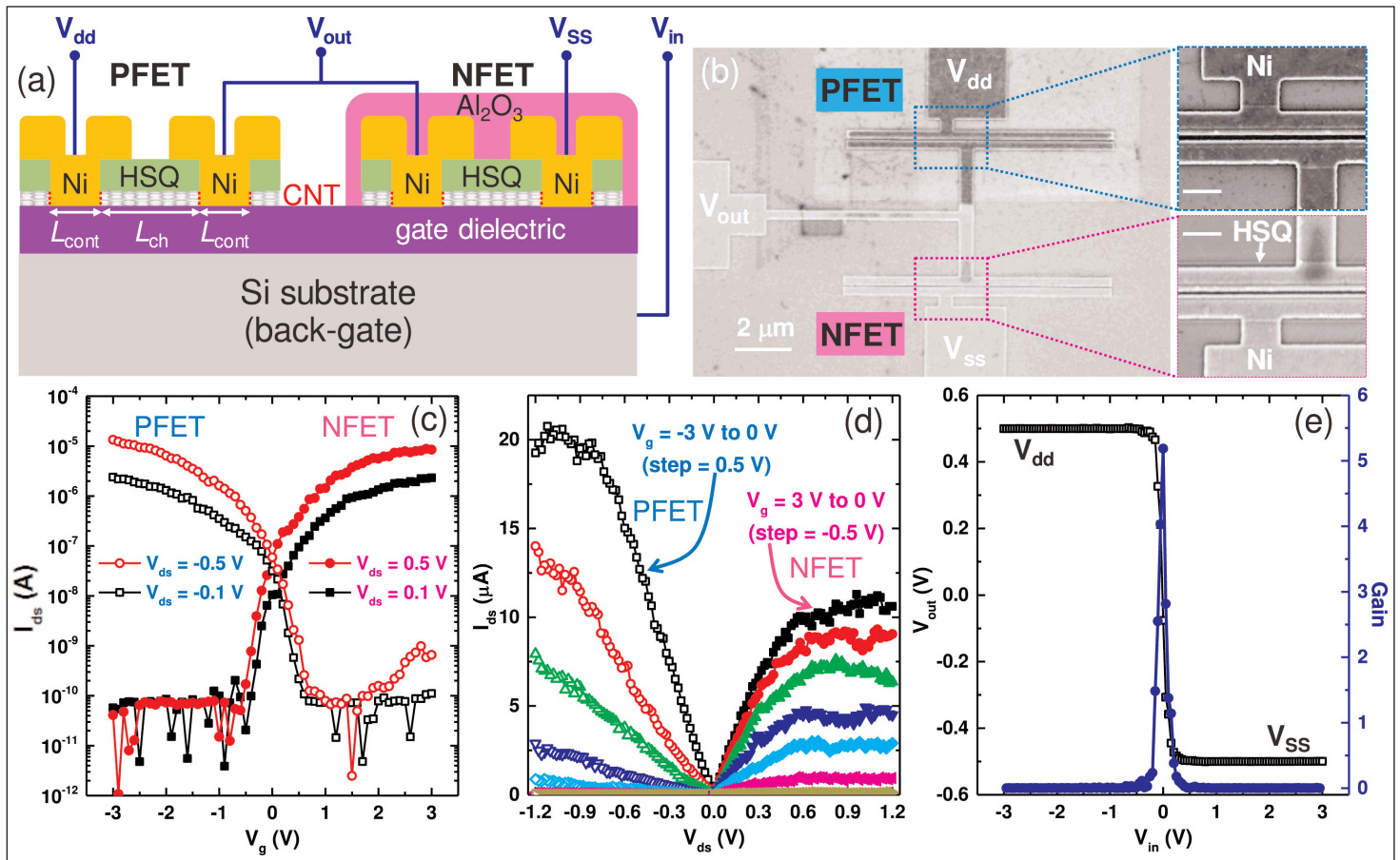


Figure 6. (a) Schematic of CNT-based CMOS inverter with entirely Ni end-bonded contacts. (b) SEM images of CMOS inverter with nominal 150nm channel and 40nm contact lengths. Insets' scale bars 400nm. (c) FET drain currents (I_{ds}) versus (c) gate potentials (V_{gs}) and (d) drain biases (V_{ds}). (e) Output voltage (left axis) and inverter gain (right axis) as function of input voltage.

SiO₂ layer on silicon substrate. Without annealing, fabricated back-gate transistors demonstrated ambipolar behavior with less than 1 μ A on-current. Annealing in the 400–600°C range converted the transistors to unipolar p-type performance with an on-current of \sim 10 μ A.

“Such a dramatic transition upon annealing hinted at a transformation in the contact scheme, that is, from Ni side-bonded contacts to end-bonded contacts,” the researchers comment. The team also suggests that the end bonding is due to carbon dissolution into the metal.

The on/off current ratio was near to 10⁶ with a peak transconductance of 3.1 μ S. The contact resistance was relatively size-independent at around 30k Ω . This is taken as indicating end-bonding rather than the usual side-bonding.

Palladium contacts had a similar performance boost on annealing, but nickel (Ni) contact devices showed less variations in operation characteristics. Apart from the better reliability, Ni is preferred in terms of cost and reduced contamination of existing silicon-based production lines.

Atomic layer deposition (ALD) of 20nm aluminium oxide (Al₂O₃) converted the transistors to n-type performance. Hydrogen silsesquioxane (HSQ) trenches

defined the contact regions and protected the CNT channel.

