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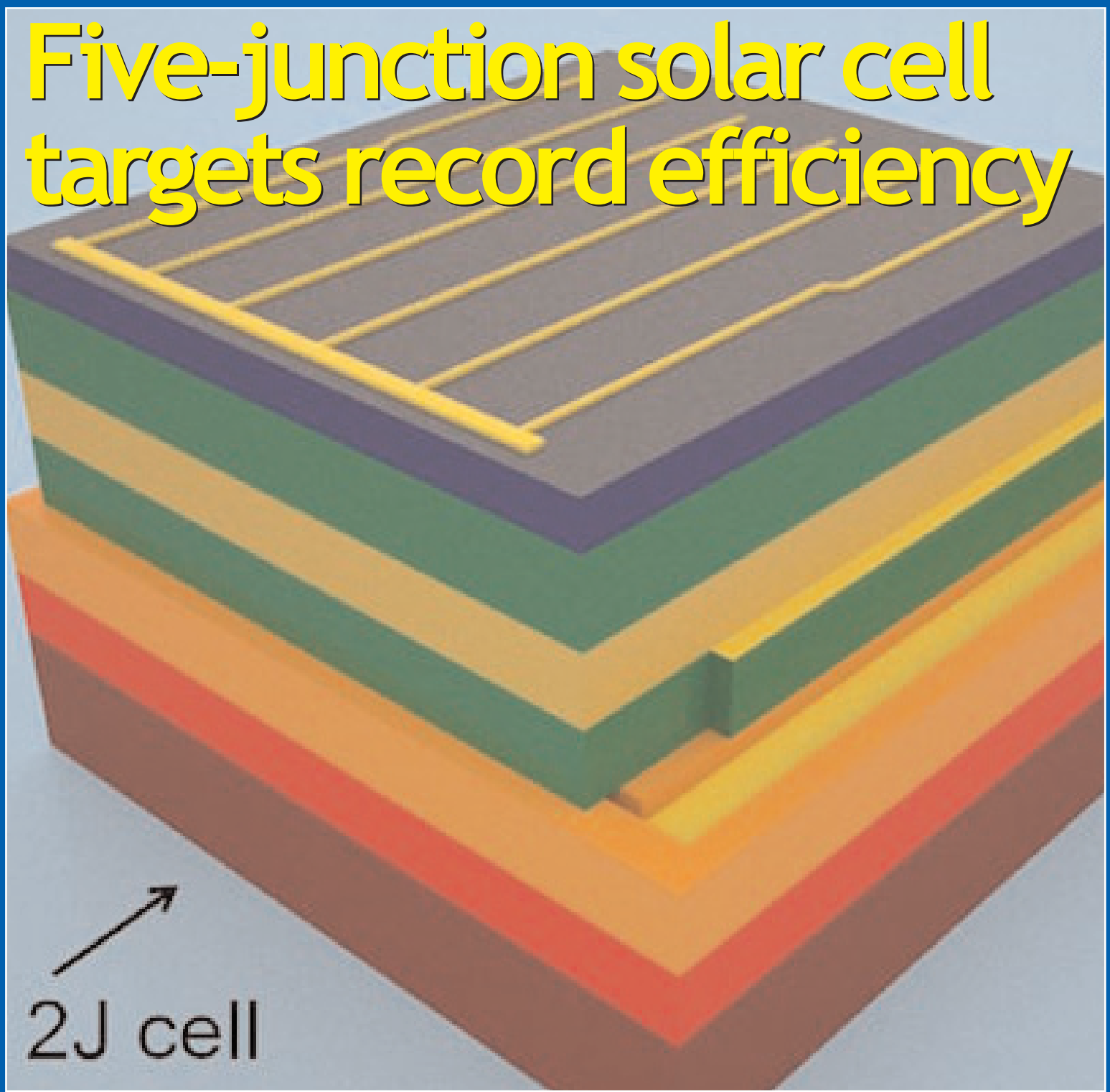
semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

Vol. 12 • Issue 5 • June/July 2017

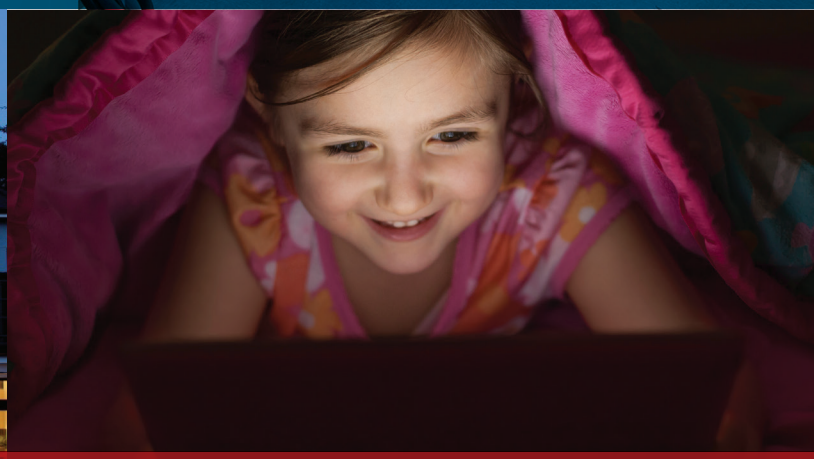
www.semiconductor-today.com

Five-junction solar cell targets record efficiency



GTAT launches 6" SiC growth furnace • Stion wins $1m DOE grant
Lumileds now independent • Sol Voltaics raises $21.3m

Lower Cost LEDs



Faster LED Adoption

Another breakthrough from Veeco. This time it's EPIK.

Introducing Veeco's new TurboDisc® EPIK700™ GaN MOCVD system

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

The EPIK700 MOCVD system combines Veeco's award-winning TurboDisc reactor design with improved wafer uniformity, increased productivity and reduced operations expenses to enable a cost per wafer savings of up to 20 percent compared to previous systems.

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The advantage is not just big. It's EPIK.

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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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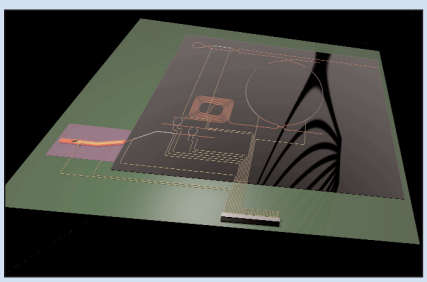
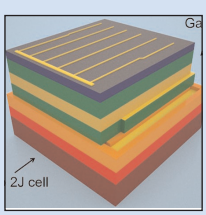
p29 IQE has received the 2017 Raytheon Supplier EPIC Award at its US facilities, in Taunton, MA.



p48 In collaboration with LioniX, the University of Twente's MESA+ research institute has developed the most narrowband diode laser on a chip.



Cover: George Washington University, NRL, Sotera, Semprius and UIUC have transfer printed a dual-junction GaSb/InGaAsSb concentrator solar cell on a GaAs-based triple-junction cell, yielding a module efficiency of 41.2%. **p54**

editorial

Power devices finding new drivers

In this issue we focus on power semiconductor devices, where compound semiconductor materials are making ever-increasing inroads, taking market share from incumbent silicon-based technology.

Yole Développement forecasts that the RF power semiconductor market (above 3 Watts) is growing at a CAGR of 9.8% over 2016–2022, rising by 75% from $1.5bn in 2016 to $2.5bn in 2022, driven by demand for telecom base-station upgrades and small-cell implementations as the transition from 4G to 5G networks approaches (see pages 74–75). While gallium arsenide will roughly maintain its market share, gallium nitride should become the dominant technology by 2025 (squeezing out silicon-based LDMOS). This is aided by defense applications (where GaAs and GaN are also replacing old vacuum tube designs) as well as the emergence of RF energy charging applications. Cross-over of high-frequency technology from defense to telecom applications is also highlighted by Northrop Grumman announcing at IMS 2017 that its MMICs meet the 5G system requirements (frequency allocations) of the Federal Communications Commission (page 13). Meanwhile, at ICNS 2017, Fujitsu announced an advance in output power density for GaN HEMTs in W-band (75–110GHz) transmitters, driven by the demands of 5G and Internet of Things applications (pages 18–19).

The compound semiconductor market overall is growing at a CAGR of 8.47% to 2021, driven by the proliferation of low-cost smartphones using more GaAs amplifiers and switches, according to Technavio (see page 7).

In the high-power sector, both silicon carbide and gallium nitride continue to see developing markets beyond the capabilities of silicon devices. In our feature article on pages 66–72 we focus on R&D on vertical GaN device structures, where current flow through a conducting GaN substrate can enable higher-power operation.

As well as applications in the power grid, hybrid and electric vehicles (HEV/EV) and self-driving vehicles present a potentially huge new market. This has been given further impetus recently by governments (such as Germany, France, and now the UK) proposing bans on the sale of petrol and diesel cars by 2030–2040. Already, car maker Volvo (owned by China's Geely but based in Sweden — a focal point of SiC power device expertise) recently committed to going all HEV/EV from 2019, while diesel emissions scandals may accelerate the transition at other manufacturers.

Despite being perhaps just a flagship, a waymark is that even a performance brand such as Porsche competing in a hybrid-electric formula has just decided to follow Audi in exiting the World Endurance Championship sports-prototype racing series, as Mercedes announced it is exiting the German touring car race series. Conversely, the all-electric Formula E race series (which already involves Renault, Audi and Jaguar) just in the last few weeks has gained future participants Mercedes, Porsche and BMW (whose venture capital firm recently invested in power-switching device maker GaN Systems — see page 22).

Wide-bandgap power device making is also a potential application for atomic layer deposition, as targeted by North Carolina State University at its National Science Foundation (NSF) Nanosystems Engineering Research Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (NERC-ASSIST), which is receiving the 500th ALD system shipped by Cambridge Nanotech (now Veeco CNT, since the acquisition in late May of CNT's parent firm Ultratech by Veeco) — see page 30.

Mark Telford, Editor

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

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HVM: High Volume Manufacturing

Micro-LED-like displays and projection modules to be available in 2018

Breakthroughs in mass transfer of micron-size LEDs to display backplane yet to materialize

A major bottleneck in the commercialization of micro-LED displays is the mass transfer of micron-size LEDs to a display backplane, according to '3Q17 Micro LED Next Generation Display Industry Member Report: Analyses on Mass Transfer and Inspection/Repair Technologies' from LEDinside (a division of market research firm TrendForce).

Many companies worldwide have entered the micro-LED market and are in a race to develop methods for the mass transfer process. However, their solutions have yet to meet the standard for commercialization in terms of production output (in unit per hour, UPH), transfer yield and size of LED chips (i.e. less than 100μm for a micro-LED).

Currently, entrants into the micro-LED market are working towards the mass transfer of LEDs sized about 150μm. LEDinside anticipates that displays and projection modules featuring 150μm LEDs will be available on the market as early as 2018. When the mass transfer for LEDs of this size matures, market entrants will then invest in processes for making smaller products.

Development of mass transfer solutions faces seven major challenges

"Mass transfer is one of the four main stages in the manufacturing of micro-LED displays and has many highly difficult technological challenges," comments Simon Yang, assistant research manager. He notes that developing a cost-effective mass transfer solution depends on advances in seven key areas: precision of the equipment, transfer yield, manufacturing time, manufacturing technology, inspection method, rework and processing cost.

LED suppliers, semiconductor makers and companies across the display supply chain will have to work together to develop specification standards for materials, chips and fabrication equipment used in micro–LED production, reckons LEDinside.

Cross-industry collaboration is necessary, since each industry has its own specification standards. Also, an extended period of R&D is needed to overcome the technological hurdles and integrate various fields of manufacturing.

Mass transfer must achieve five-sigma levels before mass production feasible

Using Six Sigma as the model for determining the feasibility of mass production of micro-LED displays, LEDinside's analysis indicates that the yield of the mass transfer process must reach the four-sigma level to make commercialization possible. However, the processing cost and the costs related to inspection and defect repair are still quite high even at the four-sigma level. To have commercially mature products with competitive processing cost available for market release, the mass transfer process must reach the five-sigma level or above in transfer yield.

True micro-LED products to first enter applications such as indoor displays and wearables

Even though no major breakthroughs have been announced, many technology companies and research agencies worldwide continue to invest in R&D on the mass transfer process. Some of the well-known international enterprises and institutions working in this area are LuxVue, eLux, VueReal, X-Celeprint, CEA-Leti, SONY and OKI. Comparable Taiwan-based companies and organizations include PlayNitride, Industrial Technology Research Institute, Mikro Mesa and TSMC.

There are several types of mass transfer solutions under development. Choosing one of them will depend on various factors such as application market, equipment capital, UPH and processing cost. Additionally, the expansion of manufacturing capacity and the raising of yield rate are important to product development.

According to the latest developments, LEDinside believes that the markets for wearables (e.g. smartwatches and smart bracelets) and large indoor displays will first see micro-LED products (LEDs sized under 100μm).

Because mass transfer is technically challenging, market entrants will initially use existing wafer bonding equipment to build their solutions, reckons LEDinside. Furthermore, each display application has its own pixel volume specifications, so market entrants will likely focus on products with low pixel volume requirements in order to shorten the product development cycle.

Thin-film transfer is another away of moving and arranging micron-size LEDs, and some market entrants are making a direct jump to developing solutions using this approach. However, perfecting thin-film transfer will take longer and more resources because equipment for this method needs to be designed, built and calibrated. Such an undertaking will also involve difficult manufacturing-related issues, concludes the report.

www.ledinside.com

Compound semiconductor market to grow at 8.47% CAGR to 2021

Asia-Pacific to be biggest market region by 2021

The global compound semiconductor market will rise at a compound annual growth rate (CAGR) of 8.47% during 2017–2021, forecasts market research firm Technavio.

The report 'Global Compound Semiconductor Market 2017–2021' identifies a primary growth factor as the global adoption of smartphones, which is expected to rise rapidly due to the availability of low-cost smartphones and the increased penetration of the Internet. This rising number of mobile devices subsequently drives growth in the market for gallium arsenide components such as GaAs amplifiers and switches. Additionally, smartphone makers are also aiming to develop smartphones powered by solar cells using GaAs (as it is the most efficient semiconductor in capturing a high amount of light and hence providing longer battery life).

The report also forecasts that one of the latest trends that will gain traction in the compound semiconductor market in the coming years is increasing industry automation, which is gaining momentum as computers and machines are being adopted for the effective and efficient control of systems. Compound semiconductor devices play a key role in ensuring efficient power consumption within the reduced size of appliances, since they can withstand elevated temperatures and voltages, notes the report.

Competitive landscape and key vendors

Competition in the compound semiconductor market is intense due to the presence of several key vendors, which the report cites as Broadcom, Skyworks Solutions, Cree, and Qorvo. Other prominent vendors are Analog Devices, Osram Opto Semiconductors, GaN Systems, Infineon Technologies, NXP Semiconductors, Advanced Wireless Semiconductor, STMicroelectronics, Microsemi, Texas Instruments, WIN Semiconductors, and AXT.

Vendors will try to gain dominant market shares through technical advances in compound semiconductor products and by designing application-specific products at competitive prices, comments the report. Additionally, vendors are also making huge investments to explore materials that can address the demand for high-power-density products and overcome the challenges in manufacturing.

Consumer electronics sector driven by growth in smartphone shipments

During 2016, the consumer electronics segment accounted for the biggest share of the compound semiconductor market, driven by the significant increase in global smartphone shipments and hence demand for GaAs-based power amplifiers and switches.

Asia-Pacific to be biggest market region by 2021

By geographical region, the Asia-Pacific (APAC) will be the major revenue contributor to the market by 2021, due to the increased demand for power applications and the economic growth in developing countries such as South Korea, China, India, Taiwan, and Malaysia. The increasing demand for wireless infrastructure will also boost market growth in this region, concludes the report.

www.technavio.com/report/global-compound-semiconductor-market

Qorvo's Beijing manufacturing facility earns automotive ISO/TS 16949 quality certification

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) says that its Beijing manufacturing facility has earned ISO/TS 16949 qualification for testing and production of automotive RF components. Certification is essential for meeting the Automotive Electronics Council (AEC)-Q100 qualification for producing reliable, robust integrated circuits for cars.

Consumer demand for in-car infotainment, mobile communications and Wi-Fi hotspot accessibility is driving rapid growth in the global connected car market, which is rising at a compound annual growth rate (CAGR) of more than 32% from 2016 to 2020, according to the report 'Global Connected Car Market, 2016–2020' issued by Technavio last December. That translates into a significant increase in the need for certified RF components that support cellular, GPS and Wi-Fi connectivity in cars, says Qorvo.

"Achieving ISO/TS 16949 certification underscores Qorvo's commitment to delivering the most robust, reliable and high-performance RF solutions for a new generation of connected cars and driver applications," says Gorden Cook, general manager of Qorvo's automotive business. "Our Beijing facility joins four other Qorvo operations — in Florida, North Carolina, Texas and Costa Rica — that have earned ISO/TS 16949 certification."

Qorvo offers a broad portfolio of 802.11p, automotive Wi-Fi, SDARS, GPS and LTE automotive solutions. In addition to meeting ISO/TS 16949 certification, Qorvo performs AEC-Q100 and AEC-Q200 testing to ensure that products meet stringent automotive industry requirements.

www.qorvo.com/applications/automotive

Microsemi expands MMIC portfolio with DC–27GHz wideband plastic-packaged and bare die GaAs MMICs

Microsemi Corp of Aliso Viejo, CA, USA (which makes chips for aerospace & defense, communications, data-center and industrial markets) has expanded its portfolio of wideband monolithic microwave integrated circuit (MMICs) by launching a family of wideband plastic-packaged and bare die (chip) MMIC devices that includes: the four plastic-packaged low-noise amplifiers (LNAs) MMA040PP5, MMA041PP5, MMA043PP4 and MMA044PP3; a wideband power amplifier (PA) chip MMA053AA; and the two plastic packaged switches MMS006PP3 and MMS008PP3. Sampling now, the new MMIC products were showcased at the IEEE International Microwave Symposium (IMS2017) in Honolulu, Hawaii (6–8 June) as a part of Microwave Week 2017.

The two new distributed LNAs (MMA040PP5 and MMA041PP5) are claimed to outperform competing parts over a wider frequency from DC to 27GHz with higher gain of 17dB and output third-order intercept point (OIP3) of 35dBm. They are packaged in a small 5mm x 5mm plastic QFN package suitable for size-constrained applications. Two additional wideband LNAs (the 4mm x 4mm 0.5-12GHz MMA043PP4 and the 3mm x 3mm 6–18GHz MMA044PP3) provide a low noise figure (NF) from 0.5 to 18GHz, typically below 2dB and no more than 2.5dB at the band edge.

The two new wideband GaAs switches (the DC–20GHz SPDT MMS006PP3 and the DC–8GHz SP4T MMS008PPS) have improved insertion loss and isolation over a wider frequency range from DC to 20GHz compared with competing products, it is claimed. The 3mm x 3mm plastic QFN packages suit high-performance requirements in size-constrained applications. The devices require minimal off-chip logic to control simplifying system-level integration.

The distributed wideband PA chip (MMA053AA) maintains flat gain of 17dB and high OIP3 of 35dBm from DC to 8GHz.

"Our new product introductions represent Microsemi's significant investment in enhancing our MMIC product portfolio as we continue to address our customers' overall requirements," says Kevin Harrington, director of strategic marketing for Microsemi's RF/Microwave Discrete Products business unit. "We are committed to being a long-term trusted supplier of superior performance MMIC products for our customers as we continue to invest and expand leading-edge MMIC devices."

The new MMIC wideband LNA, distributed wideband MMIC power amplifier and wideband MMIC switches are suitable for a front-end signal chain applications within the aerospace, defense and industrial markets, including test & measurement, electronic warfare (EW)/electronic countermeasures/electronic counter-countermeasures, high-linearity microwave radio, and unmanned aerial vehicle (UAV) and other military communications applications.

Market research company Strategy Analytics estimates that GaAs MMICs sold into the EW, radar and microwave communications markets will reach $500m by 2019.

www.microsemi.com/mmics

Qorvo launches family of DOCSIS 3.1 amplifiers and attenuator enabling VoIP and MoCA over existing wired broadband networks

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has further expanded its CATV portfolio with five new products designed to improve upstream/downstream capabilities in customer premises equipment (CPE) for consumer broadband. The firm now offers more than 65 DOCSIS 3.1-ready components (claimed to be the most of any supplier in the industry).

CableLabs reports that the most common data-intensive application across the globe is video streaming, which requires the most bandwidth of any type of broadband use (see 'Cable Broadband technology Gigabit Revolution', issue in Fall 2016). As operators deploy DOCSIS 3.1, they will be able to expand broadband network performance such as throughput and latency to meet consumer demand.

The new solutions leverage Qorvo's gallium arsenide (GaAs) and silicon-on-insulator (SOI) technologies to deliver good linearity, output power and reliability in wired broadband applications. These features enable multiple system operators (MSOs) to boost signal performance within a structure without added distortion and noise.

"We continue to invest in cable products that enable operators to provide the best possible broadband experience to their customers," says Gorden Cook, general manager of Qorvo's transport business.

The launch includes four DOCSIS 3.1 upstream amplifiers that offer high gain and what is claimed to be best-in-class linearity and support up to 16-port residential amplifiers, voice over internet protocol (VoIP) and multimedia over coax alliance (MoCA) applications. It also includes a new broadband digital step attenuator that supports fast (<500ns) glitch-free switching for dramatically improved video quality. Each of the new products is designed to support the ever-increasing consumption of higher-speed home data.

The high-performance amplifiers (QPB2318, 2328, 3311, 2231) and the QPC3614 attenuator are available for sampling now.

Qorvo's broadband cable solutions were showcased at the ANGACOM 2017 Exhibition & Congress for Broadband, Cable and Satellite, which took place in Cologne, Germany (30 May – 1 June).

www.angacom.de
www.qorvo.com/applications/network-infrastructure/broadband/catv

Qorvo launches 50V GaN-on-SiC transistors to boost efficiency and bandwidth in tactical and public safety radios

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has launched a family of 50V gallium nitride on silicon carbide (GaN-on-SiC) transistors that improve performance, increase functionality and accelerate development of mission-critical tactical and public safety radios. Operating over a frequency band of 30–1200MHz, the transistors are input-matched for wideband applications and feature a compact footprint of 6mm x 5mm, enabling smaller, next-generation communications devices.

"Military personnel and first responders must communicate across many channels and have reliable access to wideband capabilities such as data, video and GPS — all in very challenging conditions," notes James Klein, president, Qorvo Infrastructure and Defense Products. "The higher voltage of our new transistors at three different power levels ultimately translates into more powerful, more capable and more reliable radios."

Qorvo claims to be the only supplier of 50V wideband-matched GaN-on-SiC transistors. Higher-voltage transistors deliver benefits including increased output power, reduced current loss, greater reliability, and require fewer transistors in system designs. Additionally, wideband matching increases energy efficiency and allows board designs to be optimized for specialized military and first responder devices. Qorvo's newest transistors are designed for space-constrained, mission-critical applications ranging from military and land-mobile radio communications to avionics and test instruments.

Wideband matching increases energy efficiency and allows board designs to be optimized for specialized military and first responder devices

Qorvo's portfolio of GaN products was showcased at the IEEE MTT-S International Microwave Symposium (IMS 2017) in Honolulu, Hawaii (4–9 June).

www.ims2017.org
www.qorvo.com/products/discrete-transistors
www.qorvo.com/gan

Skyworks' quarterly revenue grows by a more-than-expected 20% year-on-year to $900.8m

Firm capturing more content per platform as design-win and new product pipeline expands

For fiscal third-quarter 2017 (to end-June), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of $900.8m, up 5.8% on $851.7m last quarter and up 20% on $751.7m a year ago (and exceeding the expected $890m).

Mobile sales (which include integrated mobile systems as well as power amplifiers) were 73% of total revenue (down further, from 75% last quarter), while Broad Markets sales rose to 27% of total revenue (up from 25%).

"Skyworks exceeded top- and bottom line expectations," notes president & CEO Liam K. Griffin. "Our outperformance is being driven by global demand for Skyworks' highly integrated and ultra-efficient connectivity engines. As system-level complexity and performance requirements intensify across mobile and Internet of Things ecosystems, we are extending our product reach and capturing more content per platform," he adds.

"We are aggressively expanding our design-win pipeline," says Griffin. "In mobile, we are broadening our reach across all premier OEMs". Specifically, Skyworks supported Huawei's feature-rich smartphones with SkyOne and SkyLiTE products.

Skyworks also extended its proprietary DRx solutions across Samsung's Galaxy platforms, and leveraged SkyOne and SkyLiTE at OPPO, Vivo, ZTE and Sharp, among others. "We extended our antenna tuning wins across virtually all of the leading Chinese OEMs," adds Griffin. "Huawei is a big, big player for us now; OPPO and Vivo are also important."

In broad markets, Skyworks delivered ZigBee and Wi-Fi devices for Amazon's virtual assistants, commenced volume production of 802.11p modules for vehicle-to-vehicle communications, ramped advanced 4G/LTE MIMO solutions for leading infrastructure OEMs, released optocouplers supporting healthcare monitoring systems, captured design wins with the leading supplier of 4K surveillance cameras, launched home security sensors and motion detectors at Honeywell and Bosch, unveiled what is said to be the first high-efficiency LAA (License Assisted Access) and new LTE solutions for small-cell base stations, powered NetGear's latest-generation mesh networking product line leveraging Skyworks' proprietary 802.11ac technology, and enabled cellular telematics platforms in support of a Chinese auto manufacturer.

"We are well positioned to capitalize on the rapidly approaching 5G technology wave — enabling new markets from autonomous vehicles to emerging segments in artificial intelligence, robotics and virtual reality," reckons Griffin.

On a non-GAAP basis, quarterly gross margin was 50.7%, down from 50.9% a year ago but up from 50.4% last quarter.

Operating expenses (OpEx) have risen from $107.6m a year ago and $116m last quarter to $123m (slightly above the targeted $122m, but remaining 13.7% of revenue).

As system-level complexity and performance requirements intensify across mobile and Internet of Things ecosystems, we are extending our product reach and capturing more content per platform

Operating income has grown further, from $274.7m (operating margin of 36.5% of revenue) a year ago and $312.5m (36.7% margin) last quarter to $333.1m (37% margin).