“The mechanism for the observed PFET-to-NFET conversion could be attributed to electron doping in the CNT from the fixed charge in the Al₂O₃ layer and also the electric dipole formation at the Al₂O₃/HSQ interface,” the researchers suggest. This allowed the researchers to demonstrate CMOS inverter circuits with gain higher than 5 using PFET and NFET structures (Figure 6).

Since Ni is ferromagnetic at room temperature, the researchers also believe that spintronics could be used to add more functionality in future CNT-based devices and circuits.

Researchers from South Korea and USA claimed the first demonstration of a wrap-gate CNT-FET with vertically suspended channels [session 5.2]. The team from Korea Advanced Institute of Science and Technology (KAIST), Kookmin University, NASA Ames Research Center, and South Korea’s National Nanofab Center reported enhanced gate controllability and charge transport capabilities. The CNT channels were deposited on a silicon nanowire frame, followed by source/drain and all-around gate formation with Al₂O₃ dielectric and atomic layer deposition Ni electrode (Figure 7).

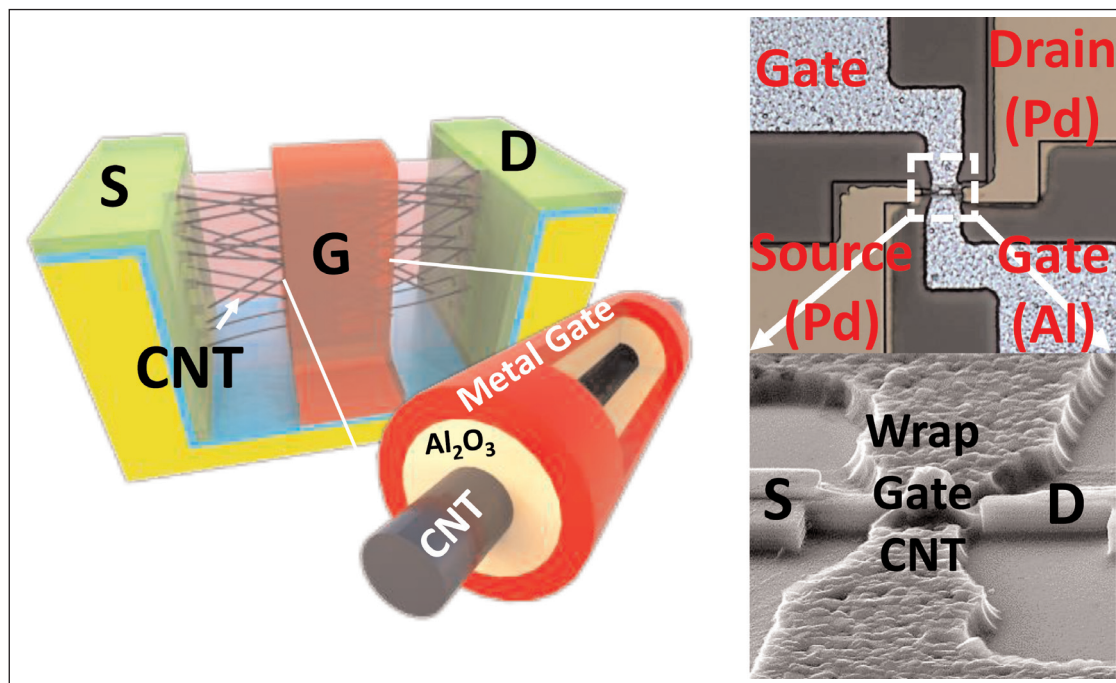


Figure 7. Gate-all-around CNT FET.

► Transition-metal dichalcogenides

Stanford University claimed record saturation current for its monolayer molybdenum disulfide (MoS_2) transistors with self-aligned 10nm top gates (SATFETs)

reduced to 2.5nm in some devices.

The device was produced by CVD on SiO_2/Si substrate. A monolayer of MoS_2 is 0.615nm thick. The gate was built by depositing a 2nm seed layer of Al that was

[session 5.6]. The current was more than $400\mu\text{A}/\mu\text{m}$.

MoS_2 is one of a range of 'transition-metal dichalcogenide' compounds that are layered at the atomic level. The layers can be separated in a similar way to graphite/graphene. An alternative transition metal is tungsten, while tellurium or selenium can be used for the dichalcogenide.

The Stanford MoS_2 SATFET also achieved sub-threshold slopes as low as 80mV/decade. The equivalent oxide thickness (EOT) was

allowed to fully oxidize in air. A thicker layer of Al was added to form the gate and a 5nm self-passivated surface oxidation layer around the entire electrode.

A 10nm gold (Au) layer covered the entire structure that was used to create self-aligned source and drain electrodes. Thicker titanium/gold (Ti/Au) metalization was used to create electrodes away from the channel. The device had a ~10nm gate length with 5–6nm gate oxide thickness.

The researchers also report 0.25 ballistic transport transmission at low temperature. Normally charge carriers will suffer a number of scattering events between the source and drain of a transistor.

Reducing the amount of

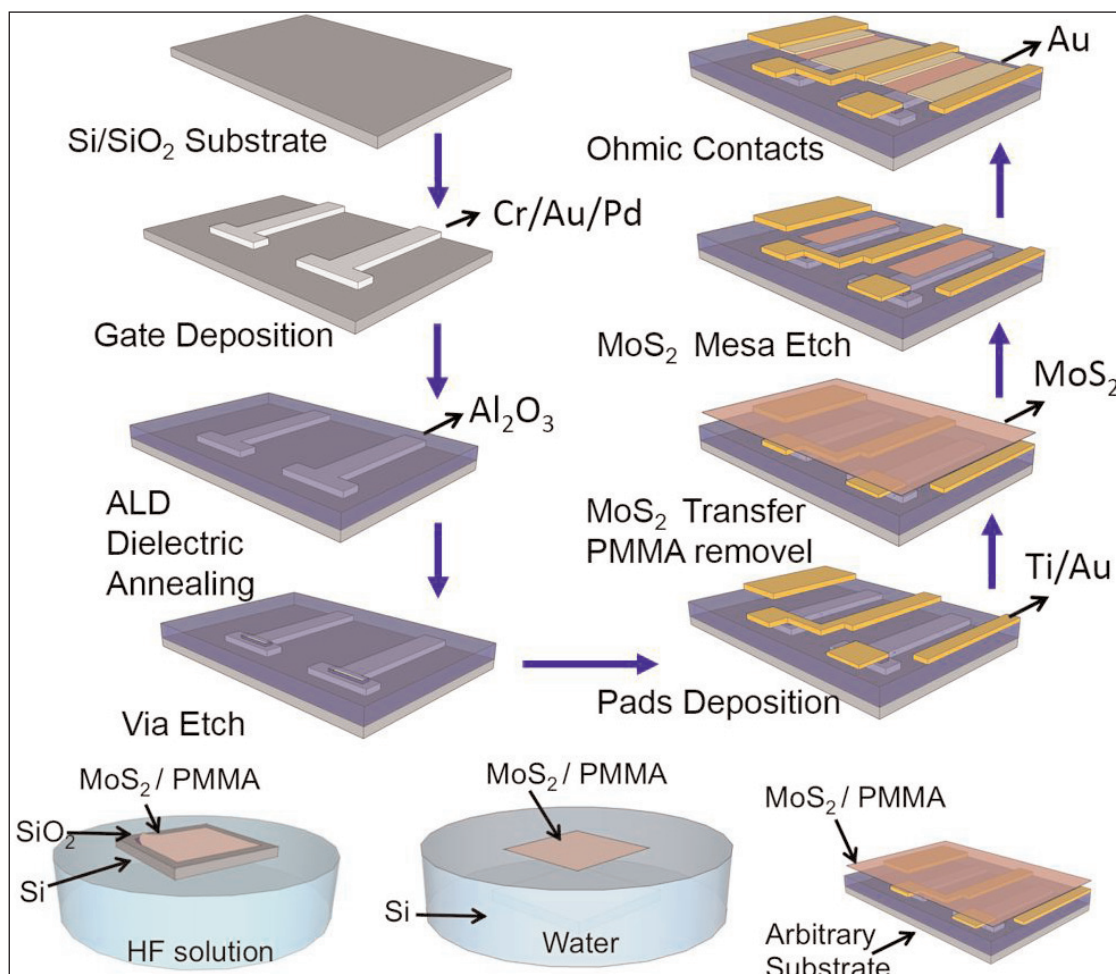


Figure 8. Overview of fabrication steps.

scattering increases conductivity in the channel. Ballistic transport describes the limit where the number of scattering events goes to zero. The researchers report: "Combining modeling and measurements, we examine diffusive versus ballistic transport and suggest a route to advance MoS₂ transistors closer to the ballistic limit."

Massachusetts Institute of Technology (MIT) and Taiwan National Tsing-Hua University is looking towards realizing high-yield large-area MoS₂ circuits with a view to co-optimization of materials, devices and circuits through a variation-aware design flow and yield model [session 5.7]. The team fabricated test chips with various inverters and basic logic gates (such as NAND and XOR) with close-to-unit yield (Figure 8).

Zhejiang University has used MoS₂ as a capping layer for germanium (Ge) quantum well channel CMOS devices [session 33.3]. GeO₂ does not easily form a stable passivated interface on Ge. Epitaxial silicon can be used for pMOS but not nMOS. Indium aluminium phosphide, a relatively new option, can enhance p- and n-MOS performance, but risks contamination of the Ge channel through diffusion.

The two-layer MoS₂ material was grown by CVD on SiO₂ and transferred to clean (100) Ge. The transistors were then fabricated (Figure 9). X-ray photoelectron spectroscopy (XPS) gave a 0.43eV valence band offset between the MoS₂ and Ge. Taking into account the 0.67eV Ge and 1.6eV two-layer MoS₂ bandgaps, the researchers estimate a conduction band offset of 0.5eV.

The team comments: "These results indicate that MoS₂ capping is sufficient to yield quantum well structures for both Ge p- and n-MOSFETs, to confine holes in Ge pMOSFETs and electrons in Ge nMOSFETs."

The team reports: "The MoS₂/Ge p- and n-MOSFETs exhibit drain current (I_d) twice as large as those in the Al₂O₃/Ge MOSFETs." The researchers attribute the improved performance of the relatively large devices to mobility enhancement.

Capacitance-voltage studies indicated hole and electron mobilities of 164cm²/V-s and 161cm²/V-s at channel carrier density 3x10¹²/cm². The enhancements for MoS₂/Ge p- and n-MOSFETs were 3x and 1.5x, respectively, compared with Al₂O₃/Ge MOSFETs. The MoS₂ offsets repel holes and electrons from the relevant interface, reducing scattering effects from traps in the gate stack.