Likewise, net income has risen further, from $238.1m ($1.24 per diluted share) a year ago and $272m ($1.45 per diluted share) last quarter to $292.7m ($1.57 per diluted share, exceeding the $1.52 guidance).

Cash flow from operations was $314.1m (up from $235.9m last quarter and $140.9m a year ago). Capital expenditure (CapEx) has doubled from $54.9m (6.4% of revenue) last quarter to $113m (12.5% of revenue). During the quarter, Skyworks paid dividends of $51.6m (level with last quarter), and spent $128.8m repurchasing 1.3 million shares of common stock (up from $95.2m last quarter). Despite this, overall cash and cash equivalents still rose by $37.1m, from $1407m to $1444m (up nearly 50% from $973.7m a year ago). The firm has no debt.

"CapEx is typically higher in the second half of our fiscal year," notes senior VP & chief financial officer Kris Sennesael. "We target to have our CapEx on or about high single digits percent to revenue," he adds. "Most of that CapEx is of course driven by a strong revenue growth that translate into more units and so we're making the necessary investments in our program fabs as well as our backend operation, assembly & test, and our filter operation. For filter operation it's not only expanding or increasing the capacity but also making sure we're making the necessary technology investments to be able to provide a higher content for a richer filter portfolio," continues Sennesael. "Currently we have approximately 50% of filters in-house. As we ramp in the second

half of calendar year 2017, there will be a new set of platforms that will further increase this probably towards 75%. And then we will continue to work on that in 2018. Probably at the maximum, we will reach 90%," he forecasts.

"Given our design-win momentum and new product pipeline, we intend to sustainably outpace growth in our addressable markets," says Sennesael. For fiscal fourth-quarter 2017, Skyworks expects a new revenue record of $980m, up slightly more than 9% sequentially and 17% year-on-year. Specifically, Broad Markets revenue (which has been growing at double-digit levels) will exceed $250m (a $1bn annualized revenue run rate going forwards). Revenue in China should be flat to up single digits (while being up double digit year-on-year).

Gross margin should grow by 30 basis points for a second consecutive quarter, to 51%. With operating expenses rising only slightly to $124m, operating margin should also grow. Diluted earnings per share should be a record $1.75.

We have approximately 50% of filters in-house. As we ramp in the second half of calendar year 2017, there will be a new set of platforms that will further increase this probably towards 75%

"Our gross margin target is to get to 53%, and we are making good progress towards that," says Sennesael. "In the December quarter, we expect on higher revenue further improvements on the gross margin."

"We are targeting in excess of $1.1bn in free cash flow this fiscal year, while systematically returning cash to our shareholders through buybacks and increasing dividends [targeting 40–50% of free cash flow, following 60% year-to-date]," says Griffin. Skyworks' board of directors has declared a cash dividend of $0.32 per share of common stock (payable on 29 August to stockholders of record at the close of business on 8 August), up 14% on the prior quarterly dividend of $0.28 per share.

High-power Bluetooth power amplifier for mobile applications

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has introduced a new product category of high-power Bluetooth power amplifiers for mobile applications targeting Wi-Fi-enabled smartphones, tablets and other portable devices.

The SKY85018-11 is a highly integrated device that is suitable for improving Bluetooth connectivity ranges, which are required for music streaming. Multiple output power ranges and a bypass mode ensure that the SKY85018-11 is reliable for high-performance devices, says the firm.

The amplifier is offered in a small-footprint 1.5mm x 1.5mm package and can run directly off battery, eliminating LDO voltage regulators. It also features high output power of 23dBm for basic data rates and 14dBm for enhanced data rates.

www.skyworksinc.com/Product/3365/SKY85018-11

Skyworks unveils first high-efficiency LAA/LTE-U solution for small cells

Skyworks Solutions has expanded its portfolio of small-cell solutions by adding the SKY66288-11, a new compact (5mm x 5mm) high-efficiency 4W-peak power amplifier with high gain, targeting License Assisted Access (LAA) and LTE unlicensed (LTE-U) spectrum for LTE-Advanced base stations.

With leading wireless carriers and telecoms manufacturers transitioning from 4G to 5G networks and deploying new equipment, there is an increasing demand for efficient, highly integrated system architectures to support emerging requirements, says Skyworks. The firm claims that the new devices offer four times higher efficiency than competing products on the market and enable small cells to easily meet Power-over-Ethernet (PoE) standards. When combined with the pin-to-pin compatible SKY6629x small-cell product family, Skyworks can support all 3GPP bands. Analog Devices Inc of Norwood, MA, USA is leveraging the new power amplifier family for its AD9375 small-cell radio reference design with integrated digital predistortion, offering a single platform with what is claimed to be the highest efficiency and linearity available in the industry. "

"We are addressing challenging infrastructure performance requirements for next generation networks," says Skyworks' VP of marketing John O'Neill. "At a higher level, Skyworks is driving connectivity across diverse applications within the wireless ecosystem."

According to an estimate from Small Cell Forum, small-cell shipments are expected to more than double from a base of 3.8 million units in 2016 to 7.8 million by 2020, creating a $6bn market segment.

Skyworks showcased its broad markets solutions at the IEEE MTT International Microwave Symposium (IMS 2017) in Honolulu, Hawaii (4–9 June).

www.ims2017.org
www.skyworksinc.com/Category/850/Small_Cells

Single-crystal BAW RF filter firm Akoustis acquires MEMS wafer fab in New York

Internalizing of manufacturing advances transition into IDM

Akoustis Technologies Inc of Charlotte, NC, USA, which designs and manufactures patented BulkONE single-crystal piezoelectric bulk acoustic wave (BAW) high-band RF filters for mobile and other wireless applications, has completed the acquisition of assets from the Research Foundation for the State University of New York (RF-SUNY) and its affiliate Fuller Road Management Corporation (FRMC), paying $2.75m in cash at closing (plus conventional closing costs including a $96,000 net inventory adjustment).

The assets include STC-MEMS, a 120,000ft^2 commercial wafer manufacturing facility in Canandaigua, NY (including Class 100/Class 1000 cleanroom space) and micro-electro-mechanical systems (MEMS) business together with all associated 150mm wafer processing tools, as well as 57-acres of associated real-estate.

The assets also include:

- Two existing leasehold tenants with recently extended, multi-year leases.
- US Department of Defense (DoD) Category 1A Trusted Foundry accreditation for MEMS processing, packaging and assembly (Akoustis is currently pursuing the required security credentials needed to transfer this, aided by support from New York Senator & US Senate Minority Leader Charles 'Chuck' Schumer in a letter to US Secretary of Defense General James Mattis).

"Completing the successful transfer of the Defense Department's Trusted Foundry accreditation is a win-win to enable Akoustis Technologies to grow new jobs while maintaining a trusted supply-chain of locally produced components needed by the Defense Department," comments Schumer.

To support and motivate its expansion into Upstate New York, Empire State Development (ESD) has offered Akoustis up to $8m in performance-based incentives under the Excelsior Jobs Program.

The STC wafer fabrication plant.

The acquisition "immediately provides a step-function improvement in our ability to design and manufacture our patented BAW RF filters and will accelerate our timeline into commercial production," says Akoustis' CEO Jeffrey Shealy.

The acquisition allows the firm to internalize manufacturing, providing substantial capacity and control of its wafer supply chain for single-crystal BAW RF filters. Akoustis plans to utilize the NY facility to consolidate all aspects of wafer manufacturing for its patented high-band RF filters targeting mobile and other wireless markets. Consolidation of the firm's supply chain into the facility is intended to reduce wafer cycle time for its RF filter products and enhance its ability to service customers. Shorter wafer cycle time reduces time-to-market, providing the opportunity to increase the number of customer engagements, it is expected.

"Over the past 90 days, our management and board have had the opportunity to engage with the employees at STC-MEMS," says co-chairman Dr Art Geiss. "The team we have transitioned from STC-MEMS to Akoustis is extremely valuable and provides a critical component to expanding our manufacturing center-of-excellence in New York State." Akoustis' staffing has hence risen from 28 to 55.

After a detailed review of STC-MEMS' customer programs, Akoustis plans to transition up to $1.5m of existing MEMS revenue in fiscal-year 2018.

Akoustis is addressing market requirements for improved RF filters, targeting higher bandwidth, higher operating frequencies and higher output power compared with incumbent polycrystalline BAW technology. Performance is driven by the advances of high-purity, single-crystal piezoelectric materials and the resonator-filter process technology. The material properties drive electro-mechanical coupling, which translates to wide filter bandwidth. High-band RF filters are achieved by leveraging the firm's high-sound-velocity, single-crystal piezoelectric materials, which offer high thermal conductivity along the path of heat flow, enabling high power handling capability of the RF filter.

Interior of the STC fab.

www.akoustis.com

Akoustis names John Kurtzweil as CFO

Akoustis Technologies Inc of Charlotte, NC, USA, which designs and makes patented single-crystal BulkONE bulk acoustic wave (BAW) high-band RF filters for mobile and other wireless applications, has made John T. Kurtzweil its chief financial officer (CFO), replacing Cindy Payne, who remains with the firm as VP of finance and corporate controller. Concurrent with becoming CFO, Kurtzweil has resigned as a director on Akoustis' board.

Kurtzweil's senior-executive leadership and financial experience includes 19 years as CFO of publicly traded technology companies, as well as the placement of an aggregate $1.9bn in equity and debt-financing instruments. He was previously VP finance at Cree Inc, which makes lighting-class LEDs, lighting and semiconductor products for power and radio-frequency applications. In addition, he was CFO of Wolfspeed, a Cree company and provider of wide-bandgap technology for power semiconductors and RF power amplifiers. Kurtzweil currently serves on the board of directors of Axcelis Technologies.

From 2012 to 2014, Kurtzweil was senior VP, CFO & special advisor to the CEO of Extreme Networks Inc. From 2006 to 2012, he was executive VP of finance, CFO and treasurer of Cree, during which time Cree's annual revenue grew from $396m to $1.2bn. From 2004 to 2006, Kurtzweil was senior VP & CFO of fabless semiconductor firm Cirrus Logic Inc. From 2002 to 2003, he was senior VP & CFO of ON Semiconductor. Kurtzweil is a CPA (WI), CMA, has an MBA from the University of St. Thomas in St. Paul, Minnesota, and a bachelor's degree from Arizona State University in Accounting.

"I have had the opportunity to interact with John since his appointment to our board this past January," notes CEO Jeff Shealy. "Having been the CFO at a number of multi-billion-dollar Nasdaq-listed technology companies, he has expertise not only in finance, but also in strategic planning, capital formation and M&A," he adds.

Kurtzweil says he is joining Akoustis as its CFO "at a time when we are squarely focused on entering the fast-growing high-band BAW RF filter market utilizing our patented single-crystal technology… My prior experiences plus insights gained from being on the board uniquely position me to make an immediate impact."

Akoustis is addressing market requirements for improved RF filters, targeting higher bandwidth, higher operating frequencies and higher output power compared to incumbent polycrystalline BAW technology. Performance is driven by the advances of high-purity, single-crystal piezoelectric materials and the resonator-filter process technology. The material properties drive electro-mechanical coupling, which translates to wide filter bandwidth. High-band RF filters are achieved by leveraging the firm's high-sound-velocity, single-crystal piezoelectric materials, which offer high-thermal conductivity along the path of heat flow, enabling high power handling capability.

www.akoustis.com

Northrop's MMICs meet FCC's 5G system requirements

At the IEEE MTT International Microwave Symposium (IMS 2017) in Honolulu, Hawaii (6–8 June), the Microelectronics Products and Services' (MPS) business of Northrop Grumman Corp of Redondo Beach, CA, USA announced that its monolithic microwave integrated circuit (MMIC) products are aligned with the Federal Communications Commission's (FCC) 5G frequency allocations.

Northrop Grumman says that it is leveraging more than 20 years of microelectronics development to offer a suite of MMICs that are applicable for 5G applications. With the expanded 5G network frequencies, Northrop Grumman's MPS technologies and products can be used to provide low noise, high linearity/high output power and/or frequency conversion across all of the 5G frequency bands. The products meet user demands for multimedia access, high quality of service (QoS) and anytime access.

"MPS's low-noise and high-power technologies and products provide a differentiating advantage that allows operators the ability to maximize the number of users and revenue generation," claims Northrop Grumman MPS' general manager Chris Brown. "The Northrop Grumman power amplifiers provide the high-linearity performance near peak output power levels required for complex modulations, which optimizes the data throughput within the FCC allocated bandwidth," he adds. "This same performance advantage is realized in the 5G receivers through the use of the Northrop Grumman low-noise amplifiers utilizing our gallium arsenide and indium phosphide technologies. Between the power amplifiers, the low-noise amplifiers and the mixers, we can address all of the 5G frequency bands."

Also at IMS, Northrop Grumman presented on high-power and high-efficiency chipsets for Ku-band, Ka-band, V-band, Q-band, E- and W-band communications, and on optimizing ground, airborne and space-based communication links using its semiconductor products and technologies.

The MPS team also presented enhanced gallium nitride manufacturing options showing the transition of communications products in everyday use.

www.ims2017.org

Anokiwave signs Cain-Forlaw as central US rep

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 with Cain-Forlaw Co of Palatine, IL for sales representation in the central USA. The agreement aligns with Anokiwave's goal to support new customers and opportunities in the central USA with a highly technical sales and applications team.

Focused on providing sales and customer service to the electronics industry, Cain-Forlaw has been a technical manufacturers' representative for over 45 years and is the largest geographical RF/MW representative in the country, with regional sales offices in Columbus, OH, Ft. Wayne, IN, Minneapolis, MN, Cedar Rapids, IA, and Dallas TX.

"This agreement enhances the technical support we can provide to customers in the central USA region with an increased presence promoting our mmW active antenna core IC solutions," says Vincent Pelliccia, Anokiwave's VP of business development. "Cain-Forlaw offers a seasoned sales team who are knowledgeable in the key areas in which they serve and is ideally positioned to drive the adoption of our solutions into the 5G, radar, and SatCom markets," he adds.

"Their product design, manufacturing and test capability is disruptive," says Cain-Forlaw's president Rick Lapiana about Anokiwave. "Anokiwave's value enables customers to introduce new, high-performance products with significantly reduced development time."

www.anokiwave.com

Infineon receives sixth Bosch Global Supplier Award

At its 15th biennial Global Supplier Award ceremony, the world's largest automotive supplier Robert Bosch GmbH presented Infineon Technologies AG of Munich, Germany with a 'Bosch Global Supplier Award' for the sixth time. Bosch is already the third global automotive firm this year, after Toyota and DENSO, to acknowledge the chip maker for outstanding quality.

With the award, the Bosch Group honors outstanding performance in the manufacture and supply of products or services – notably in quality, innovation, and logistics. Infineon supplies Bosch, for example, with radar chips for driver assistance systems, microcontrollers for engine management, and chips for body and convenience applications.

For 2015 and 2016, Bosch honored the 44 best suppliers from 11 countries. Infineon received the award in the category electronics and electromechanics. Other categories are purchasing of indirect material, resale goods, innovation, mechanics as well as raw materials and components. Currently, the Bosch Group's purchasing and logistics volume amounts to about 60% of its total sales (€73.1bn in fiscal 2016). Electronic and mechanical components are the main items purchased.

With a global market share of almost 11%, Infineon is one of the two market leaders in chips for automotive electronics. In 2016, the total market for automotive chips was $30.2bn (according to Strategy Analytics in April). Infineon claims to be the technology leader in driver assistance systems and autonomous driving as well as in electromobility. Its product portfolio for the automotive industry includes sensors, microcontrollers, power semiconductors, and power modules.

www.bosch.com
www.infineon.com/automotive

Custom MMIC launches broadband frequency doubler spanning 7–11GHz

Monolithic microwave integrated circuit developer Custom MMIC of Westford, MA, USA has added to its growing line of broadband frequency doublers with the CMD226N3, which spans input frequencies of 7–11GHz (C- and X-band, input; Ku- and K-band output). What is claimed to be low conversion loss and high Fo isolation make it suitable for use in military radar, SMDS, SATCOM, VSAT, and LO chains for point-to-point microwave/millimeter-wave radio in cellular backhaul applications.

The gallium arsenide (GaAs)-based CMD226N3 is a x2 passive frequency multiplier that offers broadband performance and is housed in a QFN-style package. With a drive level of +15 dBm, it offers 9.0dBm of conversion loss at 18GHz and Fo isolation in reference to an input level of 44dB. The 3Fo and 4Fo isolation are at least 48dBc and 50dBc, respectively.

Extremely temperature stable, the conversion gain varies less than 2dB from nominal across the entire frequency band of operation, and is also very stable under varying drive conditions. The CMD226N3's passive design exhibits what is claimed to be excellent phase noise performance, without needing biasing circuitry. It also incorporates a 50Ω matched design on chip, removing the need to RF port match the device.

www.custommmic.com/cmd226n3

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IXYS launches dual 1200V SiC Schottky diodes in SOT-227 packages with average forward current of 2 x 22A and 2 x 65A

IXYS Corp of Milpitas, CA, USA and Leiden, The Netherlands (which provides power semiconductors and mixed-signal ICs for power conversion and motor control) has launched the DCG45X1200NA and DCG130X1200NA dual 1200V-rated silicon carbide (SiC) Schottky diodes in fully isolated MiniBLOC (SOT-227) package.

Both offer two SiC Schottky diodes with an average forward current of 2 x 22A and 2 x 65A, respectively at 80°C case temperature and essentially zero forward and reverse recovery. This involve reduced turn-on and turn-off losses of the diodes and the related switches, resulting in higher power efficiency. The positive temperature coefficient of the forward voltage drop makes it easy to parallel devices for higher output power, says the firm.

The MiniBLOC package uses an advanced isolation structure with an optimized low thermal resistance. Lower dynamic losses and reduced thermal impedance allow reduced system size due to higher power density and switching frequency. Added benefits include an increase in reliability due to a lower die temperature swing in cycling power demand.

Existing products in the family include the DCG85X1200NA and DCG100X1200NA. "With these new products we are expanding our fast diode portfolio and enable applications with higher power in switching and control for inverters, UPS [uninterruptible power supplies] and rapid charger solutions," says Dr Elmar Wisotzki, director of technology for IXYS Germany.

"Our SiC Schottky portfolios give our customers more flexibility in choosing the right product for their application to improve efficiency at best performance-over-cost ratio," he adds. "The SOT-227 package is a good match with our standard power MOSFETs and IGBTs, enabling a low-profile and high-power-density design."

The diodes inside the package are electrically isolated from each other, allowing the designer to connect them either in parallel and build common cathode or phase leg configurations.

Typical applications are high-efficiency DC–DC converters, power inverters, UPS systems, high-performance power supplies, welding equipment and rapid-charger solutions.

www.ixys.com

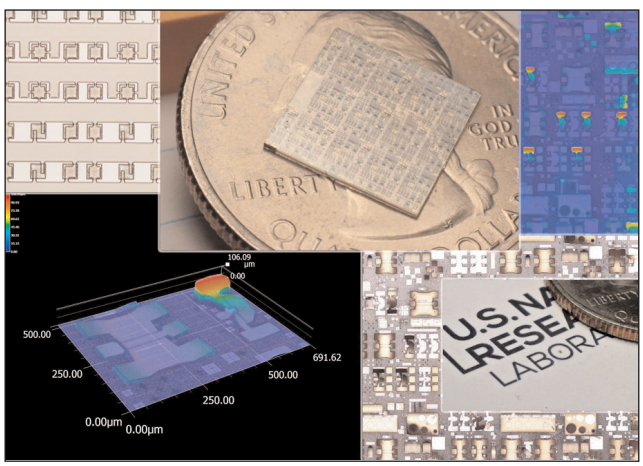
NRL demonstrates growth of thin-film niobium nitride

Patent-pending lift-off technique allows GaN to be transferred onto almost anything

The US Naval Research Laboratory (NRL) has demonstrated the ability to grow thin films of the transition metal Nb_2N (niobium nitride). The thin crystalline material has a similar structure to gallium nitride (GaN), but its electrical and physical properties are dramatically different. For example, Nb_2N is metallic instead of semiconducting and can become superconductive at cryogenic temperatures.

"We have determined that Nb_2N has several unique properties that can lead to the realization of new microelectronic devices and circuits," says Dr David Meyer, section head for wide-bandgap materials and devices in the Electronics Science and Technology Division.

One property of the new material is how it dissolves away in a reactive gas, while leaving nearby GaN electronics untouched. By inserting a thin layer of Nb_2N between a GaN transistor, LED, or circuit and the substrate on which the material is grown, Meyer and his team can perform a patent-pending lift-off technique, which allows it to be transferred onto nearly anything, it is reckoned.



"We have this method and it's really flexible," says Meyer. "We anticipate that there are several applications that would benefit from having GaN technology integrated at the device or circuit level," he adds.

NRL's patents and/or patent applications are available for licensing and collaboration via its Technology Transfer Office. The research was developed with funding from the US Office of Naval Research and Defense Advanced Research Projects Agency (DARPA).

https://www.nrl.navy.mil

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Fujitsu achieves record output density with power amplifier for W-band GaN transmitters

GaN plugs below source and drain electrodes reduce internal resistance while InGaN back barrier layer controls current leakage

At the 12th International Conference on Nitride Semiconductors (ICNS-12) in Strasbourg, France (24–28 July), Tokyo-based Fujitsu Ltd and Fujitsu Laboratories Ltd are announcing the development of a gallium nitride (GaN) high-electron-mobility transistor (HEMT) power amplifier for use in W-band (75–110GHz) transmissions. Part of the research was carried out with support from Innovative Science and Technology Initiative for Security, established by the Acquisition, Technology & Logistics Agency (ATLA), Japan Ministry of Defense.

To realize long-distance, high-capacity wireless communications, a promising approach is to utilize the W-band and other high-frequency bands that encompass a broad range of usable frequencies, and increase output with a transmission power amplifier. At the same time, demand exists for improved efficiency in power amplifiers in order to mitigate the increased power consumption of communication systems.

Fujitsu has now developed a power amplifier for use in W-band transmissions that offers both high output power and high efficiency, improving transistor performance through the reduction of electrical current leakage and internal GaN-HEMT resistance. Fujitsu has achieved record output power density in the W-band of 4.5W per millimeter of gate width, and has confirmed a 26% reduction in energy consumption compared with conventional technology.

Development background

Wireless data traffic from mobile communications has increased dramatically over the last few years, and with the spread of 5G and Internet of Things (IoT) devices, it is predicted to increase at an annual growth rate of 1.5 times until the year 2020. To build this sort of high-capacity next-generation wireless communications network, attention has been focused on wireless communication technology using the high-frequency W-band. The range of frequencies that can be used in the W-band is very broad and, because communication speed can be rapidly increased in this band, it is well suited to this kind of high-bandwidth wireless communication, says Fujitsu.

Conventional wireless communications technology has allowed for performance of several Gbit/s over distances of several kilometers, but achieving an even greater increase in wireless communication distance and capacity utilizing the W-band demands further increases to the output of power amplifiers to boost signals during transmission.

To increase distance and capacity, it is necessary to expand the frequency bandwidth that can be amplified while supporting modulation methods that transmit more information within the same frequency bandwidth, and a requirement is to have less distortion when the signal is amplified. Another aim is to keep in check the energy consumption of communication systems that accompanies greater distances and capacities, along with improved energy efficiency in power amplifiers.

To both increase the distance and capacity of wireless communications and decrease energy consumption with indium aluminium gallium nitride (InAlGaN) HEMTs, Fujitsu has developed two technologies that effectively reduce internal resistance and current leakage.

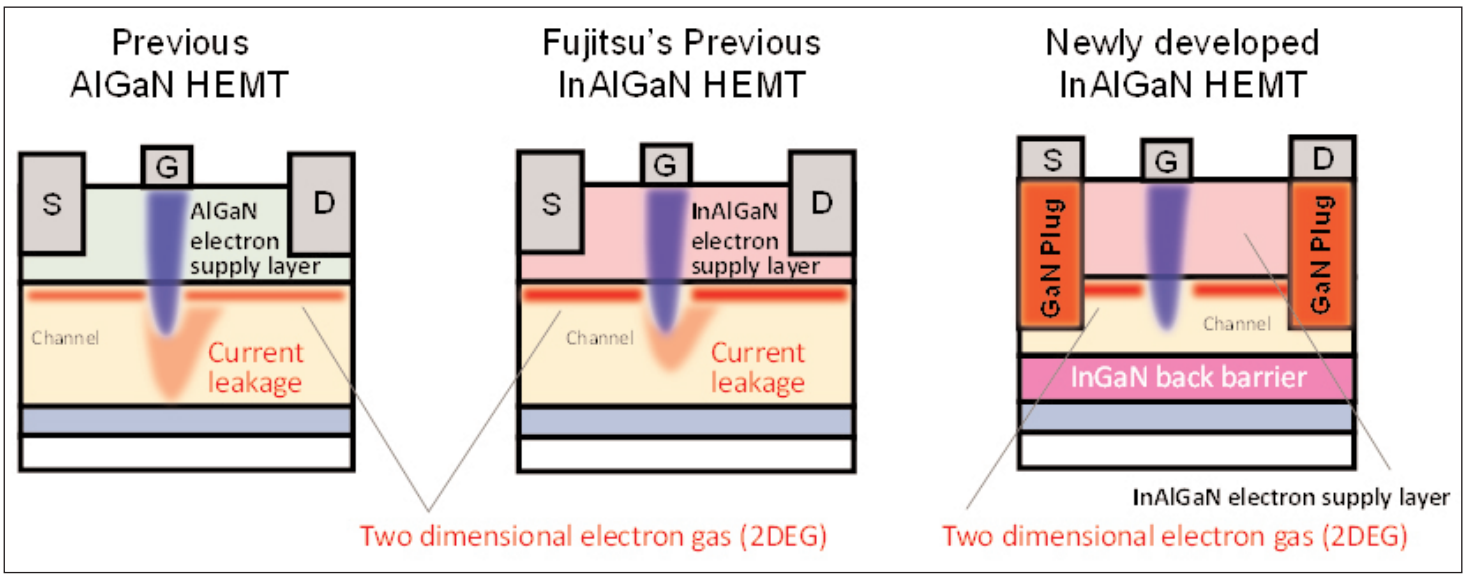

Figure 1: Schematic cross-sectional view of GaN-HEMT device structure.