Negative-bias temperature instability (NBTI) of the pMOSFETs showed smaller threshold voltage shifts for the MoS₂ structure compared with Al₂O₃/GeO_x/Ge MOSFETs, indicating improved reliability.

Researchers at ETH Zurich using first-principles simulations of 2D semiconductor devices found that metal-MoS₂ contacts suffer from limited current injection, since carriers tend to flow at the edge of the metal layer before entering the semiconductor [session 5.4].

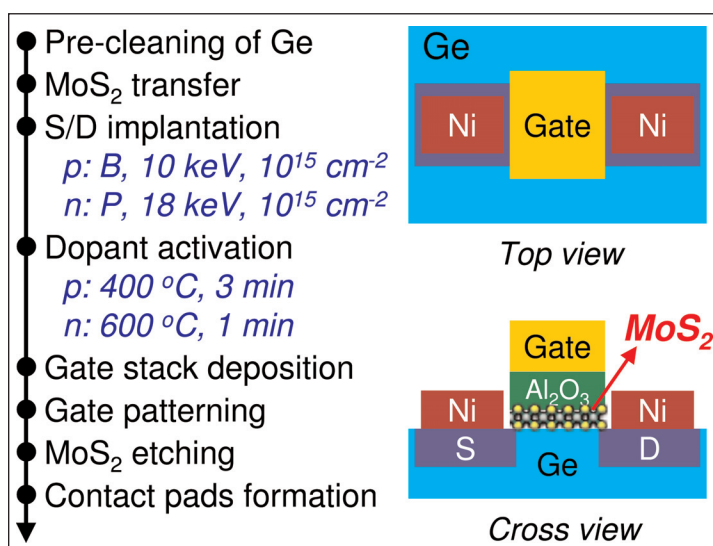


Figure 9. Fabrication procedure and device structure of MoS₂/Ge p- and n-MOSFETs.

Black phosphorus

Purdue University, Taiwan Semiconductor Manufacturing Corporation (TSMC) and US Air Force Research Laboratory reported on black phosphorus (BP) PMOSFETs with BN and Al₂O₃ gate dielectric (Figure 10) [session 5.5].

The peak transconductance (g_m) of 340μS/μm for a 200nm channel length is claimed to be the highest reported value among all BP transistors. The on-current of 850μA/μm at -1.8V drain bias and -2V gate potential is also said to be a record high. The researchers also claim record low contact resistance of 0.58kΩ-μm — "one fifth of the previous reported value of Ni/BP contact at zero gate bias", according to the team.

The sp² hexagonal BN (hBN) was grown on sapphire at 1050°C by metal-organic CVD (MOCVD). BP was

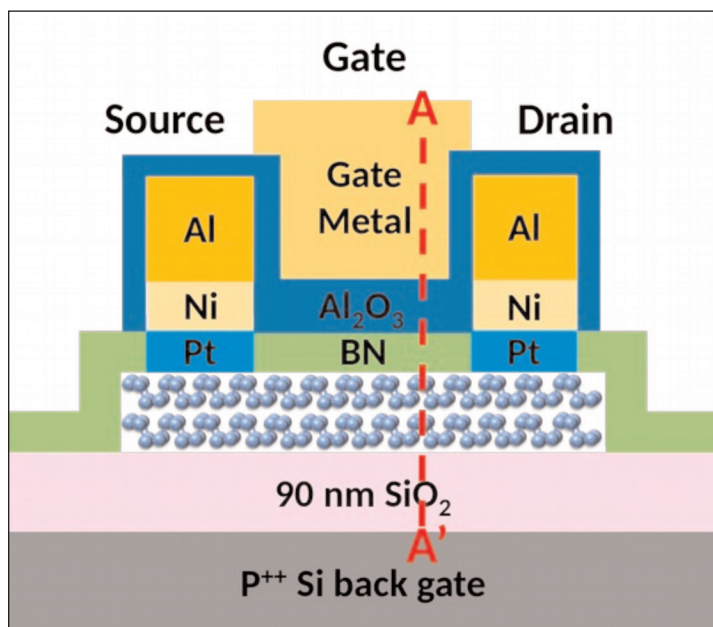


Figure 10. Schematic diagram of BP PMOSFET with BN/Al₂O₃ gate dielectric.

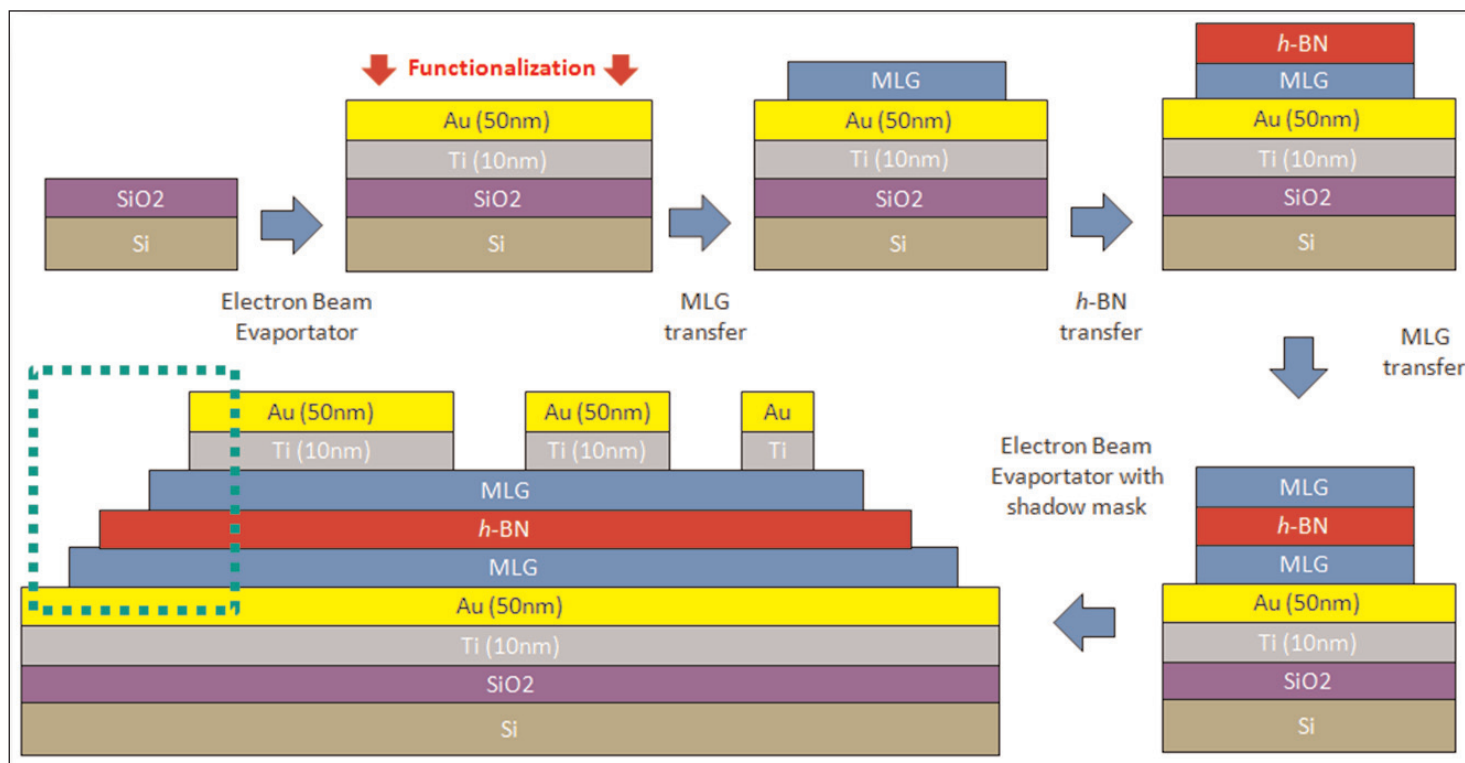


Figure 11. Fabrication flow of graphene-based samples. First, SiO₂/Si wafer is coated with Au/Ti and functionalized. Then 2D materials are transferred (sequentially), and top Au/Ti electrodes are patterned. Finally, top graphene between electrodes is removed.

produced from red phosphorus using a tin iodide/tin catalyst. BP flakes were exfoliated onto SiO₂/Si substrates. The BN was transferred onto the flakes using polymethyl methacrylate (PMMA) and polydimethylsiloxane (PDMS) coating and buffered oxide etch to peel the sapphire.

The PMMA/PDMS coating was removed and source and drain regions plasma etched into the BN before platinum (Pt)/Ni/Al (Pt) or Ni/Al metalization. The Pt/Ni/Al structure was found to have 1.6x higher on-current, compared with Ni/Al. The gate structure consisted of atomic layer deposition of Al₂O₃ dielectric and application of Ti/Au electrode.

The researchers see three factors contributing to the low contact resistance: (i) protection of the BP from oxidation by the BN; (ii) reduced interlayer resistance due to the top gate structure compared with the back gate structure; (iii) use of the high work-function metal Pt leads to a lower Schottky barrier at the BP/metal contact.

Gate leakage of the BN/Al₂O₃ bilayer gate dielectric was less than 10⁻¹²A/μm² at -1V gate potential. The equivalent oxide thickness was 3nm. The subthreshold swing minimum was 70mV/decade.

Boron nitride

A final material with 2D properties is hBN. Università di Modena e Reggio Emilia in Italy and Soochow University in China have created resistive random access memory (RRAM) based on hBN [session 34.8].

The device consisted of 5–7 layers of BN between electrodes. One device type used metal electrodes where the BN was grown by MOCVD on copper nickel substrate and bottom electrode. The top electrode was gold on tin. An alternative device used MOCVD 6-layer graphene (G) and BN assembled on Au/Ti/SiO₂/Si wafers (Figure 11). The graphene MOCVD was performed on copper.

The metal-based devices had forming voltages between 2V and 4V. After forming, the set and reset voltages were 0.7V and -0.5V, respectively. The graphene-based RRAMs had, respectively, forming, set and reset voltages of 7–9V, 2–4V and -0.5V. The graphene-based device were more stable, along with reduced cycle-to-cycle variability. The resistive switching in G/BN/G structures suggests a mechanism based on B ions and vacancies rather than B and metal cation diffusion.

Using simulations, the researchers explain the memory behavior as arising from manipulation of B-deficient conductive filaments with cyclical release and diffusion of B ions as the key physical switching mechanism. ■

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Understanding graphene–semiconductor Schottky contacts

A “simple and parameter-free carrier transport model” has been developed to describe current–voltage behavior.

Researchers in Singapore, the USA and Italy have been developing a modified model of Schottky contacts between graphene (Gr) and two-dimensional (2D) and three-dimensional (3D) semiconductors [Shi-Jun Liang et al, International Electron Devices Meeting, session 14.4, 2016].