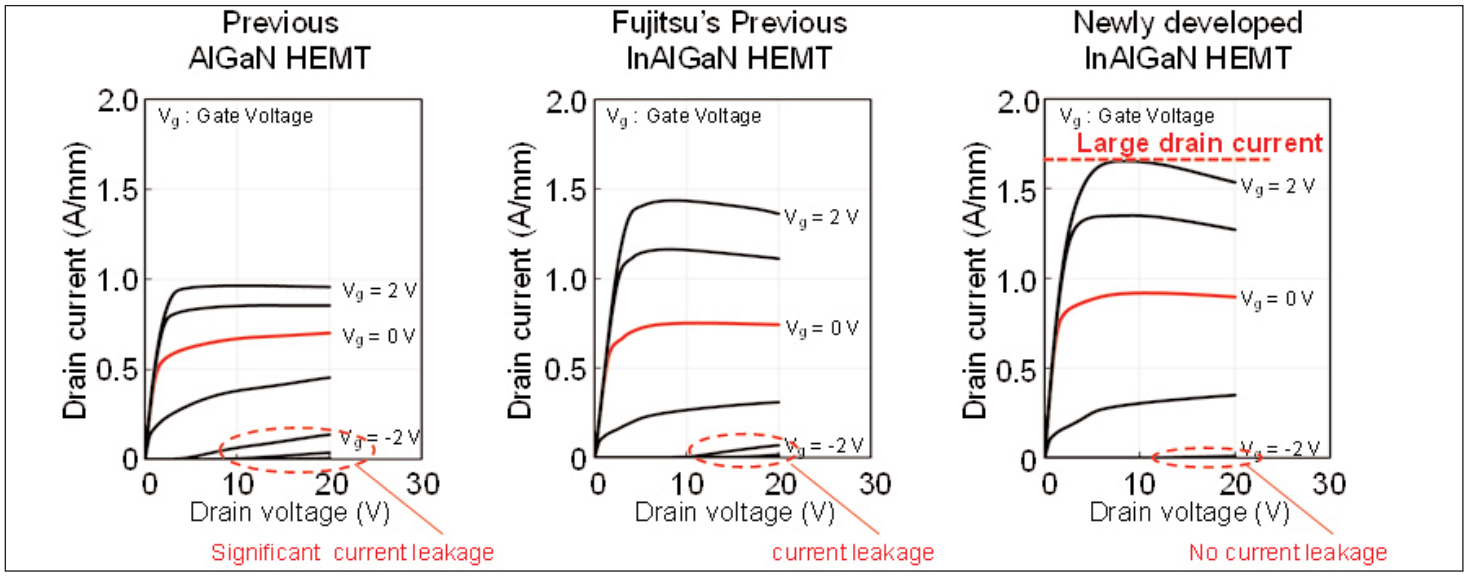

Figure 2: Comparison of transistor characteristics.

1. Technology to reduce internal resistance

Fujitsu has developed device technology that can reliably reduce resistance to one tenth that of previous technology when current flows between the source or drain electrodes and the GaN-HEMT device. The technology uses a manufacturing process that embeds GaN plugs directly below the source and drain electrodes, which generate electrons at high densities (Figure 1).

It is necessary to transport the electrons that come from the source electrode to the two-dimensional electron gas (2DEG) field as smoothly as possible. The structure of the previous technology causes the electron supply layer to become a barrier, however, and internal resistance increases between the source electrode and the two-dimensional electron gas. By applying this new technology, Fujitsu can run high currents through the transistor with significantly less resistance (Figure 2).

2. Technology to control current leakage

Current leakage occurs when the two-dimensional electron gas (which moves at high speed on the boundary at the top of the channel layer) takes a detour below the gate when the transistor is in its off-state. This leakage causes deterioration in the operational performance of the power amplifier. Normally, it is possible to reduce current leakage by placing a barrier layer beneath the channel layer, but in that case the amount of two-dimensional electron gas also decreases, reducing drain current.

The new technology maintains high drain currents by effectively distributing indium gallium nitride (InGaN) to create a barrier layer below the channel layer. This reduces electron detours during operation, successfully providing significant reductions in current leakage (Figures 1 and 2).

Performance

The previous record for power amplifier output density in the W-band for transmitters was 3.6W per millimeter of gate width (with technology developed by Fujitsu Laboratories). This has improved significantly with the newly developed technology, which delivers power output of 4.5W per millimeter of gate width for a power amplifier designed to operate at 94GHz.

In addition, the new technology achieved a reduction in energy consumption of 26% compared to the previous technology through a reduction in current leakage.

Fujitsu expects that the use of this power amplifier will allow the achievement of high-capacity, long-distance wireless communications between two connected systems at different locations at over 10Gbit/s and at distances greater than 10km.

Future plans

Fujitsu aims to apply this technology broadly to the development of power amplifiers for purposes calling for wireless communications that offer long range and higher capacity, while offering easier installation than fiber optics. The goal is to commercialize the new technology in high-speed wireless communication systems by 2020, and employ it in situations such as a method of restoring communications when fiber-optic cables have been severed by natural disasters or as a way of setting up temporary communications infrastructure when holding events.

www.fujitsu.com/jp/group/labs/en

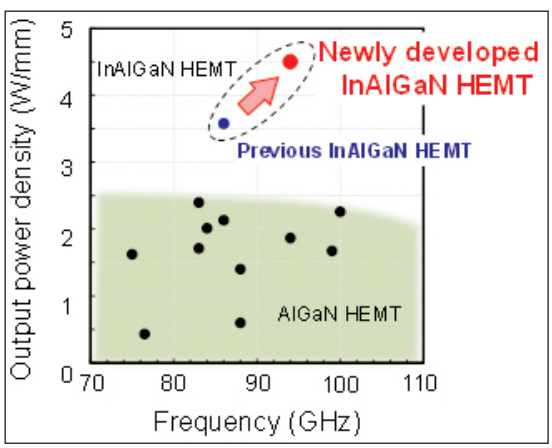

Figure 3: Comparison of GaN-HEMT power amplifier performance.

US DOE awards SUNY Poly $720,000 ARPA-E grant to develop GaN-based power switches as part of PNDIODES program

Army Research Lab, Drexel University and Gyrotron Technology to co-develop GaN doping and annealing techniques

State University of New York (SUNY) Polytechnic Institute says that interim dean of graduate studies professor Fatemeh (Shadi) Shahedipour-Sandvik and her team of collaborators have been selected to receive $720,000 in federal funding from the US Department of Energy's Advanced Research Projects Agency – Energy (ARPA-E). The grant will be used to develop more efficient and powerful high-performance power switches for power electronics applications, such as for enabling a more efficient energy grid. The research — to explore advanced doping and annealing techniques for gallium nitride (GaN)-based power devices — is in partnership with Dr Woongje Sung of SUNY Poly, the Army Research Lab (ARL), Drexel University, and Gyrotron Technology Inc.

"This award is a strong indicator of how SUNY Poly's resources and facilities are enabling the types of research that have the potential to improve power electronics devices which have become ubiquitous, from those utilized to make the power grid more efficient, to those that can improve electric car capabilities," notes SUNY Poly's VP of research Dr Michael Liehr.

"Advanced power electronic devices offer significant advances in power density, efficiency, and reduced total lifecycle cost," says Shahedipour-Sandvik.

The SUNY Poly grant is part of $6.9m in funding that ARPA-E is providing through its program Power Nitride Doping Innovation Offers Devices Enabling SWITCHES (PNDIODES) to seven institutions and organizations. With PNDIODES, ARPA-E is tackling a specific challenge in wide-bandgap semiconductor production. Wide-bandgap semiconductor materials such as GaN allow electronic devices to operate at higher temperatures and/or frequencies, for example, than existing silicon-based chips, which is why technical advances in power electronics promise energy-efficiency gains throughout the economy. However, achieving high power conversion efficiency in these systems requires low-loss power semiconductor switches. Power converters based on GaN could potentially meet the challenge by enabling higher-voltage devices with improved efficiency, while also dramatically reducing the size and weight of the device, for example.

The PNDIODES-funded research focuses on selective-area doping. Implemented well, this process can allow the fabrication of devices at a competitive cost compared with traditional silicon-based counterparts. Developing a reliable and usable doping process that can be applied to specific regions of GaN and its alloys is an important obstacle in the fabrication of GaN-based power electronics devices that PNDIODES seeks to overcome. Ultimately, the PNDIODES project teams, including the Shahedipour-Sandvik team and Dr Sung at SUNY Poly as well as the institution's partners, aim to develop new ways to fabricate semiconductor devices for high-performance, high-power applications like aerospace, electric vehicles, and the grid.

The grant will be used to develop more efficient and powerful high-performance power switches for power electronics applications, such as for enabling a more efficient energy grid

Shahedipour-Sandkvik team's research ('Demonstration of PN-junctions by ion implantation techniques for GaN (DOPING-GaN)') will focus on ion implantation as the centerpiece of its approach and use new annealing techniques to develop processes to activate implanted silicon or magnesium in GaN to build p–n junctions. Utilizing a unique technique with a beam from a gyrotron (a high-power vacuum tube that generates millimeter-wave electromagnetic waves), the team aims to understand the impact of implantation on the microstructural properties of the GaN material and its effects on p–n diode performance.

In addition to this GaN-focused research being conducted by Shahedipour and her team at SUNY Poly (which also provides hands-on research opportunities for a number of the institution's students), SUNY Poly and General Electric also lead the New York Power Electronics Manufacturing Consortium (NY-PEMC) with the goal of developing and producing low-cost, high-performance 6" silicon carbide (SiC) wafers for power electronics applications. The consortium announced first production of SiC-based patterned wafers in February at the Albany NanoTech Complex's 150mm SiC line, with production coordinated with SUNY Poly's Computer Chip Commercialization Center (Quad-C), located at its Utica campus where the SiC-based power chips will be packaged.

www.sunypoly.edu

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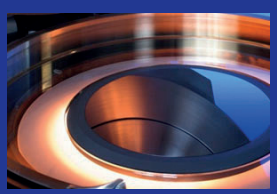

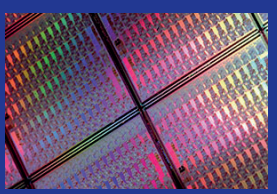

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GaN Systems completes investment round led by BMW

Funding to expand global sales & accelerate new product development

GaN Systems Inc of Ottawa, Ontario, Canada — a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control — has closed an investment round led by BMW's investment arm BMW i Ventures (which joins existing investors BDC Capital, Chrysalix Venture Capital, Cycle Capital Management, RockPort Capital and Tsing Capital).

Consistent with its investment strategy, BMW i Ventures recognizes that GaN Systems' products maximize the efficiency of electronic systems while dramatically reducing size, weight and overall system cost. The investment will be used to expand global sales and accelerate new product development.

"GaN Systems' power transistors have created new possibilities for engineers to build the power electronics demanded by today's systems. Gallium nitride-based transistors have become, in my opinion, the next big stepping stone in miniaturization," comments BMW i Ventures' managing director Uwe Higgen. "We have seen systems a quarter of the size while providing better efficiency than traditional silicon-based alternatives. With GaN, any system that needs power can become smaller, lighter and more efficient. These capabilities are particularly relevant in the automotive sector," he adds.

"From computer/phone chargers and data-center servers to factory motors and electric cars, our customers have validated the GaN value proposition of small, efficient, low-cost power electronics," reckons GaN Systems' CEO Jim Witham. "These benefits are widely recognized by the world's biggest companies across all industries," he adds.

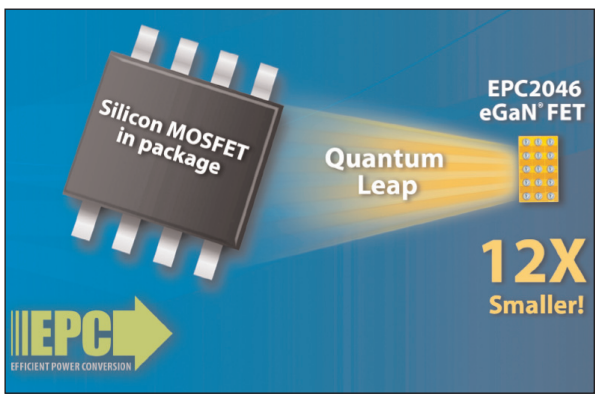
"There are many examples of how GaN benefits power systems," says Higgen. "With autonomous cars, there will be the need to massively scale the data-center infrastructure," he adds. "Data-center power consumption is one of the biggest cost drivers, and increasing the efficiency of power conversion will account for billions of dollars in cost savings and enable a more sustainable infrastructure around the globe."

www.gansystems.com
www.bmwiventures.com

EPC launches 200V, 25mΩ GaN power transistor 12 times smaller than equivalent MOSFETs

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 and ICs — has launched the EPC2046 power transistor (which has a voltage rating of 200V and maximum $R_{DS(on)}$ of 25mΩ with a 55A pulsed output current) for applications including wireless power, multi-level AC–DC power supplies, robotics, solar micro inverters, and low-inductance motor drives.

The chip-scale packaging of the EPC2046 handles thermal conditions far better than plastic-packaged MOSFETs since the heat is dissipated directly to the environment with chip-scale devices whereas the heat from the MOSFET die is held within a plastic package, says EPC. The new device measures just 0.95mm x 2.76mm (2.62mm^2), so designers no longer have to choose between size and performance, notes the firm.



"Manufactured using our latest fifth-generation process, the EPC2046 demonstrates how EPC and gallium nitride transistor technology is increasing the performance and reducing the cost of eGaN devices," says co-founder & CEO Alex Lidow. "This opens up entirely new applications beyond the reach of the aging silicon MOSFET and offers a big incentive for users of MOSFETs in existing applications to switch," he adds. "This latest product is further evidence that the performance and cost gap of eGaN technology with MOSFET technology continues to widen."

The EPC9079 development board is a 200V maximum-device-voltage half-bridge with onboard gate driver, featuring the EPC2046, onboard gate drive supply and bypass capacitors. This 2" x 1.5" board has been laid out for optimal switching performance and contains all critical components for easy evaluation of the 200V EPC2046 eGaN FET.

The EPC2046 eGaN FETs are priced at $3.51 each in 1000-unit quantities. The EPC9079 development boards are priced at $118.75 each. Both are available for immediate delivery from distributor Digi-Key.

http://epc-co.com/epc/Products/eGaNFETsandICs/EPC2046.aspx

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Indian Institute of Science gets government approval to establish commercial GaN foundry

Centre for Nano Science and Engineering's GaN-on-Si facility already producing transistors for researchers

The Indian Institute of Science (IISc) in Bangalore has received initial government approval to set up a foundry to produce gallium nitride (GaN) for next-generation strategic technologies, including radar and communication systems, according to the Indian Express.

The proposed foundry is to be developed around an existing facility for producing GaN transistors on silicon wafers, at the IISc's Centre for Nano Science and Engineering (CeNSE), led by associate professor Srinivasan Raghavan.

"The proposal is currently at the highest level of the government," says Shivashankar. "It needs about Rs3000 crore [$465m] and is seen as a strategic-sector investment," he adds.

"GaN technology will substantially help in the development of next-generation radars, seekers and communication systems, and will be useful in systems like Light Combat Aircraft," comments R K Sharma, director of India's Defence Research and Development Organisation (DRDO) Solid State Physics Lab.

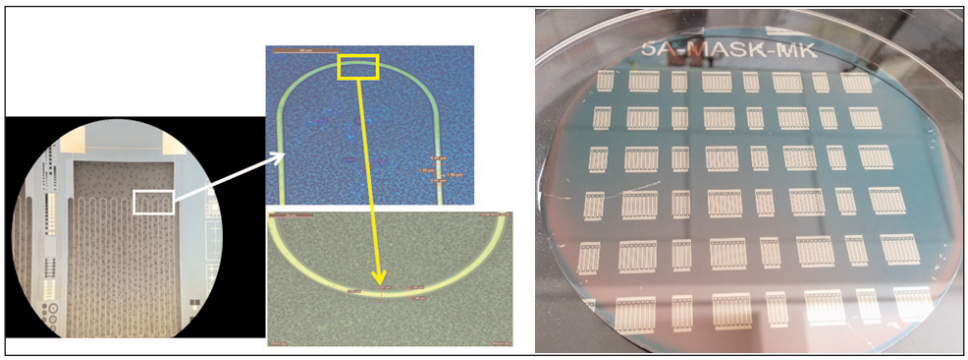
Inaugurated in 2015 by Prime Minister Narendra Modi, the CeNSE facility aims to create a GaN electronics ecosystem, spanning materials, devices and systems. GaN-based transistors from CeNSE are already being sold to researchers in India. The creation of a commercial GaN foundry would service industry demand for GaN technology.

"What we need for strategic purposes is efficient energy consumption systems, and gallium nitride conductors are the answer. Unmanned vehicles, for example, which are the future of security systems, are dependent on energy efficiency," says Sharma.

Among the areas where GaN can be used is phased-array radar for electronic warfare, such as active electronically scanned array (AESA) radars that are fitted on modern fighter jets.

"The worldwide power electronics device market is $36bn," notes Raghavan. "As power consumption goes up, the requirement for power electronics will go up. So when you start working on GaN-based materials, you are looking at potential impact on a much larger power electronics market," he adds. "What we have set up here in the IISc is a GaN platform where many of these things can mushroom."

www.cense.iisc.ac.in/research/gan-technology



Optical micrographs of 100mm-wide HEMTs for high-power switching applications. 2" GaN HEMT wafer on silicon post-fabrication shown on right.

Polish Academy of Sciences' Institute of High Pressure Physics now leaseholder of Ammono

The Polish Academy of Sciences' Institute of High Pressure Physics (IHPP PAS) says that, in the best interest of nitride semiconductor science and technology, it has become the leaseholder of Warsaw-based Ammono Company which manufactures bulk gallium nitride (GaN) wafers using the ammonothermal method but which has been in receivership since 2015.

Established by the Polish Ministry of Science and Higher Education, the tenancy is intended to enable close cooperation between the groups involved in ammonothermal and hydride vapor phase epitaxy (HVPE) crystallization of GaN. The latter is performed at IHPP PAS and, as a result of common projects, possible synergy between these two methods has been established. Ammono owns an ammonothermal GaN wafer pilot line, and IHPP PAS is building a pilot line for HVPE GaN substrates.

The lease and collaboration should lead to further development of both methods and, in the future, to merging of the two technologies and mass production of high-quality GaN wafers for GaN-based electronic and optoelectronic devices. The tenancy should also enable knowledge transfer between researchers who have been involved in GaN crystallization for over two decades.

www.ammono.com
www.unipress.waw.pl

Compound semiconductor cluster branded CS Connected

The new brand name for what is said to be the world's first compound semiconductor cluster is was introduced in an event on 5 July at Cardiff University, Wales, UK (organized by its Innovation Network, which promotes business–university interaction). Bringing together the core elements of the compound semiconductor cluster, the new banner 'CS Connected' unites international firms, policymakers and academics who are building next-generation technology.

Silicon technology has been the driving force behind today's information society but, increasingly, demands for higher performance are reliant on advanced technologies in the form of compound semiconductors, offering speeds more than 100 times faster, along with a wide range of photonic capabilities.

Cardiff-based epiwafer foundry and substrate maker IQE plc is working in partnership with its supply chain, the Cardiff University, and Welsh and UK Government to bridge the so-called 'Valley of Death' between R&D and commercial reality.

Significant economic investments are backing a number of initiatives that can translate compound semiconductor research quickly and effectively into commercial products and services. Together, these groups are making Wales home of the first compound semiconductor cluster, which could generate up to 5000 high-value jobs, it is reckoned.

Effective collaboration

As a collection of established businesses, start-ups, entrepreneurs and academic institutions working together in a particular sector and/or region, the aim of such a cluster is to encourage innovation through versatile and effective collaboration. Cardiff University is hence hosting representatives of the region's compound semiconductor expertise to show business and academics what CS Connected has to offer, and how the cluster's different parts can support innovation from fundamental research through to mass production.

Speakers included:

- Dr Drew Nelson (CEO of IQE);
- professor Diana Huffaker (director, Institute for Compound Semiconductors);
- Dr Wyn Meredith (director, Compound Semiconductor Centre Ltd);
- professor Peter Smowton (director, EPSRC Future Compound Semiconductor Manufacturing Hub); and
- Dr Andy Sellars (Innovate UK High Value Manufacturing lead, Compound Semiconductor Applications Catapult).

International interest

"Everything we do at the Institute [for Compound Semiconductors] has commercial realization in mind. Our compound semiconductor research is designed to be introduced at pace into the production environment, and we seek more direct industrial collaborations through product development and prototyping," notes Huffaker. "The regional cluster of excellence ensures our work has a number of avenues for translation… You can't make an impact on your own — you need partners. Events like this help encourage that," she adds.

"Compound semiconductors are front and centre of this century's enabling technology. By solving the scientific challenges in developing new compound semiconductor structures, and combining compound semiconductors with silicon, we will build on silicon's decades of investment and open up still more exciting applications," says Smowton. "The international interest in this event shows the appetite that exists for accelerating the translation of compound semiconductor research," he adds.

"Catapults promote business-led collaboration, helping to translate new ideas into commercial reality," states Sellars. "As an integral member of CS Connected, the Catapult complements the other facilities within the South Wales cluster. Our activity will stand to ensure that the ground-breaking technology designed and developed within the cluster, and across the UK, reaches new markets and applications."

http://csconnected.com
www.csfusion.org/cluster-open-for-business

CS Applications Catapult launches non-exec board

The South Wales-based Compound Semiconductor Applications Catapult has announced the appointment of four of the UK's leading experts in the field to its non-executive board of directors: Dr Trevor Cross, group chief technology officer of Teledyne e2v; Stephen Duffy, commercial director of Optocap; Jonathan Lyle, chief executive of UK government agency Defence Science and Technology Laboratory (Dstl); and Dr Wyn Meredith, director of the Cardiff's Compound Semiconductor Centre.

The appointments represent "a crucial step in establishing a world-class facility to help commercialize compound semiconductor technology in the UK," says the catapult's chairman Kevin Crofton. "The Catapult complements other investments in region, including the Institute for Compound Semiconductors and the Compound Semiconductor Centre, as part of the CS-Connected cluster in South Wales," he adds. Each board member brings "an in-depth understanding of the UK's R&D activity as well as the specific needs of the end-user markets we seek to target… Insight and experience brought by the newest members of our board will be invaluable in developing effective routes for commercialization."

Compound Semiconductor Cluster in South Wales strengthened by R&D program wins

Projects supported by government agency Innovate UK

The vision to establish the South Wales region in the UK as what is reckoned to be the first Compound Semiconductor Cluster is said to be gaining traction with recent research, development and innovation wins by businesses and academic institutions based in the region.

As well as already having made a major impact in enabling high-speed communications and in every smartphone and Internet-enabled communications device, compound semiconductor technology is also used in a wide range of sensor devices ranging from proximity sensing and laser focusing deployed in smartphones and cameras, to 3D sensing, optical and RF communications, healthcare technologies, aerospace and security applications through to autonomous vehicles. Compound semiconductors are central to a host of next-generation technologies that are currently under development.

Recent awards announced by government agency Innovate UK demonstrate the high level of technology activities in the region, with South Wales-based organizations representing the highest proportion of compound semiconductor-related awards across the UK.

The volume of compound semiconductor-related contract wins across the region indicates that the vision to create the first Compound Semiconductor Cluster is rapidly gaining widespread recognition, it is reckoned. "We are delighted with the breadth of projects supported by Innovate UK, clearly demonstrating that the vision to create the world's first compound semiconductor cluster in Wales is now transitioning to the delivery of tangible innovation activities and supply chain co-operation," says Dr Wyn Meredith, director of the Compound Semiconductor Centre in Cardiff, a joint venture between Cardiff-based epiwafer foundry and substrate maker IQE plc and Cardiff University.

"Building Wales' already impressive research and development capabilities are key priorities for the Welsh Government and it is excellent news that so many Welsh organizations have been successful in securing funding for research and innovation in this key enabling technology," comments Julie James. Skills and Science Minister. "Our on-going investment in further developing the cluster and supporting truly transformative projects with Innovate UK is paying dividends and we are beginning to see the economic benefits from this support," he adds.

"It's fantastic to see so many innovative projects arising from the compound semiconductor cluster in South Wales," says Paul Mason, director of emerging and enabling technologies at Innovate UK. "The high success rate, in some very competitive competitions, highlights the strength of the cutting-edge research and technology within the cluster, and the collaborative approach between academia and industry."

Branded as CS Connected, the Compound Semiconductor Cluster represents organizations that are directly associated with research, development, innovation and manufacturing of compound semiconductor-related technologies as well as organizations along the supply chains whose products and services are enabled by compound semiconductors. The UK, and Wales in particular, is home to a growing number of organizations and firms that are active in this industry sector.

In 2015, Cardiff University announced an investment of around £75m in the Institute for Compound Semiconductors (ICS) as part of its new £300m Innovation Campus. This was quickly followed by the creation of the £24m joint venture between IQE plc and Cardiff University to form the Compound Semiconductor Centre (CSC) for the development and prototyping of compound semiconductor materials. Then came the announcement that the UK Government was to invest £50m in the first Catapult Centre in Wales dedicated to the development of compound semiconductor applications. In 2016, the UK's Engineering and Physical Sciences Research Council (EPSRC) announced a £10m investment in a Compound Semiconductor Hub, based at Cardiff University.

www.csc.wales

Compound Semiconductor Applications Catapult appoints COO

The Compound Semiconductor Applications Catapult has appointed Liz Flint as chief operations officer.

Previously, Flint's career with UK Government agency Innovate UK has seen her serve as Head of Cities and Regions, Head of Innovation Networks, and Lead Technologist (for Energy).

The Catapult says that a deep understanding of the UK innovation system including academic, Government and business priorities has enabled her to develop a reputation for establishing and growing new key strategic areas, along with associated teams and processes for major Innovate UK initiatives. Flint has led the development of multiple Innovate UK teams, expansion of a University Knowledge Exchange department, and multi-partner EU-funded projects.

Flint will work alongside the Catapult's chief business development officer (CBDO) Dr Andy Sellars.

www.catapult.org.uk

IQE's strong first-half revenue growth marks start of increased VCSEL wafer demand for mass-market consumer applications

Expansion approved to meet increased demand in second-half 2018; lease agreed for new premises and MOCVD system orders placed

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK says that, for first-half 2017, it expects revenue of about £70m, reflecting increased sales in each of its three primary markets.

"All business units have progressed in line with expectations, although the Photonics unit has been the stand out," says chief executive Dr Drew Nelson.