The model takes better account of the effective ‘zero mass’ and zero gap (semi-metal) conduction/valence band structure of graphene with approximately linear energy-wavevector relations (Figure 2). Metals and semiconductors are usually modeled with quadratic energy-wavevector relations, giving non-zero effective mass.

The team from Singapore University of Technology and Design, Lawrence Berkeley National Laboratory in the USA, University of Salerno and CNR-SPIN Salerno in Italy, and the National University of Singapore and Yale–NUS college in Singapore performed both theoretical and experimental work to validate the model.

The graphene material was produced by chemical vapor deposition (CVD) on copper. A graphene–silicon junction (Figure 3) was created by placing monolayer graphene on etched nanotips etched on n-type silicon substrates. Measurements were made in the dark at atmospheric pressure.

$$J = AT^2 \exp\left(-\frac{\phi_{Bn}}{k_B T}\right) \left[\exp\left(\frac{qV}{nk_B T}\right) - 1\right] \quad \text{with} \quad A = \frac{4\pi q m k_B^2}{h^3}$$

$$J = A^* T^3 \exp\left(-\frac{\phi_B - E_F(V)}{k_B T}\right) \left[\exp\left(\frac{qV}{nk_B T}\right) - 1\right] \quad \text{with} \quad A^* = \frac{q k_B^3}{\pi h^3 v_F^2}$$

Figure 1. (Top) Metal–semiconductor Schottky diode equation. For graphene, mass (m) would be zero, giving zero current density (J). (Bottom) Graphene–semiconductor modified Schottky diode equation including effects of ultrafast Fermi velocity (v_F) and bias-tunable E_F .

The experimental work confirmed the modified Schottky equation (Figure 1) for graphene developed by the team, which describes its modification as “simple and parameter-free”. The model also described flat contacts between graphene and silicon, molybdenum diselenide (MoSe₂), gallium arsenide (GaAs), and gallium nitride (GaN) (Figure 4).

The model, based on quantum statistical theory, gave results almost the same as those derived from quantum Landauer transport theory with “excellent agreement”, according to the researchers.

The model was also able to take into account Schottky barrier height (ϕ_B/ϕ_{Bn}) inhomogeneities that have been found in graphene/Si, graphene/GaAs, and

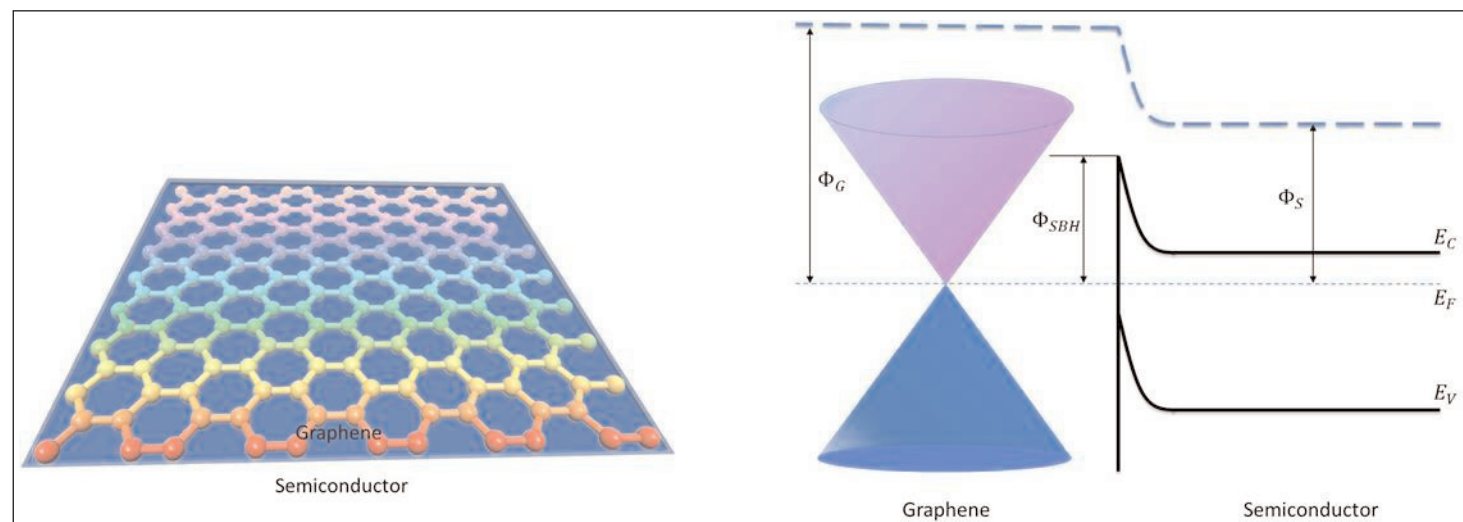


Figure 2. Graphene/semiconductor Schottky junction.

graphene/Ge contacts. The researcher believe the inhomogeneities arise from electron-hole puddles caused by randomly distributed charge impurities. Assuming a Gaussian distribution for the Fermi energy (E_F), the graphene/Si, graphene/GaAs and graphene/Ge results were described with standard deviations of 135meV, 98meV and 95meV, respectively.

The researchers found differences in behavior between graphene contacts with two-dimensional (2D, e.g. MoSe₂) and three-dimensional (3D, bulk Si, GaAs, GaN, etc) semiconductors. In the 3D case, the Schottky barrier height was only weakly correlated to the work function. By contrast, strong dependence on work function was found for contacts with 2D semiconductors. The researchers interpret the 2D behavior as showing independence from Fermi pinning effects.

These effects were explained by the team with first-principles calculations. ■

<http://iee-iedm.org/session-14-modeling-simulation-2d-materials-organic-electronics>

Figure 4. $\ln(J/T^3)$ vs $1/T$ for experimental data (symbols) and theoretical results (solid lines): (a) graphene/Si Schottky diode; (b) graphene/MoS₂ contact; (c) graphene/GaAs contact; (d) graphene/GaN contact.

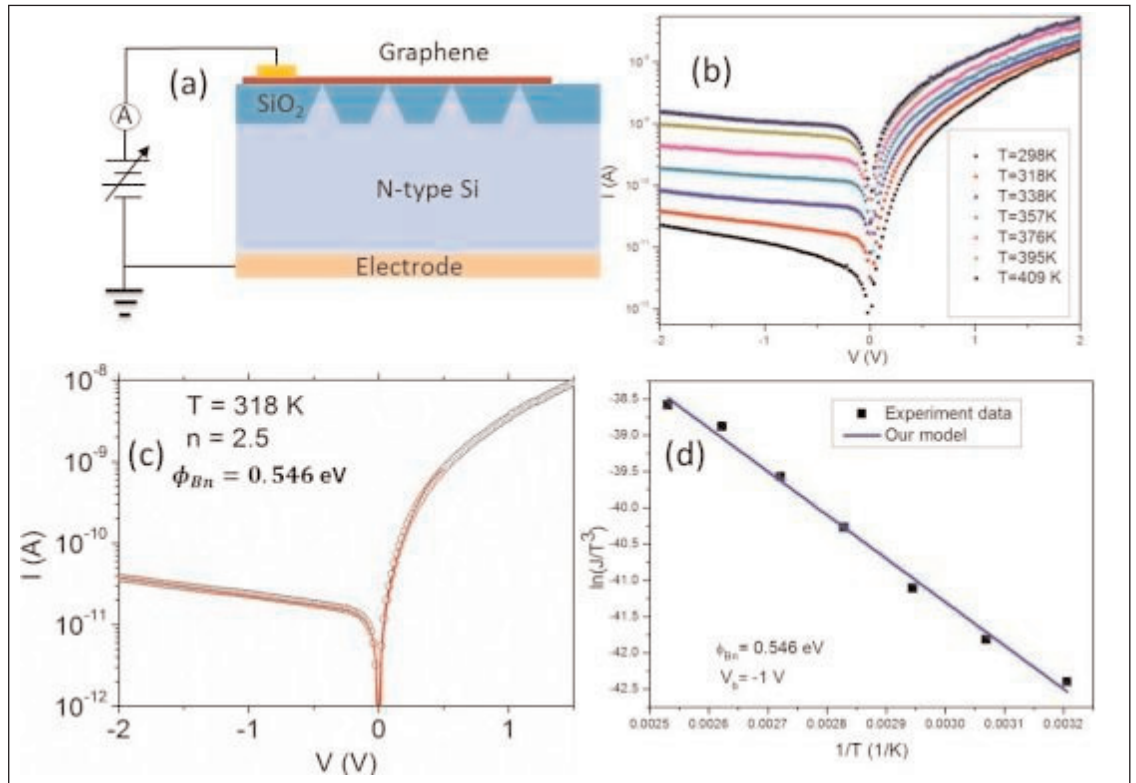
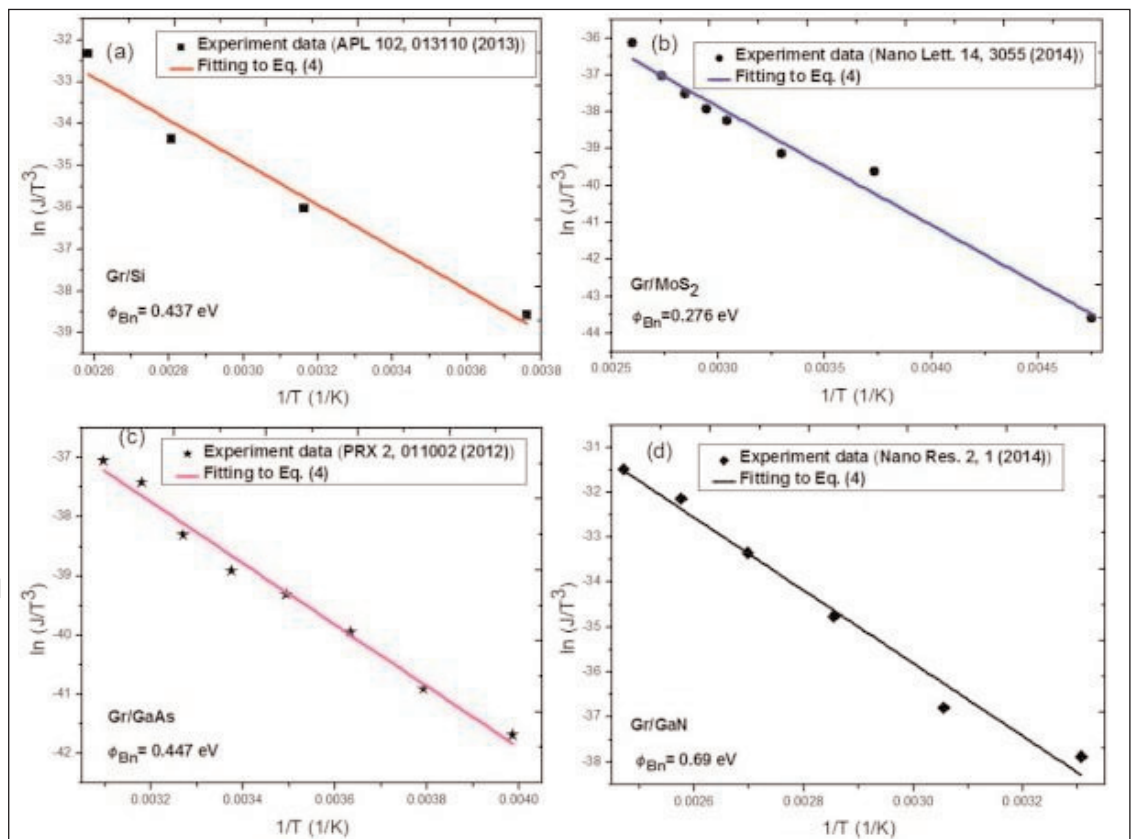