Notably, photonics continued to deliver strong double-digit growth (accelerating towards the end of first-half 2017), enjoying the early phase of a significant ramp in vertical-cavity surface-emitting laser (VCSEL) wafer supply for mass-market consumer applications. As a result, overall wafer sales are expected to grow by 16% on first-half 2016. Revenue is also supplemented by about £1m of license income (versus £3.5m in first-half 2016). IQE will report its full first-half 2017 results on 5 September.

IQE says that its broad range of end-market drivers is increasing the diversity of its wafer sales. The firm is engaged in a range of programs that provide significant upside potential to its near- and mid-term growth expectations. These include VCSELs, gallium nitride (GaN) for RF and power, full-service distributed feedback laser (DFB) wafers, infrared and cREO (crystalline rare-earth oxide).

IQE says that the start of the mass-market ramp for VCSEL wafers marks an inflection point in the commercialization of the technology. The firm has secured multiple, multi-year contracts for this VCSEL ramp, reflecting its track record of delivering wafers into high-volume consumer markets.

"The group has multiple high-growth opportunities ahead," says Nelson. The board has hence now approved a capacity expansion plan to meet higher levels of expected demand in second-half 2018 than previously anticipated. This follows increased investment during first-half 2017 in operating costs, product development and working capital to help position the firm for the expected ramp and to meet higher levels of growth in second-half 2017.

As part of its expansion plan the firm says that it has agreed a memorandum of understanding (MoU) for the lease of a new premises in South Wales from the Cardiff City Region, which has a goal of supporting the development of the Compound Semiconductor Cluster in South Wales. IQE says that the 11-year lease (with an option to either extend it or purchase the freehold) provides the infrastructure needed for its expansion in a highly cost effective manner. In parallel, IQE has placed orders for new metal-organic chemical vapor deposition (MOCVD) equipment.

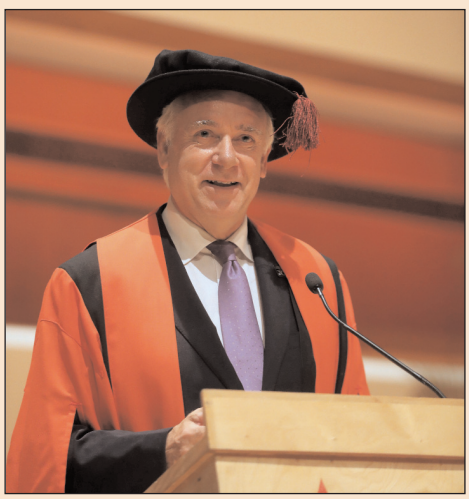
"In light of recent progress and its increasingly confident outlook, the board expects the group will now exceed market expectations for the full year," says Nelson. "Whilst it remains early into the start of the mass-market adoption of our technology, it is possible that, with the current contract momentum, a more significant upgrade to current market expectations could be delivered for 2018."

www.iqep.com

IQE's founder & CEO receives Honorary Fellowship from Cardiff Uni

Dr Drew Nelson, founder & CEO of epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK, received an Honorary Fellowship from Cardiff University at its annual degree ceremonies on 17 July.

Nelson has worked closely with Cardiff University for over 30 years and has recently played a significant role in shaping one of the university's key innovation ventures – the Institute for Compound Semiconductors (ICS), based at Cardiff University's Innovation Campus.



Throughout his career, Nelson has been actively involved in government and industry advisory groups, and in 2001 was awarded an OBE for services to the electronics industry.

"It's a great privilege to accept this award, not only on my behalf but on behalf of everybody who has supported me over the years," commented Nelson on receiving the Fellowship.

www.cardiff.ac.uk/innovation/campus-investment/translational-research-facility

IQE hosts Raytheon Supplier Excellence Program EPIC Award recognition ceremony

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK hosted the 2017 Raytheon Supplier EPIC Award ceremony in one of its US facilities, in Taunton, MA.

As part of the Raytheon Supplier Excellence Program, suppliers are awarded for their outstanding performance, contributions and support to programs across one or more Raytheon businesses. IQE was selected to receive an EPIC Award for its overall Excellence in Performance, Innovation & Collaboration.

The ceremony was attended by Raytheon representatives, as well as Taunton mayor Thomas C. Hoye Jr, Massachusetts senator Marc R. Pacheco and Massachusetts representative Shaunna L. O'Connell.

IQE New Jersey team presented with the EPIC Award.

"Your commitment to excellence is greatly appreciated," comments M. David Wilkins, VP for contracts & supply chain at Raytheon Company. "It enables our joint success and solidifies a platform for 'Building our Future Together' in support of our mutual customer, the US Warfighter," he adds.

"It is a great honor to receive the 2017 Raytheon Supplier EPIC Award, which recognizes the integrity, quality and expertise that IQE offers its customers," says Dr Wayne Johnson, VP of IQE's Power business unit.

www.raytheon.com
www.iqep.com

Veeco CNT ships 500th ALD system to NCSU

Former Ultratech/Cambridge Nanotech business presents papers at ALD 2017

Thin-film etch and deposition process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that Veeco CNT (formerly Ultratech/Cambridge Nanotech), based in Waltham, MA, has shipped its 500th atomic layer deposition (ALD) system to North Carolina State University (NCSU). The Veeco CNT Fiji G2 ALD system will enable the university to perform a variety of research applications for next-generation electronic devices, including high-performance wearables and sensors.

On 26 May, Veeco acquired Ultratech Inc of San Jose, CA, USA (which makes lithography, laser-processing, inspection and ALD systems for the manufacturing of semiconductor devices and LEDs) for $862m. Over the past 15 years since being spun off from Harvard University's Gordon Lab, the CNT business (which was acquired by Ultratech in 2012) has provided ALD systems for a wide range of university R&D and commercial applications including biomedical, electronics, energy, and optical.

"The Veeco CNT Fiji G2 ALD system will be a critical tool to meet our ambitious research goals," says Bongmook Lee Ph.D., research assistant professor at NCSU's National Science Foundation (NSF) Nanosystems Engineering Research Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies (NERC-ASSIST). "This ALD tool enables advances in our research for high-performance CMOS, non-volatile memory, next-generation wide-bandgap power devices, and environmental and physiological sensors," he adds. "We selected the Veeco CNT Fiji G2 for its demonstrated ability to reliably deposit the most challenging oxide and nitride thin films," says Lee. "We continue to engage in a strong relationship with Veeco CNT."

Veeco CNT Fiji G2 ALD system

The Fiji G2 ALD system is a thin-film next-generation ALD system capable of performing thermal and plasma-enhanced deposition in a modular, high-vacuum, flexible architecture that accommodates a wide range of deposition modes using multiple configurations of precursors and plasma gases. The intuitive interface is said to make it easy to monitor and change recipes and processes as required by customers.

"Our 500th ALD system shipment validates the increasing interest in ALD technology," says Ganesh Sundaram Ph.D., vice president of Applied Technology, Veeco CNT. "Now, with the backing of Veeco, we will continue our legacy to build and enhance the deployment of ALD technology, helping customers like North Carolina State University develop next-generation electronic devices."

This ALD tool enables advances in our research for high-performance CMOS, non-volatile memory, next-generation wide-bandgap power devices, and environmental and physiological sensors, says Bongmook Lee NCSU's NSF NERC-ASSIST Center

Veeco CNT was a platinum sponsor of the 17th International Conference on Atomic Layer Deposition (ALD 2017) in Denver, CO, USA (15–18 July), while presenting several papers:

- AS-SuA5 — 'Developing a Full Wafer-scale Approach Towards High ALD Selectivity on Copper vs Low-K (and Oxides) using a Single ALD/SAMS Platform' by Laurent Lecordier (Ultratech) and S. Armini and S. Herregods (IMEC, Belgium);
- AA-SuP51 — 'Color Modification of Metal Surfaces by Transparent ALD Film Stacks' by Ritwik Bhatia and A. Bertuch (Ultratech);
- AF-MoP24 — 'Measurement and Control of Stress of ALD Films and Nano_laminates Measured by Interferometry' by Ritwik Bhatia (Ultratech);
- EM-MoP12 — 'In Situ Characterization of Thin Film Molybdenum Carbide using Spectroscopic Ellipsometry' by Adam Bertuch (Ultratech), J. Hoglund (SemiLab), L. Makai (Semilab), J. Byrnes (SemiLab), J. McBee and G. Sundaram (Ultratech); and
- AA1-TuA13 — 'Mechanical, Physical, and Electrical Properties of Plasma_Enhanced Atomic Layer Deposition of TiVN' by Mark Sowa (Ultratech), N. Strandwitz, L. Ju (Lehigh University), A. Kozen (US Naval Research Laboratory), and B. Krick (Lehigh University).

www.cambridgenanotechald.com
www.ultratech.com
www.veeco.com

UV-C LED research firm CrayoNano orders Veeco MOCVD system for nanowire on graphene growth

Process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that ultraviolet short-wavelength light-emitting diodes (UV-C LEDs) research firm CrayoNano AS of Trondheim, Norway — which was founded in June 2012 based on research at the Norwegian University of Science and Technology (NTNU) Department of Electronic Systems — has ordered a Propel Power gallium nitride (GaN) metal-organic chemical vapor deposition (MOCVD) system, which will be used to grow semiconductor nanowires on graphene for water disinfection, air purification, food processing and life-science applications.

UV-C LEDs are free of harmful mercury, compared with typically 20-200mg of mercury found in traditional UV lamps used in these applications. They also require minimal energy to operate and have longer life cycles compared with other purification and disinfection lighting methods. The global market for UV-C LEDs used in sterilization and purification equipment is rising at a compound annual growth rate (CAGR) of 56% from $28m in 2016 to $257m in 2021, according to the '2016~2021 UV LED and IR LED Application Market Report' by LEDinside (a division of TrendForce).

"We see enormous opportunity in our focused markets and we need superior MOCVD technology to accomplish our goals," says CrayoNano's CEO Morten Froseth. "Veeco's Propel system offers us the unique opportunity to scale to 200mm graphene wafer sizes while maintaining superior uniformity, low manufacturing costs and long run campaigns," he comments.

The global market for UV-C LEDs used in sterilization and purification equipment is rising at a compound annual growth rate of 56% from $28m in 2016 to $257m in 2021

The Propel Power GaN MOCVD system is capable of processing single 200mm wafers or smaller (e.g. 2-inch) in batch mode. The system is based on Veeco's TurboDisc technology including the IsoFlange and SymmHeat technologies, which provide homogeneous laminar flow and uniform temperature profile across each wafer, up to 200mm in size.

"The Propel Power GaN system is the best choice to deposit advanced GaN-based structures, including complex semiconductor nanowires on graphene substrates with strict process demands," states Peo Hansson Ph.D., Veeco's senior VP, general manager, MOCVD. "Our Propel system offers industry-leading uniformity and process cycle time, therefore providing superior productivity compared to other technologies," he claims.

http://crayonano.com
www.veeco.com/Propel

Riber reports first-half 2017 revenue up 80% year-on-year

Full-year growth target raised from 30% to 50% after first-half orders grow 92% year-on-year

For first-half 2017, Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has reported revenue of €12.5m, up 80% on €7m in first-half 2016, comprising 57% from Asia (up from 56%), 12% from the USA (down from 24%) and 31% from Europe (up from 20%).

The strong growth reflects the major deliveries of evaporators (Cells & Sources) in the first quarter for the photovoltaic and screen industries (driving first-half sales to €8.8m, compared with just €1m in first-half 2016), as well as continued growth in sales of Services & Accessories during the second quarter (to €2.8m, up 18% on €2.4m in first-half 2016).

In terms of MBE Systems, one research system yielding €0.9m in revenue was billed during first-half 2017, compared with two systems (including one production unit) yielding €3.6m in revenue in first-half 2016.

Orders have almost doubled (up by 92%) from €8.8m in first-half 2016 to €16.8m, reflecting contributions by each business line.

Specifically, MBE System orders are up 76%, from €6m (four research systems plus one production system) in first-half 2016 to €10.5m (three research systems plus four production systems) in first-half 2017.

Orders for evaporators (Cells & Sources) have risen by70% from €0.7m to €1.2m, driven primarily by purchases relating to MBE systems.

Orders for Services & Accessories order have risen by 143% from €2.1m to from €5.1m, mainly confirming the upturn in customers' production activities.

Considering the level of business recorded for first-half 2017 and the good visibility, Riber is raising its target for full-year 2017 revenue growth from 30% to at least 50%.

First-half 2017 earnings results will be released on 26 September.

www.riber.com

Oxford Instruments using NPL's non-destructive quality control method to commercialize wafer-scale fabrication of 2D molybdenum disulphide

Raman spectroscopy used to quantify defects in CVD-grown MoS_2

UK-based Oxford Instruments says that a world-first non-destructive quality control method developed by the UK's National Physical Laboratory (NPL) has enabled it to commercialize wafer-scale fabrication technology for the two-dimensional (2D) semiconducting material molybdenum disulphide (MoS_2).

While graphene was the first 2D material to be studied in detail, there is now also a focus on other 2D materials with diverse properties and new applications. Among these, single-layer MoS_2 is generating interest due to electronic and optical properties that could pave the way for next-generation electronics and optoelectronics devices.

To commercialize electronic devices made of 2D materials, industry faces a challenge to carry out quality control checks without destroying or damaging the material. As a single layer of a 2D material is only a single atom or molecule thick, assessing its quality so far has only been possible using destructive techniques. Defects are expected to critically impact the performance of MoS_2-based electronic devices, so the ability to investigate and quantify the number of defects without causing damage is crucial for enabling large-scale manufacture of the material, device fabrication and material functionalization.

Oxford Instruments sought to develop a new deposition system and process that could produce MoS_2 in a more industrially scalable manner to help further the commercialization of MoS_2. The researchers needed a suitable quality control approach, and turned to NPL's National Graphene Metrology Centre (NGMC), which has expertise in the characterization and measurement of 2D materials.

"We were investigating the use of Raman spectroscopy for characterizing MoS_2 and found that it is a viable high-throughput and non-destructive technique for quantifying defects," says Dr Andrew Pollard, senior research scientist at NPL. "Importantly for this study we could controllably introduce known defects into MoS_2 as a first step, using a technique from our previous work in graphene," he adds.

"We were able to use NPL's industrially focused research as a framework for developing our own quality control measure that uses Raman spectroscopy to quantify defects in MoS_2 produced using chemical vapour deposition (CVD)," notes Dr Ravi Sundaram, senior scientist at Oxford Instruments. "While such techniques are widely used for graphene, there was no established way of checking the quality of MoS_2 in a non-destructive manner before NPL's work was published," he adds. "Being able to measure the quality of the material enables us to optimize the growth process. This ensures we are able to provide very high-quality, low-defect-density MoS_2 films from our tools."

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NPL's work on MoS_2 provided Oxford Instruments with the methodology needed to develop its own quality control process, which characterizes the 2D MoS_2 layers without having a destructive impact on the material's structure. This enables the team to efficiently characterize the MoS_2 produced via an industrially scalable technology, helping to accelerate the commercialization of 2D materials.

"We have both academic and industry customers who are looking for efficient production and characterization of these novel materials," says Ravi. "MoS_2 is a promising material for electronics, and quite a few industries are interested in it. Being able to manufacture it efficiently is vital to making the material commercially viable and attractive, and this technique has helped us offer a high-quality and competitive product to our customers."

MoS_2 shows promise in both electronics and optoelectronics. Its inherently thin atomic structure not only offers several advantages in scaling down traditional electronics but also opens up the possibility of adding further functional elements on a chip for applications such as sensors. In addition, its semiconducting electronic structure renders it interesting for optical applications such as photovoltaics and light emission. As such, scaling up the MoS_2 production and assessing its quality using non-destructive approaches offers vast benefits not only to manufacturers, but also to the industry as a whole, says the firm.

www.oxinst.com/mos2

Oxford Instruments unveils ALD plasma processing system for 2D materials

UK-based Oxford Instruments says that its atomic layer deposition (ALD) and 2D technical specialists have teamed with the research teams of Eindhoven University of Technology (TU/e) in The Netherlands to develop the FlexAL-2D for ALD of 2D transition-metal dichalcogenides (TMDs) for nanodevice applications.

The firm says the system offers the following benefits:

- 2D materials growth: at CMOS-compatible temperatures, with precise digital thickness control, over a large area (200mm wafers).
- Robust ALD processes for 2D materials: self-limiting ALD growth; molybdenum disulfide (MoS_2) — oxygen and carbon free (<2%), high growth per cycle ~0.1 nm/cycle, and crystalline material above 300°C.
- Tunable morphology: control over basal plane or edge plane orientation.
- Growth of ALD dielectrics and other ALD layers on 2D materials in one tool, for creating advanced 2D device structures.
- RF substrate biasing option for film property control.

The wide parameter space offered by the system allows the growth of 2D transition-metal dichalcogenides at lower temperatures than employed in chemical vapor deposition (CVD) furnaces. First results on the growth of 2D MoS_2 material by ALD at 450°C and lower temperatures were presented by Eindhoven researchers on 16 July at the 17th International Conference on Atomic Layer Deposition (ALD 2017) in Denver, CO, USA. Plasma-enhanced ALD was implemented to synthesize layers of 2D MoS_2 films with tunable morphologies, i.e. in-plane and vertically standing nano-scale architectures on CMOS-compatible SiO_2/Si substrates. The 2D in-plane morphology has potential applications in nanoelectronics, while the 3D fin structures are suitable for catalysis applications such as water splitting.

"Dr Bol and the Plasma & Materials Processing (PMP) group at TU/e are pushing the boundaries of ALD research into new application areas," comments Chris Hodson, ALD product manager at Oxford Instruments Plasma Technology (OIPT). "2D materials are a hot topic and utilizing ALD to allow growth at lower temperatures and combine 2D materials with ALD deposition and other processing methods at 200mm provide a new capability with many possibilities."

The TU/e researchers are particularly interested in relatively low temperatures. "For CVD processes, typically temperatures of over 800°C are needed," notes Dr Ageeth Bol., associate professor in the Plasma & Materials Processing group "That is often fatal for applications in semiconductors because the high temperature increases the diffusion of the atoms, which makes it harder to place them at the right spot," he adds. "We want to have a process that yields materials of high quality at lower temperatures. This is especially important for the two-dimensional heterogeneous layers I am working on, since at lower temperatures less diffusion of atoms between the layers will occur."

www.phys.tue.nl

GTAT launches SiC boule growth furnace addressing emerging demand for 6" wafers

Portfolio expanded to address growing power electronics market

GT Advanced Technologies of Merrimack, NH, USA (which produces crystal growth equipment for the solar PV and power electronics industries as well as sapphire material for precision optics and other specialty industries) has made available for commercial sale a silicon carbide (SiC) production system with what is said to be a stable and repeatable process, capable of producing semiconductor-grade, 6-inch silicon carbide boules.

The firm hence now offers a complete SiC production solution capable of achieving what are claimed to be industry-leading cost points, including the SiClone200 production-ready sublimation furnace, along with process technology, hot zones and technical support to companies aiming to produce SiC boules and wafers.

"Much of the world's silicon carbide production remains captive, which limits supply and keeps prices high," notes CEO Greg Knight. "Our silicon carbide solution will help to increase the availability of silicon carbide semiconductors at significantly lower costs by increasing supply as production increases," he adds. "We view this as a key step in enabling new high-power semiconductor applications targeting market verticals such as electric vehicles and next-generation PV inverters."

GT says that it has a history of developing SiC equipment and solutions going back more than 15 years. The firm claims to have pioneered the growth of 2-inch and 4-inch SiC boules in its SiClone sublimation furnaces, and reckons that it is well positioned to offer production-ready solutions with technology covering the entire production process.

www.gtat.com

Picosun collaborating with Taiwan's NCTU and Atom Semicon on ALD

ALD targeted at boosting performance and reliability of GaN HEMTs, speeding R&D, and shortening time-to-market

Atomic layer deposition (ALD) thin-film technology firm Picosun Oy of Espoo, Finland, Taiwan's National Chiao Tung University (NCTU) and Atom Semicon Co Ltd of New Taipei City, Taiwan have begun a joint collaboration on the improvement of gallium nitride (GaN) devices using Picosun's ALD technology. The collaboration was announced by Xiaopeng Wu, CEO of Picosun Asia, and professor Hao-Chung Kuo of NCTU's Institute of Electro-Optical Engineering at the 3rd ALD Taiwan workshop on 23 June.

The three-way collaboration aims to directly support manufacturers working with GaN technology. Picosun says that intelligent ALD solutions can improve the performance and reliability of devices and speed up the R&D phase of novel components, shortening the time-to-market of the products.

"Picosun is our long-term, trusted partner in ALD. We have used our PICOSUN ALD equipment for years to develop state-of-the-art GaN technology," says Kuo. "Globally, Taiwan is a key hub for semiconductor manufacturing, and our close contacts with the prominent industries in the field facilitate short ramp-up times for novel innovations. Picosun's ALD technology supports this with its upscalability and the leading variety of equipment from R&D phase to fully automated, large-scale production," he comments.

"These devices are crucial when energy consumption and size of the power module have to be minimized," says Picosun Asia's chief technology officer Dr Kevin Lin. "Picosun's goal is to provide comprehensive, production-proven ALD solutions to the manufacturers to improve the efficiency, reliability, and operating life of their devices," he adds.

"The collaboration between NCTU and Picosun has always been a success regarding novel, industrial applications of ALD," notes Bob Lin, VP of Atom Semicon. "It's quite important to leverage this to create new value for Taiwan's semiconductor industry… We will soon see yet more breakthroughs in reliable GaN HEMT [high-electron-mobility transistors] technology."

www.picosun.com

ZEISS enters semiconductor process control market

ZEISS Group of Oberkochen, Germany is fueling its growth strategy by expanding into the process control market. Through its new Process Control Solutions (PCS) business unit — part of the ZEISS Semiconductor Manufacturing Technology (SMT) business group — it will draw on ZEISS' established innovations in microscopy and leverage its core technology solutions and partnerships to address the particular needs of semiconductor customers.

"We see a strong trend in semiconductors toward complex 3D chip structures and new materials," says Dr Karl Lamprecht, head of the SMT business group. "As development cycles lengthen and R&D costs climb, the role of metrology changes. Our customers need effective process control solutions delivering integrated, actionable information that speeds time to problem resolution and time to production."

With shrinking structure sizes, ever more sophisticated designs and hundreds of individual working steps, the semiconductor manufacturing workflow has become increasingly challenging, says ZEISS. Fast and cost-effective process control solutions play a key role in ensuring the functioning of semiconductor devices. ZEISS already provides a portfolio of lithography optics and mask metrology and repair solutions, and is now bringing its decades of semiconductor equipment experience into the market for process control solutions.

The PCS business unit will utilize and expand on ZEISS' existing product portfolio, including its core proprietary microscopy technologies, to penetrate the semiconductor lab and fab space. Key products to be deployed include electron microscope products Crossbeam and MultiSEM (the latter of which incorporates the firm's unique multi-electron-beam technology), ion-beam microscope ORION NanoFab, as well as the Xradia Versa and Xradia Ultra non-destructive 3D x-ray microscope systems. Process control solutions will be offered across the spectrum of semiconductor manufacturing process steps, including front end of line (FEOL), back end of line (BEOL), packaging and assembly.

"Our process control solutions offer comprehensive structural, chemical and electrical information," says Dr Raj Jammy, head of the PCS business unit in Pleasanton, CA, USA. "By creating a single window into ZEISS for our semiconductor customers, we will enable them to address their process control challenges with seamlessly integrated technologies, helping them get their products to market faster," he adds.

Jammy, who has more than 20 years of extensive semiconductor industry experience, joined ZEISS in February 2016. After obtaining a Ph.D. in electrical engineering from Northwestern University, he started his career at IBM in New York and held subsequent leading positions at SEMATECH and Intermolecular. He and his team will collaborate closely with global customers to address semiconductor inspection and review, failure analysis, defect detection, 3D tomography, and process characterization and analysis.

To aid in this effort, a new ZEISS Customer Center in the Bay Area was opened in Pleasanton on 15 June. Located near the heart of Silicon Valley, this facility joins ZEISS' global network of customer centers in making its portfolio of optical, ion, electron and x-ray microscopy offerings (including process control solutions) available for demonstrations, application development and training.

ZEISS showcased its latest microscopy products and solutions for semiconductor manufacturing at the SEMICON West 2017 event in San Francisco, CA (11–13 July).

www.zeiss.com/semiconductor-process-control

BluGlass appoints non-executive director

BluGlass Ltd of Silverwater, Australia — which was spun off from the III-nitride department of Macquarie University in 2005 to develop a proprietary low-temperature process using remote-plasma chemical vapor deposition (RPCVD) to grow materials including gallium nitride (GaN) and indium gallium nitride (InGaN) on glass substrates — has appointed James Walker as a non-executive director on its board.

Walker is said to be a seasoned executive, with a track record in commercializing cutting-edge technology in emerging markets. He has headed a number of Australian and international technology companies, including as CEO of DroneShield and chief financial officer of Seeing Machines, and has held leadership positions in a number of growth companies including Hotel Dynamics, Fluorotechnics and Optalert.

Walker is currently the CFO of Fulcrum, an Australian technology company with proprietary software that enables large organizations to drive rapid commercial outcomes through an improved, data-driven customer experience. It is reckoned that his experience of finance, strategic management, mergers & acquisitions (M&A) and initial public offerings (IPO) will add value to the BluGlass board.

www.bluglass.com.au

AES launches PLC-based GSM-V Controller to replace microprocessor-based GSM-5 Gas Safety Monitor

Applied Energy Systems (AES) of Malvern, PA, USA — which provides high- and ultra-high-purity gas systems, services, and solutions (including design, manufacturing, testing, installation, and field service) — has introduced the GigaGuard GSM-V Controller to replace the GSM-5 Gas Safety Monitor, a legacy technology from the firm's SEMI-GAS line of ultra-high-purity gas delivery systems. The new controller has been modernized with a color touchscreen interface as well as an EtherCAT PLC-based control system, and is optimized for drop-in replacement by customers to easily upgrade AT-Plus Series gas source systems that currently use the GSM-5. For legacy switchover systems, (2) GSM-V controllers replace (2) GSM-5 controllers, (1) AS200 controller, and (1) MPC controller.

The GSM-V, which conforms to SEMI S2 standards, is identical to its predecessor in form factor, shape, dimension (8" T x 10" W x 12" D), and mounting and connector locations, but now includes added features to improve ease of use and monitoring flexibility. Key upgrades to this programmable controller include:

- a 7" Beckoff color touchscreen interface that offers step-by-step guides for purging, cylinder changeout, daily operations, data logging, and input and output configurations to minimize human error;
- control for (8) solenoid valves, with the option for expansion to control up to (14) solenoid valves.
- monitors digital and analog process sensor inputs and (8) configurable Form C relay outputs; and
- Ethernet-ready communications and capability to integrate with a facility's safety monitoring system.

"Our customers have been asking for a modern alternative to the microprocessor-based GSM-5 controller, and our controls engineering team has delivered it with the GSM-V," says Dave Stetz, chief engineer of R&D Controls Technology at AES. "The addition of a touchscreen, PLC-based control system, and expansion options make it simpler to program, operate and configure for each customer's unique environment," he adds. "Not only is the GSM-V superior to the GSM-5 in its gas safety monitoring capabilities, but it takes customers just minutes to make the replacement. It is designed to 'plug and play' so that with a few steps, they can immediately start experiencing the benefits of these new features."

www.appliedenergysystems.com/semi-gas/gigaguard-control-technology

AP&S triples size of in-house application laboratory

AP&S International GmbH of Donaueschingen, Germany (which designs and produces batch- and single-wafer wet process equipment for surface treatment of substrates under cleanroom/sterile conditions) says that, after making a significant investment in the expansion and modernization of its in-house laboratory in 2016, its size has now almost tripled — from 23m^2 originally to 66m^2 after the renovation. Since reopening this year, the modified laboratory (the firm's new Demo Center) is open to customers worldwide, offering a variety of single-wafer process demonstrations.

AP&S says that, as the purchase of a wet process application is a significant decision (in which many important aspects and complex contexts must be considered), it aims to support customers during the decision-making process to ensure they receive the optimal wet process solution that meets their specific requirements. In the new Demo Center, customers can test the wet process application of interest and obtain all crucial information, such as a comprehensive test report containing complete parameters of the process set-up, a recommendation for the process recipe due to test results, and further key system configuration details.

AP&S' new Demo Center.

The firm says that the Demo Center plays a significant role not only before the booking but also during the production of the application ordered. Prior to tool delivery, the Demo Center prepares all relevant steps for rapid tool commissioning and optimal production start-up. The range of services includes an in-house process evaluation with a definition of process parameters, a calculation of the throughput and chemical consumption as well as trainings for the customer's staff.

Different wafer materials with various thicknesses can be processed, such as silicon, SiC, GaN, GaAs, sapphire, glass etc... with other materials and substrate types possible

Available process demonstrations include: advanced metal lift-off, metal etching, mask cleaning, photoresist development and strip as well as various cleaning processes. Wafer sizes that can be handled: diameter (round substrates) up to 300mm; side length (square substrates) up to 9"; and thickness up to 10mm. Possible chuck variations are low-contact chucks, various vacuum chucks as well as back- or front-side protection chucks. Different wafer materials with various thicknesses can be processed, such as silicon, silicon carbide (SiC), gallium nitride (GaN), gallium arsenide (GaAs), sapphire, glass etc, as well as Taiko wafers (with other materials and substrate types possible).

www.ap-s.de/rd/demo-center.html

Monocrystal delivers 150-millionth two-inch-equivalent sapphire product

Monocrystal Inc of Stavropol, Russia, which manufactures large-diameter synthetic sapphire substrates and cores for LED, optical product and RFIC applications, has shipped its 150-millionth two-inch equivalent (TIE) product.

Since its incorporation in 1999, Monocrystal has transformed from a niche sapphire market player into a high-volume manufacturer, supplying to more than 130 sapphire customers worldwide.

Historically, more than 60% out of 150 million TIE have been large-diameter wafers and ingots for LED. "We are now seeing an increasing demand for our 6-inch wafers, since major LED manufacturers prefer our product due to its impeccable performance during nitride growth," says CEO Oleg Kachalov. "Monocrystal's low-stress wafers demonstrate low thermal bow in the epitaxial process. As a result, our customers get tighter wavelength uniformity and increase their binning yields by 2–3%, which is significant for high volume production. 6-inch wafers are yet to become the driver of efficiency improvement, while Monocrystal's customers are already enjoying the benefits of stable yields and lower costs," he adds.

"The LED industry has made significant progress over the past few years but still there are future opportunities," says Ludmila Zubova, VP marketing. "For instance, microLEDs seem to be a feasible and promising technology. Monocrystal has already delivered ultra-clean wafers for this application," she adds. "We have several initiatives running to support customers engaged in microLED development."

www.monocrystal.com

DOWA readies mass production of highest-output 280nm deep UV LEDs

Capacity of 1 million chips per month targets disinfection applications

Dowa Holdings Co Ltd subsidiary Dowa Electronic Materials Co Ltd of Tokyo, Japan has developed a deep ultraviolet LED chip with dimensions of 1mm x 1mm and what is claimed to be the industry's highest output power of 75mW at a peak wavelength of 280nm. The firm has prepared for mass production, with capacity equivalent to 1 million LED chips per month.

Since deep UV emitters with a wavelength of 280nm have high efficiency for disinfection, replacing conventional mercury lamps with such LEDs enables equipment to be smaller and mercury-free. Together with other advantages such as power saving, the firm expects the product to find new smart applications.

Combining a high-quality aluminium nitride (AlN) template with what is claimed to be unique crystal growth technology, Dowa Electronic Materials began to mass produce deep ultraviolet LED chips in 2010. It has since continued to serve potential customers and emerging applications while improving its performance. Most recently, the firm has achieved output of 75mW at the 280nm wavelength due to better luminous efficiency, applying improved crystal growth technology together with an LED chip design that has been optimized in dimensions and structure.

Dowa says that the new products can provide light source manufacturers with greater flexibility in selection of package formats, such as lamps and chip-on-board (COB). Meanwhile, by supplying not only chips but also some finished products such as various kinds of the surface-mount device (SMD) and conventional TO-can packages, Dowa Electronic Materials says that it can flexibly meet the diverse requirements of customers. Manufacturing subsidiary Dowa Semiconductor Akita Co Ltd will continue to bolster performance and productivity while expanding production capacity to meet demand.

www.dowa.co.jp

Cree expands architectural lighting range with new 1-Watt RGBW LEDs plus PC Amber option

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has expanded its family of architectural lighting class LEDs with the new CLQ6A RGBW (red, green, blue and white) LED.

Claimed to be the first individually addressable 1W RGBW LED in its class, the CLQ6A is said to open up new designs that were previously not possible. The four-in-one LED provides a single point source for optical control, efficient color mixing and simplified design, enabling lighting manufacturers to offer differentiated architectural lighting.

"Architectural lighting is one of the most challenging applications because of the scale, visibility and complexity of the installations," comments Li Yong Tao, R&D director at Grand Canyon LED Lighting Systems Co Ltd. "Cree LEDs deliver superior luminous flux output, rich color options and excellent color consistency that are perfect for architectural lighting," he adds.

Cree's CLQ6A RGBW LED

"Cree's high reliability enables us to offer products that perform well even in harsh outdoor conditions."

Delivering 8.2lm for blue, 30lm for green, 14lm for red and 25lm for white at a drive current of 100mA in a 5mm x 5.2mm package, the CLQ6A LED improves brightness by seven times over similar 4:1 LEDs that have not been optimized for architectural lighting, it is claimed.

Cree is also extending its CLX6F family with a phosphor-converted PC Amber option that delivers 23lm at 105mA in a 3.4mm x 3.5mm package.

The new LEDs are said to provide unique design options and expand Cree's portfolio of LEDs for architectural lighting, which includes the high-power XLamp XQ-A, XQ-E, XP-E2 and XM-L color LEDs.

"Cree continues to develop new application-optimized LEDs that provide our customers with the best options to meet their design requirements," says Dave Emerson, Cree LEDs senior VP & general manager. "Previously, lighting manufacturers only had high- and low-power LEDs to choose from for these color options. With the new CLQ6A and CLX6F LEDs, we are expanding the industry's best portfolio of LEDs for architectural lighting with the light output and reliability innovations expected from Cree to fill the performance gap in the market," he adds

Product samples of the CLQ6A and CLX6F LEDs are available now with standard lead times.

www.cree.com/architecture

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Bridgelux refutes Everlight lawsuit alleging patent infringement by 2835 SMD LEDs

On 10 June, Taiwan-based Everlight Electronics Co Ltd filed a lawsuit in the US District Court (Northern District of California – San Francisco Division) alleging that Bridgelux Inc of Fremont, CA, USA (a vertically integrated manufacturer of solid-state light sources for lighting applications) is infringing US Patent 6,335,548 and 7,253,448 (which concern essential and fundamental structures in LEDs) by manufacturing and selling LED products including, for example, the 2835 series packaged surface-mount device (SMD) LEDs. The patented technology is broadly used in high-, mid- or low-power LED products.

In addition to the US market, Everlight's patent protection on such structures extends to Europe, Korea, and Japan. However, the scope of the lawsuit is limited only to such products in the USA and does not cover any jurisdictions outside the USA.

The lawsuit asked the court to enjoin Bridgelux from selling, manufacturing, importing or exporting any infringing products, and to award Everlight damages sufficient to compensate for Bridgelux's infringement.

Bridgelux believes that Everlight's infringement claims are entirely without merit and intends to vigorously defend itself against these claims. "As history demonstrates, Bridgelux respects the intellectual property rights of others and will not be intimidated by the misuse of litigation from those seeking an unfair advantage or seeking to limit the advantage Bridgelux has earned from our technology investments," says Bridgelux's CEO Tim Lester.

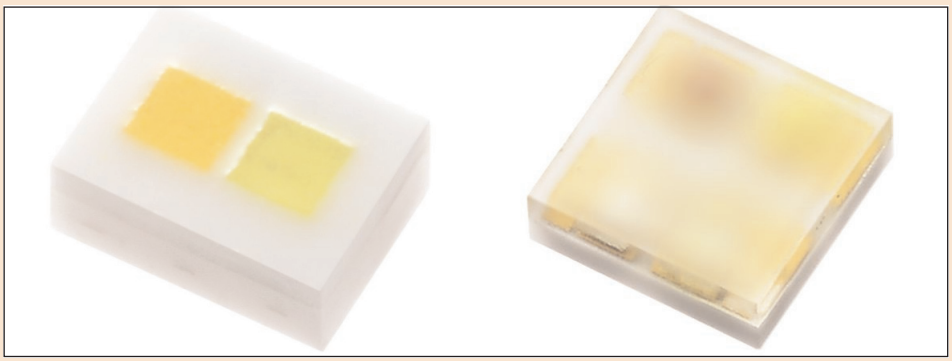
Bridgelux says that it believes the lawsuit is the result of the success of its 2835 SMD products in the market and Everlight's inability to compete with a competitive offering. Because its patent portfolio (of more than 300 worldwide patents extending from chips to luminaires) covers many core LED technologies, Bridgelux intends to employ its own patent portfolio to protect its rights.

www.everlight.com
www.bridgelux.com

Everlight launches 2- and 4-chip EL Multi Color LED packages for automotive interior ambient lighting

Taiwan-based Everlight Electronics Co Ltd has launched the EL Micro Multi (1216) and EL Multi Color (2525) series with two chips and four chips, respectively, in ceramic packages, designed specifically for ambient lighting applications in vehicle interiors.

The EL Micro Multi Series is offered in an extremely small (1.2mm x 1.6mm x 0.7mm) ceramic MSL1 rated SMD package (the smallest dual-color package on the market). The product consists of two different chips that can separately control and mix the color temperature of cool white (6000K) and warm white (2700K), according to preference. This allows a customized color combination of two colors such as cool white (6000K) combined with yellow, red, green or blue. In cool (6000K) and warm (2700K) white, it offers a brightness intensity of 20lm at a drive current of 80mA, ESD protection of 8kV, and operates over temperatures from –40°C to +110°C. The two-chip EL Micro Multi Series is available at a price that meets the budget requests of automotive original (1216) equipment vendors.



Everlight Electronics' EL Micro Multi (1216) and EL Multi Color (2525) for ambient automotive interior lighting applications.

The EL Multi Color series (within a 2.5 x 2.5 x 0.75mm ceramic MSL1 rated SMD package with a gold plating leadframe for sulphur resistance) comprises four different chips for customized RGBW and RGBY color options. Benefitting from an individual and mixed phosphor design of white color among four chips, this avoids luminous decay of each chip and hence provides uniform light and better overall performance for applications, it is claimed. EL Multi Color can control the brightness separately, mix color and light up upon request. The viewing angle is 140°, and the ESD protection is 8kV. The EL Multi Color 4-chip package addresses and meets the requirements of automotive original equipment vendors for higher performance than regular budget EL Micro Multi Series 2-chip packages.

www.everlight.com

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Lumileds becomes independent company as Apollo funds and Philips complete transaction

Philips retains 19.9% stake after selling 80.1%

Lumileds of San Jose, CA, USA — which develops, manufactures and distributes LED technology and lighting products for the automotive, mobile, Internet of Things (IoT) and illumination segments — says that funds affiliated with Apollo Global Management LLC and Lumileds' parent firm Royal Philips have completed their transaction (announced on 12 December 2016), resulting in Lumileds operating as an independent company.

As agreed, Philips has sold a 80.1% stake in Lumileds to funds managed by Apollo while retaining the remaining 19.9%. Apollo is a global alternative investment manager with assets under management of about $197bn (as of 31 March) in private equity, credit and real-estate funds, invested across a core group of nine industries, where Apollo has considerable knowledge and resources.

"We are fortunate to have Apollo and Philips' support as Lumileds embarks upon our next chapter as an innovator of high-performance LEDs and a leader in advanced lighting solutions," says Lumileds' CEO Mark Adams. The firm employs more than 9000 team members with operations in over 32 countries.

"Lumileds has over 100 years of innovation as a pioneer in the lighting industry," comments Apollo senior partner Robert Seminara. "We look forward to working with the Lumileds team in support of what we believe will be a very successful future."

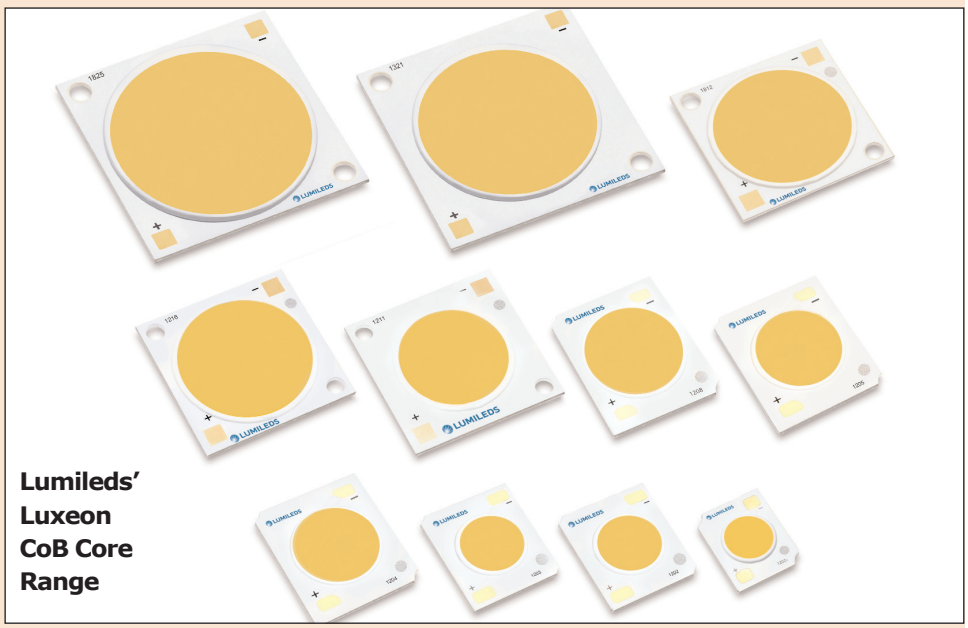
www.lumileds.com
www.agm.com

Lumileds extends LUXEON CoB Core Range to 30,000 lumens for streetlights and high-bay & low-bay lighting applications

Lumileds has added three new products to its LUXEON CoB Core Range to satisfy high-lumen-output applications such as streetlights, stadium lights and high-bay & low-bay fixtures.

"We now have the ability to address not only 40W and 50W applications but up to 100W and 120W applications with these high-lumen packages, at the same high efficacy as our LUXEON CoB Core Range (Gen 3) products," says Eric Senders, product line director for the LUXEON CoB (chip-on-board) family.

The high-lumen extension of the LUXEON CoB Core Range (Gen 3) has light-emitting surfaces (LES) of 23mm, 29mm and 32mm, nominal fluxes of 8800lm, 11,000lm and 16,000lm at drive currents of 1.2A, 2.1A and 2.2A, plus luminous efficacy up to 161lm/W. The arrays are offered over a color temperature range of 2700–5700K and color rendering index (CRI) options of 70, 80 or 90, with an efficient 70-CRI solution in warmer 3000K for outdoor lighting as well as a special color requirement for studios and stadiums where cool color temperatures and high (>90) CRI are required.



Lumileds' Luxeon CoB Core Range

The CoBs are mounted on square metal core PCBs (MCPCBs), which provide what is said to be the industry's lowest thermal resistance, enabling smaller heat-sinks and optics for lower overall system cost. "Feedback from many CoB customers indicates that heat-sinks alone make up a substantial portion of system cost," says Senders. "By keeping the LES as small as possible and having a low-thermal-resistance substrate, a smaller heat-sink can be used and a good portion of the cost has been removed from the system."

LUXEON CoB Core Range (Gen 3) LEDs are compatible with an existing ecosystem of optic, drivers and holders that is said to enable faster time to market of outdoor streetlights, high-bay & low-bay fixtures.

www.lumileds.com/LUXEONCoBCoreRange

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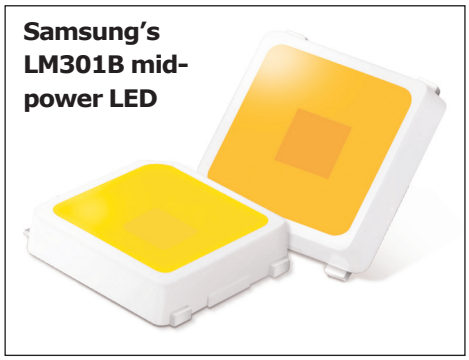
FerroTec

Samsung achieves 220lm/W luminous efficacy with new mid-power LED package

South Korea's Samsung Electronics Co Ltd has begun mass producing a new mid-power LED package, the LM301B (with samples available now), featuring what is claimed to be the industry's highest luminous efficacy of 220 lumens per watt. The package is suited to a range of LED lighting applications including ambient lighting, downlights and most retrofit lamps.

Samsung says that it was able to achieve this efficacy — at a drive current of 65mA, color temperature of 5000K, and color rendering index (CRI) of 80+ — by incorporating an advanced flip-chip package design and state-of-the-art phosphor technology. The LM301B's flip-chip design uses a highly reflective layer-formation technology to enhance light efficacy at the chip level. Also, complete separation between its red phosphor film and green phosphors allows minimal interference during the phosphor conversion process, resulting in higher efficacy than conventional phosphor structures. The firm says that these combined technology enhancements enable a 10% increase in overall efficacy compared with competing 3030 platform packages, without compromising on premium-quality light output.



Samsung's LM301B mid-power LED

"With our LM301B, we are able to deliver even greater mid-power value and help lower the total cost of ownership for LED lighting manufacturers," says Jacob Tarn, executive VP of the LED Business Team at Samsung Electronics.

www.samsung.com

Toyoda Gosei develops automotive headlamp LEDs

Toyoda Gosei Co Ltd of Kiyosu, Aichi Prefecture, Japan has developed its first automotive headlamp LED as a new product. According to in-house tests, the LEDs achieve what is claimed to be world-class luminance with low energy consumption.

Toyoda Gosei has applied the blue LED crystal growth technology that it developed over many years to improve the structure of gallium nitride (GaN) crystals in the new LED light source, with flip-chip technology adopted for good heat dissipation. The headlamp LEDs can achieve high luminance of 2300lm and can be used in bi-functional systems that produce both low and high beams from a single light source.

Toyoda Gosei says that headlamps employing such LEDs can help to reduce energy consumption in electric vehicles, fuel cell vehicles and other next-generation vehicles, and are expected to come into widespread use in the future as an environmentally friendly product.

Toyoda Gosei aims to continue to develop various types of headlamp LED light sources to meet demand.

www.toyoda-gosei.com

Plessey extends portfolio with MIDION mid-power LEDs, targeting general lighting applications

UK-based lighting and sensing product and component maker Plessey has extended its LED product portfolio into a variety of mid-power LED packages.

The new MIDION range includes products with luminous efficacies up to 210lm/W, modules with zero flicker, and LED components with a color rendering index (CRI) of 90. All lumen maintenance is certified to LM-80 and offered in standard color temperatures for all general lighting applications. Available throughout the portfolio are various high CRIs, high-voltage, super-efficient, and three-step MacAdam ellipse (SCDM) as standard and single-step MacAdam ellipse (SCDM) reels available on request.

The MIDION product range augments and enhances the firm's existing LUCIAN range of high-power LED products. "Plessey has established itself as a credible European-based manufacturer of LEDs with best-in-class performance and competitive pricing," claims sales director Giuliano Cassataro. "Our new extended offering of mid-power LEDs enables us to address an even wider range of lighting applications."

The MIDION range features the ultra-small dotLED plus variants of the industry-standard 2835, 3014, 3030, 5050 and 5630 PLCC packages. The series spans colour temperatures of 2700–6500K with nominal flux levels of 20-140lm and a typical viewing angle of 120°.

www.plesseysemiconductors.com/products/mid-power-leds

Osram takes 25% stake in LiDAR firm LeddarTech

Investment strengthens Osram's position in autonomous driving sector

Osram GmbH of Munich, Germany has made an investment (in the mid double-digit million euros range) to acquire a strategic 25.1% stake in LeddarTech Inc of Québec, Canada, which was founded in 2007 and has developed patented Leddar LiDAR sensing technology integrated into semiconductors and sensor modules for self-driving cars and driver assistance systems.

LeddarTech specializes in solid-state LiDAR (light detection and ranging) systems that use infrared light to monitor the area around them. Leddar comprises what is said to be a unique combination of light-wave digital signal processing and software algorithms that enable the production of solid-state LiDARs delivering superior performance and reliability at the highly competitive price. LeddarTech's sensors are used in multiple mobility-related markets including automotive, intelligent transport systems, drones, and industrial vehicles.

The firm's optical sensing technology is reckoned to be highly complementary with Osram's semiconductor products, and the two firms already work together.

Osram's investment in LeddarTech is a response to the growing demand for LiDAR technology (an essential component in self-driving vehicles and in many other mobility-related applications), which — similarly to radar technology — detects objects and measures distances and speeds, but using infrared light.

"Osram is already the world's leading provider of sensor lights for autonomous vehicles and is experiencing steadily rising demand," says Stefan Kampmann, chief technology officer at Osram Licht AG. "We see the investment in LeddarTech as a logical step on the way to becoming the leading provider of solutions in this area," he adds.

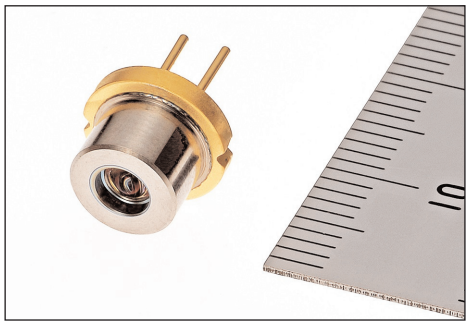
"We see a great natural fit between our two companies," says LeddarTech's CEO Charles Boulanger. "LeddarTech is on its way to becoming the reference in solid-state LiDARs for the automotive industry, and we believe our association with the market leader in automotive lighting represents an important milestone in that direction," he adds. "This investment from Osram is part of a larger financing round currently under way by LeddarTech and expected to be finalized shortly."

www.leddartech.com
www.osram-group.de

Mitsubishi Electric unveils first high-power 638nm red laser diode with built-in meniscus lens

Mitsubishi Electric Corp has unveiled the ML562H84 high-power 638nm-wavelength red laser diode (to be launched on 1 September) with what is believed to be the first built-in meniscus lens (all in a 9.0mm TO-CAN package). This collimates 98% or more of the laser beam, offering what is claimed to be industry-leading output power of 2.5W (under pulse operation), equal to that of conventional products with built-in lenses.

Conventional mercury lamp light sources for projectors are being replaced by solid-state light sources offering higher energy efficiency, a wider range of color expression and longer life. Laser diodes deliver especially high output power, low power consumption due to efficient power-conversion, an unmatched color range due to narrow spectrum, and superior picture quality with high contrast ratio.



High-power 638nm-wavelength red laser diode with build-in lens (ML562H84).

In September 2015, Mitsubishi Electric launched its ML562G84 high-power red laser diode, which achieved 2.5W output (under pulse operation) as a red light source in three colors for projectors. However, when this model incorporated in projectors, it is necessary to collimate the laser beam using an external lens (or similar) and efficiently irradiate the imaging device. The new ML562H84 high-power 638nm red laser's built-in lens collimates the laser beam and reduces spread to about 1/700th. This eliminates the need for an external collimator lens, contributing to simplification of the optical design, miniaturization and cost reduction for projector applications.

The high-luminosity 638nm laser light and 2.5W output (under pulse operation) yield 120 lumens per laser diode. Due to the large 9.0mm-diameter transistor-outline can (TO-CAN) package with excellent heat dissipation, the range for operating case temperature (T_C) is what's said to be an unmatched 0–45ºC (at 2.5W output power with a pulse duty ratio of 30%).

www.mitsubishielectric.com/semiconductors/products/opt/

Daylight completes acquisition by Leonardo DRS

US mid-IR quantum cascade laser firm acquired by defense contractor

Daylight Solutions Inc of San Diego, CA, USA — which makes molecular detection, imaging and illumination systems based on mid-infrared quantum cascade lasers (QCLs) for scientific research, life science, industrial process control and defense applications — says that its acquisition by Leonardo DRS of Arlington, VA (formerly DRS technologies, now the US subsidiary of Italy's Leonardo S.p.A) was completed on 23 June after the receipt of final regulatory approvals. Daylight signed a definitive agreement to be acquired by DRS in March, after Daylight's stockholders approved the $150m acquisition.