Figure 3. (a) Setup of graphene/n-Si tips Schottky junction device. (b) Current-voltage (I - V) characteristics of device shown in (a) at different temperatures. (c) I - V curve (red solid line) obtained using model with linear dependence of E_F on V compared with measured curves (open circle symbol) at 318K. I - V curve at high forward bias is dominated by series resistance and high injection and is not included in fit. (d) Temperature dependence of reverse current at reverse bias of $-1V$ ($\ln(I/T^3)$ versus $1/T$). Extracted reverse current data (square black symbol) compared with model (blue line).



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www.microchem.com

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(see section 5 for full contact details)

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16 Assembly/packaging equipment

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17 Assembly/packaging foundry

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18 Chip foundry

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Kolkata, India

E-mail: junanocon@gmail.com

www.issmd.org/home

8–10 March 2017

5th German Swiss Conference on Crystal Growth (GSCCG-5/DKT 2017)

Chemistry Faculty of the University of Freiburg,
Germany

E-mail: stephan.riepen@ise.fraunhofer.de

www.dkt2017.de

14–16 March 2017

SEMICON China 2017

Shanghai New International Expo Centre,
China

E-mail: semichina@semi.org

www.semiconchina.org

19–23 March 2017

OFC 2017"

Optical Fiber Communication Conference & Exhibition

Los Angeles Convention Center,
Los Angeles, CA, USA

E-mail: OFC@compusystems.com

www.ofcconference.org

26–30 March 2017

Applied Power Electronics Conference and Exposition (APEC 2017)

Tampa Convention Center, FL, USA

E-mail: apec@apec-conf.org

www.apec-conf.org

3–5 April 2017

19th European Conference on Integrated Optics (ECIO 2017)

Science Park of the Technical University of Eindhoven,
The Netherlands

E-mail: info@jakajima.eu

www.ecio-conference.org

3–5 April 2017

2017 Joint International EUROSIOI Workshop and International Conference on Ultimate Integration on Silicon (ULIS)

Institute of Nanoscience & Nanotechnology of NCSR
'Demokritos', Athens, Greece

E-mail: a.nasiopoulou@inn.demokritos.gr

www.eurosoi-ulis2017.inn.demokritos.gr

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Anaheim Convention Center, CA, USA

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Clarion Congress Hotel, Prague, Czech Republic

E-mail: info@spieeurope.org

www.spie.org/SPIE-Optics-Optoelectronics

1–3 May 2017

13th International Conference on Concentrator Photovoltaics (CPV-13)

University of Ottawa, Canada

E-mail: info@cpv-13.org

www.cpv-13.org

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29th International Conference on Indium Phosphide and Related Materials (IPRM 2017)

Berlin, Germany

E-mail: info@csw2017.org

www.csw2017.org

14–19 May 2017

Conference on Lasers and Electro-Optics (CLEO 2017)

San Jose Convention Center, San Jose, CA, USA

E-mail: CLEO@compusystems.com

www.cleoconference.org

16–17 May 2017

ITF Belgium (Imec Technology Forum 2017)

Antwerp, Belgium

E-mail: Olfa.Marzouk@imec.be

www2.imec.be/be_en/events.html

21–23 May 2017

International Wide Bandgap Materials Power Electronics Applications Workshop (IWBGPEAW 2017)

Stockholm, Sweden

E-mail: veyrier@yole.fr

www.b2match.eu/iwbgpeaw2017

22–25 May 2017

2017 CS ManTech (International Conference on Compound Semiconductor Manufacturing Technology)

Hyatt Regency Indian Wells Resort & Spa, CA, USA

E-mail: lynn_fincher@msn.com

www.csmantech.org

28 May – 1 June 2017

29th International Symposium on Power Semiconductor Devices and ICs (ISPSD 2017)

Sapporo, Japan

E-mail: ispsd2017reg@ech.co.jp

<http://eds.ieee.org/eds-meetings-calendars.html>

30 May – 2 June 2017

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Messe München, Munich, Germany

E-mail: info@intersolar.de

www.intersolar.de

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IEEE Radio Frequency Integrated Circuits Symposium (RFIC 2017)

Hawaii Convention Center, Honolulu, HI, USA

<http://rfic-ieee.org>

5–8 June 2017

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www.vlsisymposium.org

25–29 June 2017

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www.cleo-europe.org

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www.ieee-pvsc.org/PVSC44

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