Daylight will operate as one of eight Leonardo DRS lines of business, and will maintain its current management and location. All three co-founders Dr Timothy Day, Paul Larson and Sam Crivello will remain with Leonardo DRS. The transaction has been devised to be essentially transparent to Daylight's existing customers and supply chain partners. All current contracts will continue to be executed without change.

Daylight was represented in the transaction by the legal firm of Morris, Manning & Martin LLP. Mooreland Partners acted as bankers for the transaction.

Daylight will operate as one of eight Leonardo DRS lines of business. The transaction has been devised to be essentially transparent to Daylight's existing customers and supply chain partners

Daylight provides laser technology for protecting aircraft against shoulder-fired, heat-seeking missiles. It also provides next-generation technology for cancer research, tissue diagnostics, and pharmaceutical process control.

Leonardo DRS supplies integrated products, services and support to military forces, intelligence agencies, and prime contractors worldwide, specializing in naval and maritime systems, ground combat mission command and network computing, global satellite communications and network infrastructure, aviation support and avionics systems, and intelligence and security solutions. DRS also builds power systems and electro-optical/infrared systems for commercial customers.

www.daylightsolutions.com
www.drs.com

US-backed consortium AIM Photonics gains Mentor as newest tier-1 member

Software provider to unify electronic and photonic design processes

The Rochester, NY-based consortium AIM Photonics (American Institute for Manufacturing Photonics), an industry-driven public–private partnership advancing the USA's photonics manufacturing capabilities, has announced electronic design automation (EDA) software provider Mentor (a Siemens Business) as its newest tier-1 member. Mentor brings its expertise in electronic photonics design automation (EPDA), a critical design technology enabler for AIM Photonics' process design kit (PDK) and multi-project wafer (MPW).

Mentor's software and hardware design solutions enable companies to develop electronic products more quickly and cost-effectively. They will help engineers in AIM Photonics and member companies overcome design challenges for increasingly complex board and chip designs, especially regarding integrated silicon photonics.

"AIM Photonics has built an integrated photonics design solution package that is second to none, mainly due to the membership of global electronic design leaders like Mentor," says AIM Photonics' CEO Dr Michael Liehr. "Their expertise in functional verification, design for test, and PCB design are a plus for our new Test, Assembly, and Packaging (TAP) facility now under construction," he adds.

"Mentor's goal in joining AIM is to unify the electronic and photonic design processes so that custom IC designers can be successful with their photonic IC designs," says Robert Hum, vice president, Deep Sub Micron Division at Mentor. "We are enhancing our Pyxis-based custom design flow to achieve this goal. The photonic design flow also includes Eldo, Questa ADMS and Calibre for verification."

Since fall 2016 AIM Photonics has released a number of versions and updates to its PDK, in support of its MPW program and third call for proposals. Mentor also recently presented on PIC design for AIM MPW at the AIM Photonics Proposer event in Rochester. Since then, numerous commercial, government and university organizations have signed up to participate in the PDK and MPW programs.

Mentor recently provided details on a new integration with PhoeniX Software B.V. of Enschede, The Netherlands (also an AIM Photonics EPDA member) that reduces tape-out time for integrated photonics designers by enabling faster iterations between final sign-off verification and the design tool. Designers using the new integration will be able to more quickly identify and correct layout issues to ensure that their designs comply with manufacturing requirements.

"The exceptional response to our PDK and MPW offerings is a testament to what Mentor brings to AIM Photonics' EPDA program," comments Brett Attaway, AIM Photonics' EPDA executive director. "The fantastic synergy between AIM's EPDA members has been instrumental in bringing new integrated photonic design solutions to the market quickly," he adds.

www.aimphotonics.com
www.mentor.com

Princeton Infrared Technologies announces first megapixel SWIR camera with no ITAR export restrictions

Princeton Infrared Technologies Inc (PIRT) of Monmouth Junction, NJ, USA — which designs and makes both shortwave-infrared cameras and one- and two-dimensional imaging arrays based on indium gallium arsenide (InGaAs) — has announced what it claims is the first megapixel shortwave-infrared (SWIR) camera with no ITAR (International Traffic Arms Regulations) export restrictions.

The newest camera in the firm's family of SWIR imaging products to fall under the no ITAR restrictions umbrella is the 1280SciCam, which has a 1280 x 1024 image sensor on a 12µm pitch, featuring long exposure times, low read noise, 14-bit digital output, and full frame rates up to 95Hz. Designed for advanced scientific and astronomy applications, the camera detects light from the visible to the SWIR (0.4–1.7µm), and is available with a variety of lens formats. PIRT's 1280SciCam and LineCam12 cameras are now classified by the Export Administration Regulations as EAR 6A003.b.4.a for export.

"After an exhaustive Commodity Jurisdiction process, which occurred at the very same time as the new US export reform rules went into place, we are thrilled to have our entire product line defined in the EAR," says president Dr Martin Ettenberg. "We are now ideally positioned to serve the scientific and astronomical communities, in addition to machine vision and spectroscopy, with our non-ITAR SWIR imaging products."

"Our 1280SciCam has already generated sales and applications with leading research entities overseas," notes sales director Bob Struthers. "An EAR export classification will propel our ability to serve these customers promptly and efficiently," he reckons.

www.princetonirtech.com

University of Twente develops record 290Hz-linewidth narrowband laser

InP–Si_3N_4 hybrid laser widely tunable over 81nm at 1550nm using LioniX's TriPleX process

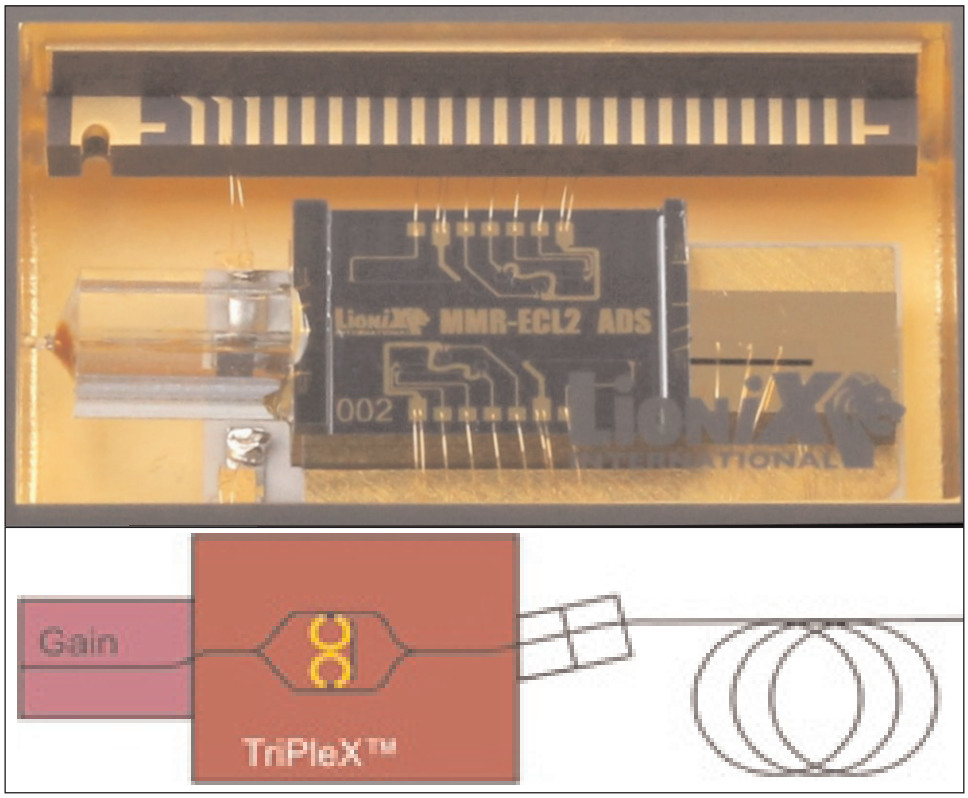
Working in collaboration with LioniX International BV of Enschede, The Netherlands, researchers at the University of Twente's MESA+ research institute have developed what is claimed to be the most narrowband diode laser on a chip, targeting applications such as 5G Internet and accurate GPS (Youwen Fan et al, '290 Hz Intrinsic Linewidth from an Integrated Optical Chip-based Widely Tunable InP-Si3N4 Hybrid Laser', Conference on Lasers and Electro-Optics (CLEO): Applications and Technology 2017, paper JTh5C.9).

We are slowly reaching the bounds of what is possible with electronics. That is why scientists and the private sector are committed to photonics — a key technology that makes numerous other innovations possible. This involves the deployment of photons (light particles) for transporting and processing data.

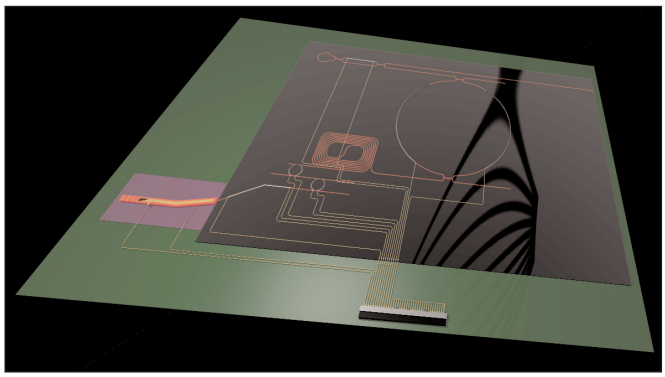
For photonic chips to function as efficiently as possible, one has to be able to properly control the light signals. This means that all the light particles being transmitted must have, as closely as possible, the same frequency - that is, the same colour. The University of Twente researchers have developed a laser on a chip with a maximum bandwidth (the maximum uncertainty of frequency) of just 290Hz, which is claimed to be by far the most accurate laser on a chip ever created. "Our signal is more than ten times more coherent — or clean — than any other laser on a chip," says lead researcher professor Klaus Boller.

The new InP-Si3N4 hybrid laser (comprising two photonic chips, optically connected to each other) is also tunable over a broad spectral range (81nm at 1550nm).

It is reckoned that the record-setting laser could bring many applications within reach, such as controlling movable antennae on phone masts for 5G mobile Internet, faster data flows through fiber-optic networks, or more accurate GPS systems and sensors for monitoring the structural integrity of buildings and bridges.



The integrated-photonics narrowband tunable laser was fabricated on a chip provided by LioniX (top). A laser-gain section is hybridly attached to a tunable reflector photonic integrated circuit (PIC), creating an external-cavity laser (bottom). The gain section creates the first mirror and the necessary gain, while the silicon nitride (Si_3N_4)-based portion (created using LioniX's TriPleX process) acts as a tunable wavelength-dependent mirror.



Three-dimensional view of hybrid laser.

The research was carried out by Youwen Fan and Klaus Boller of the Laser Physics and Nonlinear Optics department at the University of Twente MESA+ research institute, Applied Nanophotonics, in collaboration with Ruud Oldenbeuving, Chris Roeloffzen, Marcel Hoekman, Dimitri Geskus, and René Heideman at LioniX.

www.osapublishing.org/abstract.cfm?URI=CLEO_AT-2017-JTh5C.9
http://lpno.tnw.utwente.nl
www.lionix-international.com

CST Global appoints University of Glasgow's Tony Kelly as consultant on high-speed opto technology

III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK (a subsidiary of Sweden-based Sivers IMA Holding AB) has appointed Dr Tony Kelly (a photonics expert with over 200 journal and conference publications to his name) as consultant on next-generation, high-speed, opto-electronic technology.

Kelly will divide his time equally between CST and the University of Glasgow, where he remains a staff member in the School of Engineering's

Electronics and Nanoscale research division. The secondment is supported through the UK Engineering and Physical Sciences Research Council (EPSRC) Impact Acceleration Account.

"Tony is a world authority on gallium nitride and indium phosphide optical devices, with both academic and commercial experience in these areas," comments CEO Neil Martin. "He has successfully commercialized a range of technologies, critical to next-generation, high-speed applications, where CST Global is currently producing and developing new products."

Kelly began work at BT Laboratories and the Corning Research Centre. He then co-founded Kamelian Ltd and Amphotonix Ltd for the commercial production of semiconductor optical amplifiers (SOAs), raising over $30m of venture capital funding.

"Tony's appointment provides essential expertise to support CST Global's development of high-speed, laser technology," says Martin.

Real-time electronic barcode tracking of all work in progress

CST Global has introduced real-time, electronic barcode tagging for all work in progress (WIP) in its III-V optoelectronic foundry.

"Our laser production now exceeds 1 million per month, so managing production electronically is essential," says senior production engineer Meg Armstrong. "A barcode is allocated to each wafer when it is released to our production line and becomes a 'lot'. This barcode is used to track the lot, containing up to 100,000 lasers, as it progresses through the production line to finished goods. As part of our new management execution system (MES), this enables real-time, accurate tracking of WIP, SPC data (statistical process control) and inventory. It delivers enhanced traceability and visibility of lots, throughout production, as well as cycle and queue time data," she adds.

"A barcode reader instantly provides production staff with specific device-type and associated process flow information. Staff immediately know what the product is, where it is and what process comes next. This reduces errors, removes paper work and is fully compliant with our ISO 9001: 2015 quality standards. The barcode system is applied to both our own products and our out-sourced, foundry services," Armstrong continues.

"Barcoding is also a useful tool for supply chain management; improving efficiency and productivity throughout the foundry. By tracking the progress of all jobs in real-time, we can improve production planning and delivery accuracy. We also gather data relating to quality and yield, for on-going process and supplier improvement," she concludes.

Barcoding, and the electronic measurement of real-time work in progress, is essential for implementing a lean production strategy within CST Global, the firm states.

www.CSTGlobal.uk

Automatic visual inspection machine trebles laser test throughput

CST Global has introduced an automatic visual inspection machine, trebling laser throughput and increasing test accuracy.

"We do a visual inspection of all lasers," says production project engineer Colin Jackson. "Our recently introduced automatic bar stacker machine produces up to 50 2-, 3- or 4-inch wafer bars at once. The bars are held in a gel pack for inspection. At 110 lasers per bar, this is over 5000 lasers at a time," he notes. "We used to manually inspect two gel packs per 12-hour shift. Since introducing the bar stacker, this manual inspection was not fast enough. The new automatic visual inspection machine easily handles six gel packs per shift." This increases throughput from 10,000 to 30,000 lasers per shift, removing the bottleneck.

CST worked with the visual inspection machine maker Keyence and software developer Wolf to commission, develop and optimize the new visual inspection machine. "Software is used to recognize the laser ID number, recording an image of each laser for reference," says Jackson. "It removes human error, making the process auditable, repeatable and totally consistent."

"We now only need one inspector per shift, allowing us to re-deploy valuable resources elsewhere," comments Jackson. "We can track wafer batch quality, working with our key suppliers to help increase yield. Finally, we are streamlining the visual inspection process to handle yet more gel packs per shift. We expect throughputs to near 40,000 lasers per shift shortly."

PLAT4M matures three silicon photonic platforms

Commercialization of technology accelerated by linking silicon photonic ecosystem

Micro/nanotechnology R&D center CEA-Leti of Grenoble, France says that the European Union Seventh Framework Program (EU FP7) project PLAT4M (Photonic Libraries And Technology for Manufacturing) has now been completed with results that exceeded expectations.

Silicon photonics has long been expected to bring substantial breakthroughs in very-high-speed data communications, telecommunications and supercomputing. It is also one of the most promising industrial-production candidates because of its potential for large-scale and low-cost production capability in existing CMOS foundries.

The European Commission launched the 15-member PLAT4M project in 2012 to build a silicon photonics supply chain in Europe that would speed industrialization of the technology by enabling its seamless transition to commercial production.

PLAT4M's main objective was to advance existing silicon photonics research foundries and seamlessly transition to pilot-line operation and industrial manufacturing of products based on silicon photonics. The supply chain is based on three different but complementary technology platforms of Leti, STMicroelectronics and imec.

Leti platform

Leti's 8500m^2 cleanroom facility includes a 200mm pilot line that enables fabrication of passives, detectors, modulators and integrated lasers with a focus on high-bandwidth devices. The project team developed a new silicon photonic platform based on a 310nm silicon film on top of an 800nm buried oxide (BOX) on a high-resistivity silicon substrate. Since the targeted applications for the project were O-band transceivers and receivers, most of the developed devices are suitable for 1310nm operations.

CEA-LETI has developed three process design kits (PDKs) dedicated to multi-project wafers (MPW) runs on this silicon photonics technology which is now offered via the brokers CMP and Europractice. Moreover, III-V Lab has designed and co-fabricated a state-of-the-art integrated hybrid III-V/Si transmitter using a wafer-bonding technique on this platform.

STMicroelectronics platform

AS the first 300mm wafer silicon photonics device manufacturer, STMicroelectronics has been a key solution provider for 100Gbps transceiver products since 2016. In parallel to its industrial activity, during the PLAT4M project ST developed another silicon photonics technology aimed at generating and nurturing further application-specific industrial nodes. This technology platform creates an advanced photonic nanoscale environment, and combines state-of-the-art CMOS foundry tools with the flexibility necessary to support R&D efforts. Strong collaboration with research partners such as CEA-LETI and University Paris Sud have been devoted to advanced studies in power consumption management, optical excess loss reduction and higher-data-rate transmission using complex modulation formats, signal multiplexing and higher-Baud-rate devices.

CEA-LETI has developed three PDKs dedicated to MPW runs on this silicon photonics technology which is now offered via the brokers CMP and Europractice. Moreover, III-V Lab has designed and co-fabricated a state-of-the-art integrated hybrid III-V/Si transmitter using wafer-bonding

With R&D exploration that goes as far as core-to-core optical interposers, ST has also evaluated notions of device and circuit footprints toward large-scale system integration (LSI).

In the context of PLAT4M, the participants chose a 4x25G transceiver as a wavelength-division multiplexing (WDM) data-communication demonstrator to validate both LETI and ST R&D platforms. The device functionalities were evaluated for compatibility with the 100GBase-LR4 standard, implying signal transmission over four channels, spaced by 800GHz around 1310nm window, one fiber out and one fiber in.

imec platform

In the course of the PLAT4M project, nanoelectronics research centre Imec of Leuven, Belgium imec has consolidated and further developed its silicon photonics technology platform ISIPP25G using its 200mm pilot-line facilities to support industrial prototyping for various applications and markets. The imec platform component portfolio has been expanded to specific devices for sensing and high-power free-space applications. Furthermore, imec's technology is supporting state-of-the-art modulation and detection at 50Gb/s and beyond with a variety of modulator options (GeSi EAM, Si MZM, Si MRM) now offered under its ISIPP50G technology along with both edge and surface fiber-coupling technology and a library of O-band and C-band high quality passive components.

The technology is accessible through imec's PDK, which is supported by software tools from several vendors including project partner PhoeniX Software. In collaboration with Mentor (a Siemens business), imec has also explored LVS verifications to reduce design

errors and performed litho-friendly design analysis to improve the patterning predictability. Using the imec technology with new processing steps, TNO (the Netherlands Organization for Applied Scientific Research in Delft) has demonstrated a multi-channel ring-resonator-based sensor system. Polytec demonstrated the operation of a multi-channel laser Doppler vibrometer. THALES has demonstrated an integrated FMCW (frequency-modulated continuous-wave) LiDAR system with eight switchable output channels, enabling scanning of directions as well as a coherent beam combiner with 16 beams with linear operation up to a maximum input power of 26dBm. The thermal phase-shifter elements achieved a power efficiency of 10mW for a p-phase shift.

Finally, imec has demonstrated new advances in its technology such as a very-low-loss silicon waveguide technology (~0.6dB/cm for a 220nmx450nm waveguide) applying leading-edge CMOS patterning technology developed in its 300mm pilot line with immersion lithography. It has also demonstrated a further reduction of thermal phase-shifter elements down to 4mW for a p-phase shift.

Unified design environment

The PLAT4M project has led to a qualitative leap in the design flow for silicon photonics, allowing the photonics community to design more complex and more robust circuits. Mentor and PhoeniX Software have worked closely together on an integrated electronics/photonics co-design workflow. This has been accomplished by building on existing tool-sets wherever possible and developing new technologies when required.

The supply chain includes electronic design automation (EDA) solutions such as Mentor's Pyxis and Calibre, which were extended to 'understand' photonics. Interfaces were developed between these tools and photonic IC design solution OptoDesigner from PhoeniX Software to create integrated design flows using the best practices from both photonics and electronics design. In addition, PDF elements were developed for Mentor's Calibre DRC, Calibre LVS and Pyxis tools, incorporating new components, added models and fabrication information.

The consortium developed advanced technologies and tools by building a coherent design flow, demonstrating manufacturability of elementary devices and process integration, and developing a packaging toolkit

Producing a packaging toolkit

Packaging played a key role in the development of the project demonstrators. The skills and processes developed by Germany's Aifotec GmbH and Ireland's Tyndall-UCC (University College Cork) advanced the development of the silicon photonic packaging toolkit. This toolkit establishes standardized packaging processes for optical fibers, active devices, electronic components and thermo-mechanical systems to ensure that photonic integrated circuits (PICs) can be more easily packaged in a timely and cost-effective way. A design rule document was made available through EuroPractice by Tyndall and also implemented into PDKs for OptoDesigner.

"The consortium developed advanced technologies and tools by building a coherent design flow, demonstrating manufacturability of elementary devices and process integration, and developing a packaging toolkit," says PLAT4M project coordinator Jean-Marc Fedeli. "The high level of maturity of the technology offered by these platforms makes them readily accessible to a broad circle of users in a fabless model."

http://plat4m-fp7.eu
www.leti-cea.com

Emcore selected by Raytheon for Premier Supplier Excellence Award

Emcore Corp of Alhambra, CA, USA — which provides indium phosphide (InP)-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets — says that Raytheon has recognized it with a Premier Supplier Excellence Award. Premier awards are awarded to suppliers that have demonstrated premier achievement for Raytheon in Business Management, Technical, Partnership, or Affordability. Emcore has been selected to receive a Premier Award for its overall commitment to Affordability.

As part of the Raytheon Supplier Excellence Program, suppliers are awarded for their outstanding performance, contributions and support for Raytheon's programs. Emcore has worked with Raytheon in developing its advanced navigation systems based on its fiber-optic gyroscope (FOG) and inertial measurement unit (IMU) technology, which delivers performance at lower cost, with lower size, weight and power (SWaP) requirements than competing systems, it claims.

Emcore showcased its complete line of fiber-optic gyro and inertial navigation products at the 2017 Space Tech Expo in Pasadena, CA (23–25 May). It was also at the Joint Navigation Conference (JNC) hosted by the Institute of Navigation (ION) in Dayton, Ohio (6–7 June).

www.emcore.com

POET focuses on proprietary Dielectric Hybrid Platform to accelerate revenue growth

Strategic partner sought to develop and commercialize monolithic GaAs platform after manufacturability challenges delay optical engine

At its annual general meeting of shareholders (AGM), POET Technologies Inc of San Jose, CA, USA — which has developed the proprietary planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — has provided a review of its strategy, technology roadmap and product development activities.

POET's strategy is based on photonics integration (utilizing both monolithic and hybrid approaches) to lower cost and increase performance of disruptive solutions for the data communications and sensing markets, while focusing on the highest return on investment (ROI) opportunities available to the firm.

POET reckons that recent explosive growth in the market for indium phosphide (InP)-based solutions for datacoms at 100Gbps utilizing wavelength-division multiplexing (WDM) provides an opportunity for it to leverage its InP facility and production capability in Singapore, its proprietary dielectric technology, and its wafer-level packaging expertise into a new Hybrid Dielectric Photonics platform strategy.

POET has demonstrated the functionality of its proprietary dielectric waveguides for multiplexing and de-multiplexing light signals, allowing for the development of an optical engine suitable for transceivers operating at 100Gbps. Engineering samples of these devices should be delivered to customers this quarter.

POET is strategically allocating resources to capitalize on the rapidly growing InP photonics market (which is forecasted to grow to an $11bn addressable market by 2021) in order to increase ROI, accelerate time to revenue, and deliver shareholder value.

Technical challenges related to the manufacturability of the monolithic gallium arsenide (GaAs) platform have delayed POET's development of a GaAs-based optical engine. The additional development time and cost associated with the GaAs platform will require the firm to secure a strategic partner in order to develop and commercialize this platform.

POET also announced that its Narrow Linewidth Laser products have demonstrated what it claims is industry-leading performance with 'super-wide' tunability for high-resolution sensing applications such as gas & chemical sensing, coherent communication, meteorological sensing and atmospheric LIDAR. Additional developments (including the incorporation of dielectric waveguides and wafer-level packaging) are expected to accelerate growth in the sensing product line in 2018 and beyond.

www.poet-technologies.com

Director compensation

In an effort to reduce cash expenses, and following a review of peer group companies, the board of directors recently reduced the cash compensation paid to its executive chairman, and (effective 1 April) eliminated per-meeting fees and reduced the annual cash retainer paid to directors.

In the recent past, the demands on the board to address key strategic and operating challenges resulted in frequent and numerous meetings, with per-meeting fees representing a substantial portion of total director compensation.

In the newly adopted program, the executive chairman is paid US$200,000 annually, the annual cash retainer for each director is reduced to US$30,000, and each committee chairperson receives an additional annual retainer of US$10,000. The balance of director compensation is paid in stock options worth US$90,000 annually, plus US$10,000 per year of options to each committee chairperson.

Options grant

At the meeting of the board following the AGM, as part of the incentive stock option grant program, options were granted to certain directors, officers and employees to purchase up to a total of 9,225,000 common shares (about 3.55% of the outstanding shares of the company), comprising 2,225,000 for employees, 4,000,000 for management, and 3,000,000 for directors.

The options are exercisable for 10 years at a price of CAD$0.28 (US$0.22), i.e. the closing price of the shares on 12 July. The directors' options vest quarterly in arrears over the one year of service as a director until the next AGM. All other options granted to employees and management vest 25% on the first anniversary of the grant and the balance vests quarterly over a further three-year period thereafter. The grant to the directors represents the option portion of directors' fees for the 15-month period from 1 April (when the cash fees were reduced) through the next AGM.

The options were granted subject to provisions of the company's stock option plan and are subject to the TSX Venture Exchange policies and applicable securities laws.

Henning and Bett take over as directors of Fraunhofer ISE

Professor Hans-Martin Henning and Dr Andreas Bett have assumed a dual leadership role as the new directors of the Fraunhofer Institute for Solar Energy Systems ISE in Freiburg, Germany, succeeding professor Eicke R. Weber.

Both have been at Fraunhofer ISE for many years (including as division directors and deputy institute directors). The two are said to be renowned worldwide in their field and collectively hold expertise in photovoltaics, building energy technology and energy system analysis.

Henning received his doctoral degree in physics from the University of Oldenburg in 1993, and has been working at Fraunhofer ISE since 1994. In 1996 he became group leader of Thermal Systems and Components and in 2005 department head of Thermal Systems and Building Technology. Henning has served as deputy director since July 2009 and simultaneously as division director of Thermal Systems and Building Technology. Until recently he was professor of Technical Energy Systems at the Faculty for Mechanical Engineering, Karlsruhe Institute of Technology (KIT). He has been the spokesman for the Fraunhofer Energy Alliance since last December.

Bett received his doctoral degree in physics from the University of Constance, and has been working at Fraunhofer ISE since 1986. In 1993 he took over as group head of III-V Epitaxy and Solar Cells and in 2007 division director of Materials – Solar Cells and Technology. Bett has also served as deputy director since July 2009. For his research work he has received the Joseph von Fraunhofer Prize, the Becquerel Prize and the German Environmental Prize, among other distinctions.

Through their academic careers and past leader positions at Fraunhofer ISE, both Henning and Bett have already played a large role in building up and establishing the scientific standing of the institute.

Henning's focus is in building energy technology as well as the system integration of renewable energies. Recently he was in charge of developing a simulation model for complex energy systems, which involved pioneering investigations on the path for Germany's future energy supply.

Professor Hans-Martin Henning (right) and Dr Andreas Bett (left), now directors of Fraunhofer ISE.

Bett has worked for many years in concentrator photovoltaics (CPV) and has been distinguished multiple times for his work in this field. With its multi-junction solar cells for use in CPV, the 'Materials – Solar Cells and Technology' division has achieved record solar energy conversion efficiency of 46%.

Efficiency increases and system integration

Since 2009, both scientists served simultaneously as deputy institute directors and most recently as acting institute directors, organizing the R&D topics at Fraunhofer ISE within the context of energy transformation. "We will continue to make the transfer of R&D developments into industrial production our highest priority," says Bett. "This includes maintaining our lead in the international race for record solar cell efficiencies. We intend to increase our competence in combining different cell concepts, as in tandem solar cells, and thus cross over into new boundaries."

Beyond continuing dedicated research in the institute's five business areas, the system integration of renewable energy will play an increasing role in Fraunhofer ISE's research portfolio. "In the past years, we have successfully developed technologies for energy generation which convert solar radiation into electricity and heat," says Henning. "The transformation of our energy system is moving now into a new phase: A comprehensive integration of renewable energy at all system levels and within all end-use sectors is pertinent for its success. With this in mind, Fraunhofer ISE is consequently expanding its research activities to include all of the necessary technologies including digitization," he adds. "At the same time, systemic issues are gaining ever more importance." Besides system integration, these include sector coupling and related technologies, especially storage, hydrogen technologies, building energy technology, power electronics and also solar thermal energy.

Research and teaching

In a joint selection procedure between the Fraunhofer-Gesellschaft and the University of Freiburg, Henning was appointed as institute director & executive manager of Fraunhofer ISE as well as professor at the Institute of Sustainable Systems Engineering (INATECH) in the University of Freiburg's Faculty of Engineering. Bett was appointed as institute director following a selection procedure of the Fraunhofer-Gesellschaft. He will also assume teaching activities at INATECH. "The cooperation between the Faculty of Engineering at the University of Freiburg and Fraunhofer, which has greatly increased recently, is becoming yet more enriched through the teaching activities of Henning and Bett at INATECH," says professor Gunter Neuhaus, vice rector of the University of Freiburg and prorector of research.

www.ise.fraunhofer.de

Five-junction solar cell yields module efficiency of 41.2%

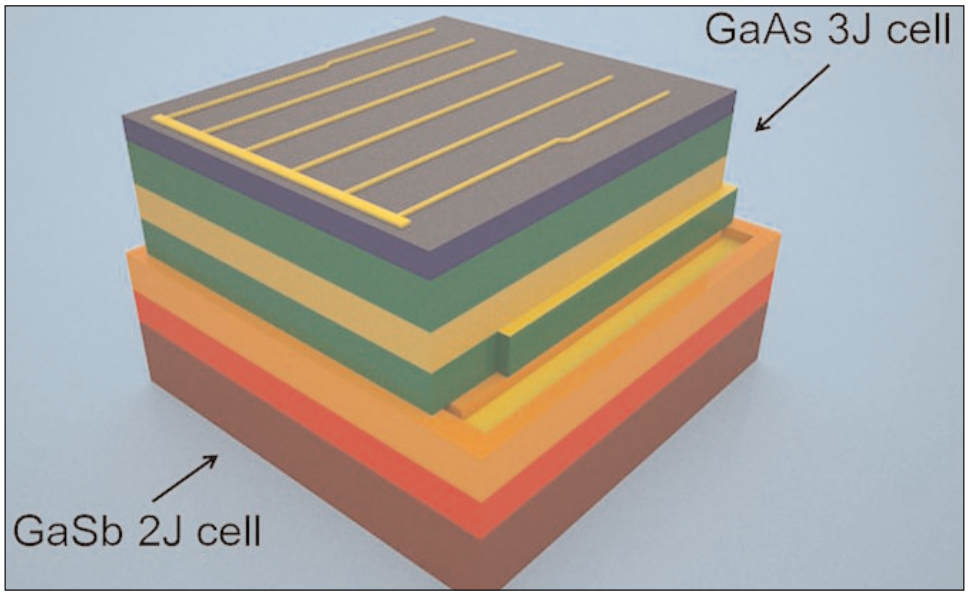
GaAs-based triple-junction cell stacked on GaSb-based dual-junction concentrator cell by transfer printing

A research team at the George Washington University, US Naval Research Laboratory, Sotera Defense Solutions of Annapolis Junction, MD, USA, Semprius Inc, Durham, NC, USA and University of Illinois Urbana-Champaign has designed and constructed a prototype solar cell that integrates multiple cells stacked into a single device capable of capturing nearly all of the energy in the solar spectrum (Matthew P. Lumb et al, 'GaSb-based Solar Cells for Full Solar Spectrum Energy Harvesting', Advanced Energy Materials (2017); doi: 10.1002/aenm.201700345). The new design has solar energy conversion efficiency of 44.5%, giving it the potential for record solar cell efficiency, it is reckoned.

The new device uses concentrator photovoltaics (CPV), employing lenses to concentrate sunlight onto micro-scale solar cells. Because of their small size — less than 1mm^2 — solar cells utilizing more sophisticated materials can be developed cost effectively.

In the stacked cell, tailored materials in each layer absorb the energy of a specific set of wavelengths. By the time the light is funneled through the stack, just under half of the available energy has been converted into electricity (compared with only a quarter for the most common solar cells currently).

"Around 99% of the power contained in direct sunlight reaching the surface of Earth falls between wavelengths of 250nm and 2500nm, but conventional materials for high-efficiency multi-junction solar cells cannot capture this entire spectral range," notes lead author Matthew Lumb, a research scientist in George Washington University's School of Engineering and Applied Science. "Our new device is able to unlock the energy stored in the long-wavelength photons, which are lost in conventional solar cells, and therefore provides a pathway to realizing the ultimate multi-junction solar cell."



The new cell is claimed to have two novel aspects. First, it uses materials based on gallium antimonide (GaSb) substrates (which are usually found in applications for infrared lasers and photodetectors). The dual-junction GaSb/InGaAsSb concentrator solar cell — which can efficiently convert the long-wavelength photons that are typically lost in a multi-junction solar cell – has had its performance optimized via a combination of modeling and experimental device development. This cell is assembled into a stacked structure along with a commercially available high-efficiency GaAs-based triple-junction solar cell grown on conventional substrates that capture shorter-wavelength photons. In addition, the mechanical stacking procedure uses the transfer-printing technique, which enables three-dimensional assembly of the devices with a high degree of precision.

The cell is assembled in a mini-module with a geometric concentration ratio of 744 suns on a two-axis tracking system and demonstrated a combined module efficiency of 41.2%, measured outdoors in Durham, NC. Taking into account the measured transmission of the optics gives an implied cell efficiency of 44.5%.

This particular four-terminal, five-junction solar cell is very expensive. However, the researchers believe it was important to show the upper limit of what is possible in terms of efficiency. Despite the existing costs of the materials involved, the technique used to create the cells shows much promise. Eventually a similar product may be brought to market, enabled by cost reductions from very high solar concentration levels and technology to recycle the expensive growth substrates, it is reckoned.

The research builds on the advances made by the MOSAIC Program, a $24m project funded by the Advanced Research Projects Agency-Energy (ARPA-E) that funds 11 separate teams across the USA, each seeking to develop technologies and concepts to revolutionize photovoltaic performance and reduce costs. The researchers note that funding for this type of research is essential for developing viable commercial technology in the future.

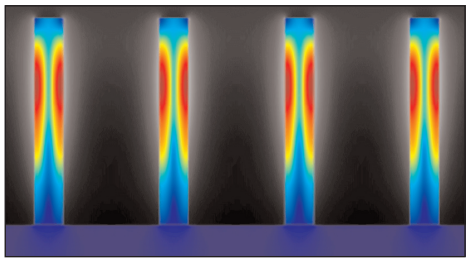
http://onlinelibrary.wiley.com/doi/10.1002/aenm.201700345/abstract

Sol Voltaics raises $21.3m to commercialize 50% efficiency-boosting GaAs nanowire PV technology

Total funding rises to $38m in last 12 months

Sol Voltaics AB of Lund, Sweden, which is developing nanomaterials technology for enhancing solar cell efficiency, has closed a record funding round of $21.3m (reckoned to be the largest finance raise for a European solar technology company since 2015). The new funding will be used to accelerate commercialization of its SolFilm efficiency-boosting technology, which promises to increase conventional solar panel efficiencies by up to 50%.

The latest funding features new investment from Norwegian firm Watrium AS, alongside previous investors Kagra Gruppen AS, Nordic VC firm Industrifonden, FAM AB, Nano Future Invest, Blue Marlin AB and Teknoinvest AS. The investment brings total funding raised to $38m in the past 12 months, following the $17m funding round in 2016.



As a patented, low-cost thin film consisting of billions of highly efficient gallium arsenide nanowires, SolFilm enables solar panel makers to reach efficiencies of up to 27% when integrated as a tandem-junction module. Having recently confirmed the manufacture of nanowires using its low-cost process Aerotaxy, Sol Voltaics is now in the final stages of technology optimization, expecting samples of SolFilm to be sent to partners by the end of 2018.

"This latest round of finance gives us the critical capital required to commercialize our efficiency-boosting technology for the solar market," says CEO Erik Smith. "Having achieved our final major technology milestone with Aerotaxy earlier this year, we are now fully focused on reaching mass production of SolFilm."

Last month Sol Voltaics enhanced its technology team by appointing Dr Stephanie Essig as senior device & characterization scientist. Essig — who previously worked with the US Department of Energy's National Renewable Energy Laboratory (NREL) and the Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg, Germany — is a solar cell world-record holder, having converted non-concentrated (1-sun) sunlight into electricity using a dual-junction III-V/silicon PV cell, reaching 29.8% one-sun efficiency.

www.solvoltaics.com

US DOE awards Stion $1m for CIGSSe PV module efficiency R&D

Interconnection technology to boost efficiency and reduce panel cost

Through the Department of Energy's SunShot Initiative Program (which aims to drive down the cost of solar electricity and support solar adoption), Stion Corp of Hattiesburg, MS, USA has been awarded a $956,630 grant and, in conjunction with Colorado State University, will investigate improvements in scribing and monolithic interconnection technology that should increase module efficiency, leading to a lower levelized cost of electricity for consumers.

Stion produces its monolithically integrated copper indium gallium sulfur selenium (CIGSSe) thin-film solar modules from start to finish at its 700,000+ square foot manufacturing and engineering center in Mississippi, supported by the firm's R&D and project teams in San Jose, CA, USA. The 150MW factory has been running for more than five years with what is described as excellent process control, and can produce 160W modules (15% STC/11.3% NOCT efficiency). Stion plans to increase existing product efficiency through funding provided by the DOE.

The grant will fund a project to develop an all-laser interconnect architecture that can be patterned in one step after cell deposition on Stion's module manufacturing line in Hattiesburg. This process could potentially increase module efficiency by 6% (relative) and lower the manufacturing cost by radically streamlining the production flow, the firm says.

Stion was selected as a part of the SunShot Initiative's Photovoltaics Research and Development 2 funding program, which seeks to transform PV module design, explore high-risk emerging technology research, and devices and designs that facilitate rapid solar installation. Projects under this program will investigate new solar technology innovations that have the potential to make solar power affordable throughout the USA.

Professor James Sites and his PV group at Colorado State University have worked with Stion on several occasions. "Our PV measurement and analysis capabilities should nicely support Stion's novel ideas for enhancing the performance of CIGS solar panels," Sites comments.

www.stion.com
www.energy.gov/sunshot

Indium gallium nitride solar cells on non-polar and semi-polar substrates

Researchers find non-polar devices have improved performance over conventional c-plane cells.

Arizona State University and University of California Santa Barbara (UCSB) in the USA have compared indium gallium nitride (InGaN) solar cells produced using non-polar, semi-polar and polar substrates [Xuanqi Huang et al, Appl. Phys. Lett., vol110, p161105, 2017]. The non-polar m-plane devices showed the best overall photovoltaic (PV) performance.

Table 1. Key device parameters for InGaN/GaN MQW solar cell devices.

	E_g (eV)	V_{oc} (V)	W_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	Peak EQE (%)	Peak IQE (%)
m-plane	2.85	2.32	0.53	0.803	55.5	39.4	61.4
(20$\bar{2}$1) plane	2.73	1.92	0.81	0.736	43.2	27.1	39.6
c-plane	2.45	0.33	. . .	0.644	29.9	21.5	25.2

InGaN solar cells should be able to convert photons of energy spanning the solar range, with InN having an energy gap of 0.7eV (infrared) and GaN 3.4eV (ultraviolet). In practice, charge polarization of the III-nitride bond leads to strong electric fields in heterostructures arising from spontaneous and strain effects. Growing III-nitride structures in non-polar or semi-polar directions can eliminate or at least reduce these fields and improve performance.

At present, InGaN solar cell demonstrations tend to be in the upper part of the 0.7–3.4eV range, limiting solar conversion efficiencies to a few percent. These high-energy photon converters could be used as top cells in ultra-high-efficiency (>50%) multi-junction solar cells for space and terrestrial concentrating (i.e. focused multi-sun power density) photovoltaics.

Solar cell structures were grown on non-polar m-plane, semi-polar (20$\bar{2}$1) and polar c-plane GaN substrates by metal-organic chemical vapor deposition (MOCVD). The layer sequence was 1μm n-GaN, 10nm n$^+$-GaN,

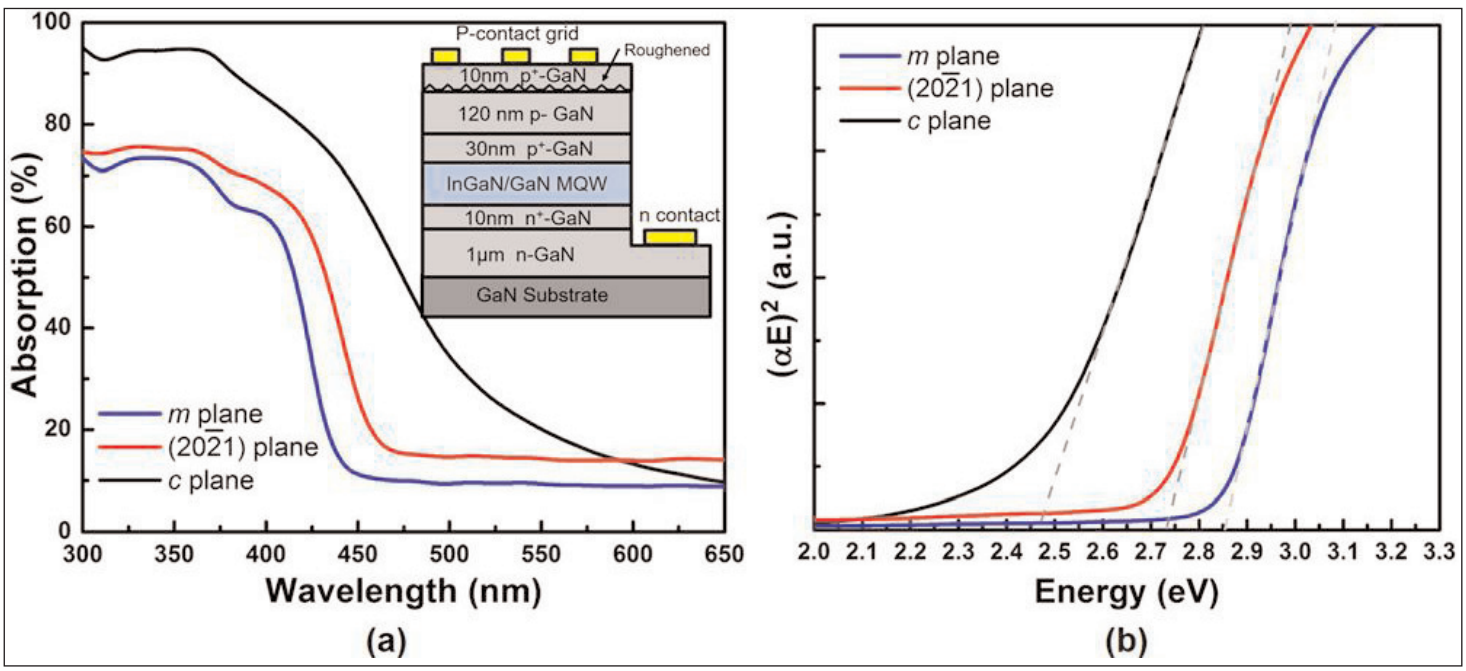
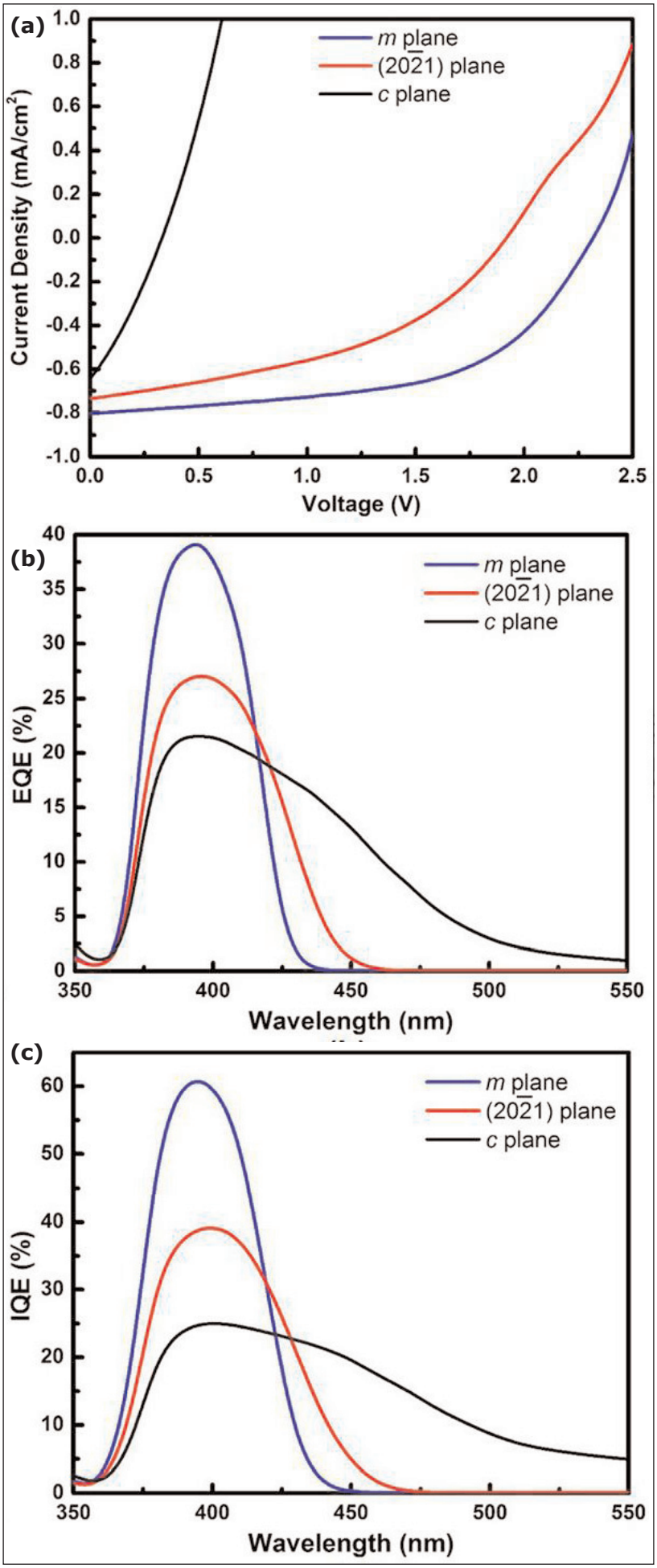


Figure 1. (a) Room-temperature transmission spectra and (b) Tauc's plots of m-plane, (20$\bar{2}$1) plane, and c-plane InGaN MQW solar cells. Inset: cross-sectional schematic of MQW InGaN solar cells.

Figure 2. (a) Illuminated J–V curves for m-plane, (20$\bar{2}$1) plane, c-plane, InGaN MQW solar cells. (b) EQE and (c) IQE curves for m-plane, (20$\bar{2}$1) plane, c-plane InGaN MQW solar cells.



20-period 6nm/10nm $In_{0.2}Ga_{0.8}N$/GaN multiple quantum well (MQW), 30nm p^+-GaN, 120nm p-GaN, and 10nm p^+-GaN. The 120nm p-GaN layer was intentionally roughened.

Devices were fabricated with 1mmx1mm mesas, titanium/aluminium/titanium/gold n-contact electrodes, and a nickel/gold p-contact grid with 200μm spacing.

Absorption spectra (Figure 1) indicated a red-shift of the bandgap energy (E_g) with increasing polarization in the sequence m-plane, semi-polar, and c-plane (Table 1). Polarization also broadens the absorption edge. Despite the higher cut-off energies, reducing polarization improves other features of solar cell performance such as open-circuit voltage (V_{oc}), bandgap-voltage offset ($W_{oc} = E_g/q - V_{oc}$, where q is electron charge), short-circuit current density (J_{sc}), fill factor (FF), and peak external quantum efficiency (EQE) and internal quantum efficiency (IQE) — see Figure 2.

The team comments: "Although the absorption spectra of c-plane solar cell are much higher than non-polar and semi-polar devices, the poor carrier collection efficiency, represented by IQE, leads to a very low J_{sc} and poor PV performance. Conversely, the non-polar m-plane and semi-polar (20$\bar{2}$1) solar cells showed higher EQE despite the lower absorption than that of the polar c-plane device, which can be attributed to improved carrier collection efficiency from reduced polarization-related effect." ■

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http://dx.doi.org/10.1063/1.4980139

Author: Mike Cooke

Toward visible & ultraviolet III-nitride lasers on silicon

Researchers study optically pumped microdisk lasers with output from 280nm deep ultraviolet to 500nm blue-green/cyan.

Researchers in France have created a range of optically pumped III-nitride microdisk lasers on silicon covering a wide range of wavelengths, from 280nm deep ultraviolet to 500nm blue-green/cyan [J. Sellés, Appl. Phys. Lett., vol109, p231101, 2016]. Two types of multiple quantum well (MQW) structure were produced: gallium nitride (GaN) wells with aluminium nitride (AlN) barriers (deep UV), and indium gallium nitride (InGaN) with gallium nitride barriers (violet and blue-green).

The non-alloyed GaN/AlN structures avoid spectral broadening from alloy disorder, compared with more usual AlGaN-based samples. Further, "low interface roughness limits the impact of monolayer fluctuations on the QW transition energy," according to the team.

The team from Laboratoire Charles Coulomb, Centre de Nanosciences et de Nanotechnologies, Centre de Recherche pour l'Hetero-Epitaxie et ses Applications, Université Grenoble Alpes, and Institut Nanosciences et Cryogénie (INAC), see their work as complementary to the development of infrared integrated photonics for telecommunications. In the case of visible-UV devices, potential applications include bio-chemical analysis and on-chip optical interconnects.

The researchers add: "The broad tunability paves the way to the development of a UV-visible integrated photonic platform embedding microlasers, possibly addressing multiple wavelengths. A further step will deal with the electrical injection, following the recent progresses in electrically injected InGaN lasers on Si-substrates."

Ammonia molecular beam epitaxy (MBE) was used on (111)-oriented silicon to produce a range of GaN/AlN and InGaN/GaN structures (Table 1). All the structures

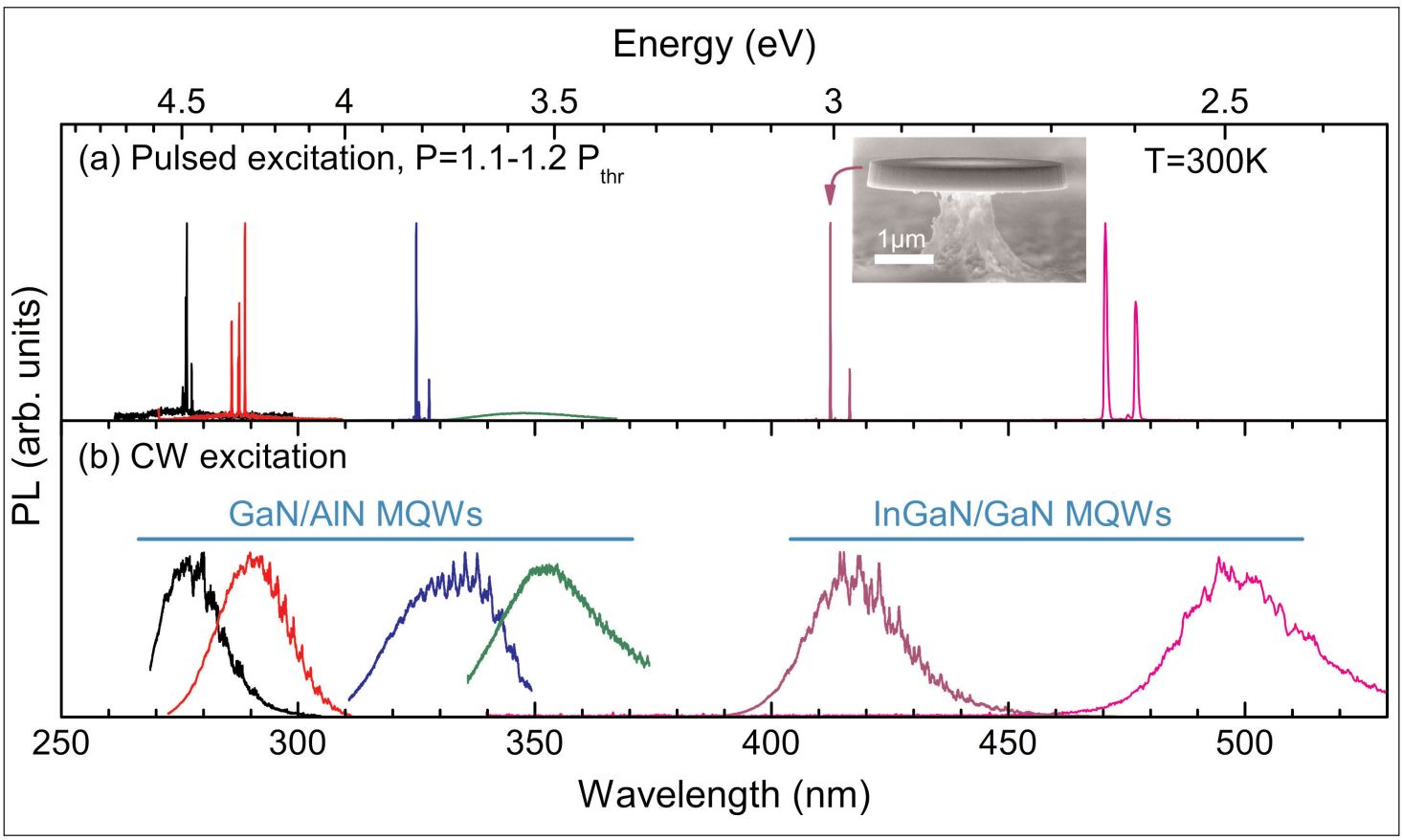

Figure 1. Photoluminescence spectra of six microdisk samples (from left to right, GaN-1 to GaN-4, InGaN-1, InGaN-2); (a) microlaser spectrum above threshold, under pulsed optical pumping; (b) microdisk spectrum in linear regime, under CW excitation. Inset: electron micrograph of 4μm microdisk from InGaN-1 series.

Table 1. Sample active layers.

Sample	Well/barrier materials	Well thickness (nm)	Number	CW wavelength (nm)
GaN-1	GaN/AlN	0.7	20	280
GaN-2	GaN/AlN	0.7	10	290
GaN-3	GaN/AlN	1.2	10	330
GaN-4	GaN/AlN	1.8	10	350
InGaN-1	$In_{0.12}Ga_{0.88}N$/GaN	2.2	10	417
InGaN-2	$In_{0.2}Ga_{0.8}N$/GaN	2.2	10	500

Table 2. Microdisk geometries and microlaser characteristics.

		Resonator		Laser	
Sample	Diameter (μm)	Thickness (nm)	Q	Threshold (mJ-cm^2 per pulse)	Wavelength (nm)
GaN-1	3	220	4000	15	275
GaN-2	6	160	2000	27	290
GaN-3	6	160	2000	35	330
GaN-4	6	160	>1000		
InGaN-1	4	515	2500	3	412
InGaN-2	5	1300	2500	3	47

were grown on an AlN buffer. The InGaN/GaN structures also included a GaN buffer on top of the AlN. In the InGaN-2 sample, the GaN buffer was silicon-doped to encourage electron injection into the MQW active region.

Microdisks were patterned and dry etched before selective under-etch of the substrate to create microdisks (3μm to 12μm diameter) on silicon pedestals (Figure 1). The output was derived from optical pumping with 266nm-wavelength laser light with continuous wave (CW) or pulsed (400ps, 4kHz) operation. The longest-wavelength GaN-4 device was unable to achieve lasing — the researchers attribute this to the quantum-confined Stark effect (QCSE), where electric fields from charge polarization of the III-nitride bonds inhibit electron-hole recombination into photons. GaN-4 contains the thickest wells, compared to the other devices.

The laser threshold was an order of magnitude smaller for the InGaN/GaN devices, compared with GaN/AlN microdisks (Table 2). "This can be interpreted as the difference between resonant and non-resonant excitation," the researchers write. "Indeed, the laser energy is below the AlN bandgap and above the GaN bandgap. The 266nm laser pumps the excited states of the GaN/AlN QW, and the 10 QWs can only absorb part of it. On the contrary, the entire pulse energy is absorbed by the GaN barrier in the case of InGaN QWs, leading to a larger carrier density per QW if we assume that all carriers are transferred from the barrier to the well." ■

http://dx.doi.org/10.1063/1.4971357

Author: Mike Cooke

Gallium nitride fin transistor with high linearity and output power

Researchers see significant advantages of the tri-gate configuration over planar devices for microwave power applications.

Nanjing Electronic Devices Institute in China has used fin structures to improve the linearity of aluminium gallium nitride/gallium nitride (AlGaN/GaN) high-electron-mobility transistors (HEMTs) [Kai Zhang et al, IEEE Electron Device Letters, vol38, issue 5, pp615–618]. The team comments: "To the best of our knowledge, this is the first demonstration of superior power performance of high-linearity GaN finFETs, indicating significant advantages of tri-gate configuration over planar HEMTs for microwave power applications."

Fin structures allow better electrostatic control of channel conduction by transistor gates, reducing the negative short-channel effects of the scaled gate-lengths needed for high-frequency operation. Linearity in radio frequency (RF) operation is also highly desired for mobile communication platforms.

An AlGaN/GaN epitaxial structure — a 16nm $Al_{0.3}Ga_{0.7}N$ barrier, a 1nm AlN spacer, and a 1.5μm GaN buffer — was grown on silicon carbide (SiC), giving a two-dimensional electron gas with $1.06x10^{13}/cm^2$ carrier density of $2170cm^2/V$-s mobility, according to Hall measurements.

Device fabrication began with alloyed titanium/aluminium/nickel/gold ohmic contact formation, argon ion implant for electrical isolation, and plasma-enhanced chemical vapor deposition (PECVD) of 100nm silicon nitride passivation.

A gate opening with 180nm gate-length footprint was made in the silicon nitride before 800nm-long nanowire patterns were etch down 30nm to completely remove the AlGaN/GaN channels between the wires. The fin width was 152nm. The period of the fin structures was 400nm.

The 0.9μm field-plate gate electrode was formed from nickel/gold. A further 250nm silicon nitride passivation layer was deposited, followed by gold air-bridge interconnections. The T-gate overhang was 0.36μm in both directions. The source–drain distance was 4.0μm.

The gate width and pitch were 2x125μm (250μm

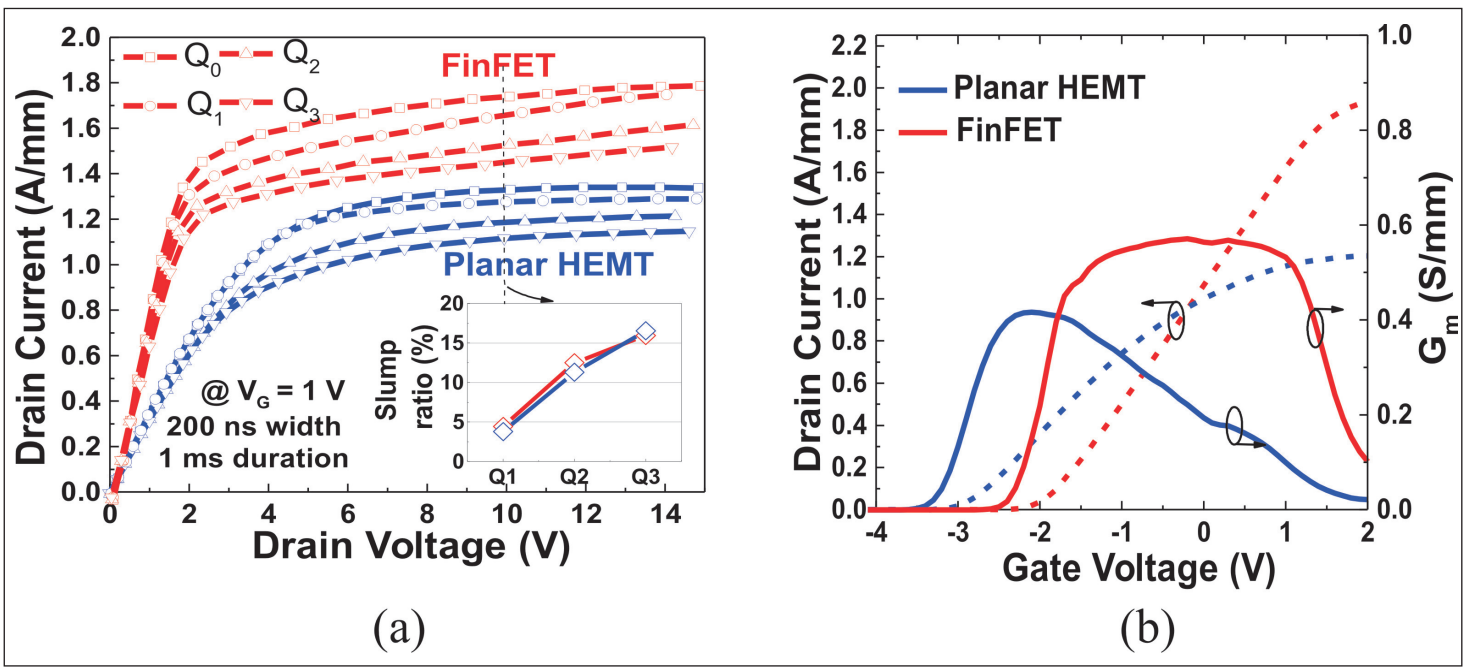

Figure 1. (a) Current dispersion and (b) DC transfer characteristics of planar HEMT and finFET measured at 10V drain bias.

total) and 20μm, respectively. The number of fins in the field-effect transistor (FET) was 625 (250μm/400nm). The effective gate width was 95μm (625x152nm).

The maximum DC current density at 1V gate potential was 1.64A/mm, which was 1.45x that of a comparison planar HEMT. With 14V drain bias, planar HEMTs suffered from a 21% drop in current compared with pulsed operation, suggesting performance degradation due to severe self-heating. The drop at the same bias for the finFETs was 9%. "This remarkable improvement could be attributed to reduced thermal resistance in finFETs stemming from additional lateral heat spreading of sidewall gates," the team comments.

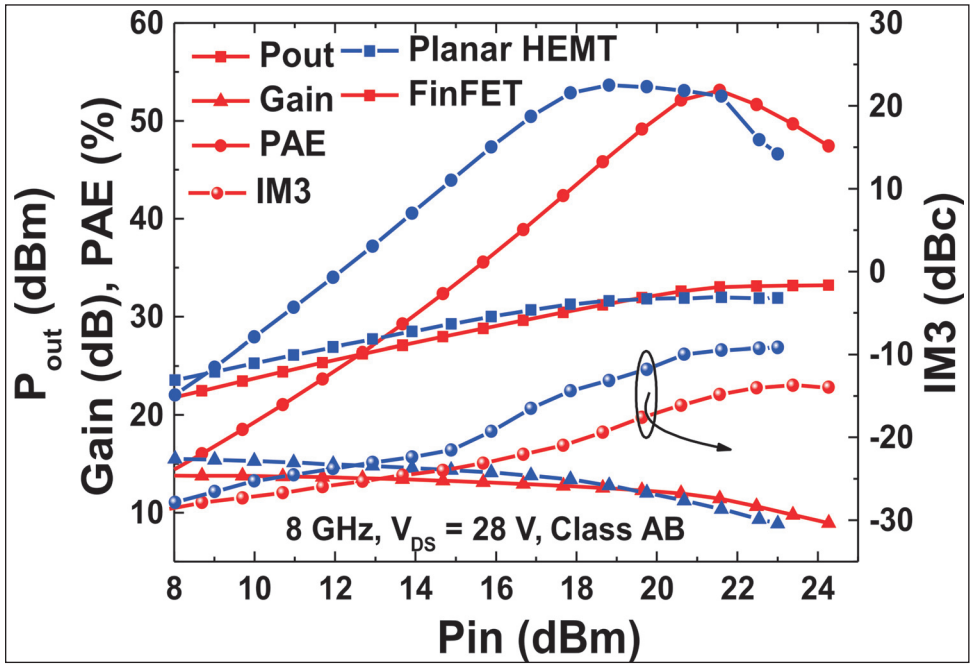

Figure 2. Two-tone power linearity characteristics of finFET and planar HEMT.

Current collapse measurements using different quiescent/off states showed similar performance effects from charge trapping for fin and planar HEMTs.

Another effect of the fins is a positive shift in threshold of about 1V due to depletion effects on the fin sidewalls (Figure 1). Also, the transconductance (G_m) is near the maximum over a broader range than for planar HEMTs. Further, the finFET transconductance peak is higher than that of the planar device.

Gate leakage through the sidewalls of the finFET does impact on/off current ratio somewhat. The drain-induced barrier lowering (DIBL) was improved (35mV/V) over that of the planar device (68mV/V). The subthreshold swings (SSs) were similar. Improved off current, DIBL and SS could come from an optimized etching process, forming a steep fin shape, the team believes.

Small-signal radio frequency measurement resulted, respectively, in peak cut-off (f_T) and maximum oscillation (f_{max}) frequencies of 31GHz and 78GHz for the finFET, and 45GHz and 92GHz for the planar HEMT.

The researchers comment: "As a result of incorporation of T-gate structure, the balanced f_T/f_{max} values are achieved, indicating the proposed finFET with high-linearity G_m characteristics is suitable for microwave power applications. The relative lower frequency performance in finFET is mainly caused by additional parasitic capacitance originating from etched GaN region and sidewall gates."

In 8GHz two-tone load-pull testing, the output power reached 11.3W/mm for the finFET, while the planar HEMT produced 6.8W/mm (Figure 2). The drain bias was 28V and the quiescent current was 10% of the maximum. While both devices had a similar power-added efficiency (PAE) of ~53%, the finFET showed improved linearity, with ~5.5dBc (decibels relative to carrier) less third-order intermodulation (IM3) distortion.

The researchers believe that scaling down the gate length would allow access to higher-frequency performance. ■

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Author: Mike Cooke

Fluorinated graphene passivation for AlGaN transistors

Technique improves performance under direct current and pulsed operation, reducing current collapse.

Shanghai Institute of Microsystem and Information Technology and Shanghai Normal University in China have used fluorinated graphene (FG) to improve the performance of aluminium gallium nitride (AlGaN) metal-insulator-semiconductor high-electron-mobility transistors (MIS-HEMTs) [Lingyan Shen et al, IEEE Electron Device Letters, vol38, issue 5, pp596–599]. The FG was inserted as passivation between the epitaxial semiconductor and the gate-insulator dielectric. The researchers claim that their work is the first use of FG for passivation of AlGaN/GaN HEMTs.

The performance was improved both in terms of DC testing but also under pulsed conditions, where current collapse is a continuing problem for III-nitride transistors. III-nitride devices are being developed for power and microwave applications.

The HEMT material was grown on sapphire with a layer sequence of 3.9μm carbon-doped GaN buffer, 300nm GaN channel, 1nm AlN spacer, 20nm AlGaN barrier, and 2nm GaN cap.

Device fabrication consisted of a 400nm mesa etch, annealed titanium/aluminium/nickel/gold ohmic contacts, graphene transfer and fluoridation, 14nm of atomic layer deposition (ALD) aluminium oxide, 200nm plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide, and annealed nickel/gold gate formation

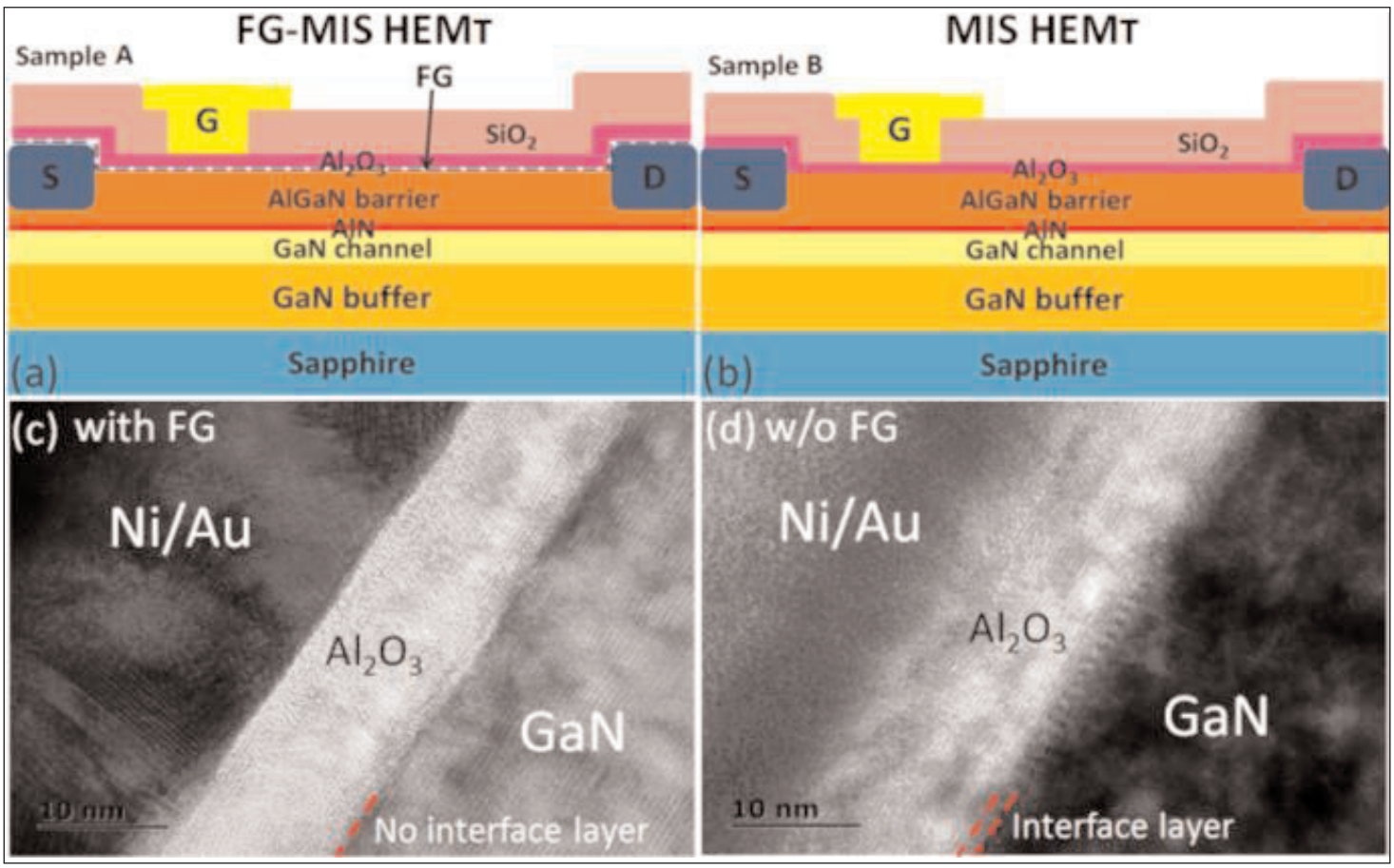

Figure 1. Schematic cross sections of (a) FG-MIS HEMT and (b) traditional MIS HEMT. HRTEM image in gate region of (c) FG-MIS HEMT and (d) traditional MIS HEMT.

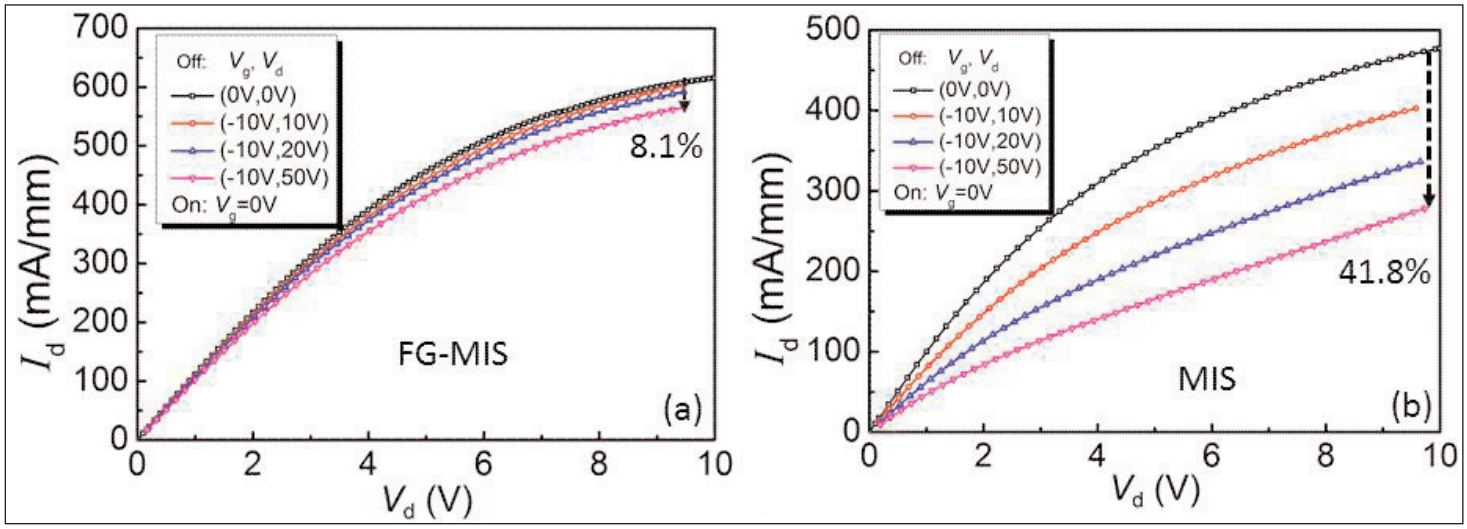

Figure 2. Output characteristics of (a) FG-MIS HEMT and (b) MIS HEMT with various off-state bias conditions, measured at 0V gate potential.

on the aluminium oxide dielectric.

The graphene was grown by chemical vapor deposition (CVD) on copper foil. The graphene was then separated by electrochemical delamination and transferred to the HEMT. Fluoridation was achieved by exposure to sulfur hexafluoride plasma.

The HEMT parameters were 3μm gate length, 15μm gate-to-drain spacing, and 3μm gate-to-source spacing.

The fluorinated graphene increased the peak transconductance by 14%, compared with a conventional MIS-HEMT. The threshold voltage of the FG devices was also 0.6V more positive (see Table 1). However, the threshold was still negative, meaning that at 0V gate potential the device was 'on' — i.e. 'normally-on'. Another improvement in the FG device was two-orders reduced leakage current in the 'of' state (as low as 10^{-8}mA/mm).

Table 1. Extracted parameters from DC characteristics.

Parameter	Unit	FG-MIS	MIS
Threshold	V	−6.7	−7.3
Peak transconductance	mS/mm	44.6	39.0
On-resistance	Ω-mm	7.40	9.44
Saturation drain current	mA/mm	618	460
Off current leakage	mA/mm	~10^{-8}	~10^{-6}
Gate leakage	mA/mm	~10^{-6}	~10^{-4}

The researchers attribute the improved performance to a clear and sharp interface between the GaN cap and aluminium oxide gate dielectric in the FG MIS-HEMTs, as revealed by high-resolution transmission electron microscopy (HRTEM). The interface in the conventional MIS-HEMT without FG was blurred with a 2nm transition region.

The researchers attribute the improved performance to a clear and sharp interface between the GaN cap and aluminium oxide gate dielectric in the fluorinated graphene MIS-HEMTs, as revealed by high-resolution transmission electron microscopy. The interface in the conventional MIS-HEMT without fluorinated graphene was blurred with a 2nm transition region

Capacitance–voltage analysis found that interface fixed charges were reduced to 2.5x10^{11}/cm^2 from 1.0x10^{12}/cm^2 by the use of FG. The researchers see the fixed charges as being related to the ability of nitrogen and oxygen to exchange between the GaN and aluminium oxide layers when there is no FG barrier.

Fixed charges adversely impact channel mobility and are a factor in current collapse under pulsed operation (Figure 2). The off state was for a −10V gate potential and the on state was 0V. The off-state stress was varied up to a 50V drain bias. The devices were toggled on and off at 20-second intervals.

The on-state current with 10V drain bias was reduced by 41.8% with a 50V off-state stress in the conventional MIS-HEMT. The effect was reduced to 8.1% with the FG device. The researchers see the fixed interface charge of the non-FG transistor as trapping electrons that act as a 'dummy gate' and are slow to be released when the device is turned on.

The FG MIS-HEMT turned on faster than the conventional device and the on-state current was only slightly impacted by off-state drain bias as it increased to 100V. In addition to slower turn-on, the conventional MIS-HEMT saw a reduction of more than 2x in current as the off-state drain bias increased from 10V to 100V. ■

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Author: Mike Cooke

Optimizing trench profiles for power gallium nitride electronic devices

Tetramethylammonium hydroxide wet etch has been used to round corners and repair sidewalls, lowering surface fields in structures.

Researchers in the USA and Singapore have been seeking to optimize electric fields in trench-based gallium nitride (GaN) power electronic devices with vertical architectures [Yuhao Zhang et al, Appl. Phys. Lett., vol110, p193506, 2017].

The vertical structure should push peak fields deep inside the GaN material, avoiding premature breakdown through surface effects. A number of groups have reported trench-based devices including Schottky rectifiers, fin field-effect transistors (FETs), metal-oxide-semiconductor field-effect transistors (MOSFETs, and current-aperture vertical electron transistors.

The team from Massachusetts Institute of Technology (MIT) in the USA, Singapore–MIT Alliance for Research and Technology, and IQE RF LLC in the USA comments: "Among the demonstrated vertical GaN power devices, trench-based structures have achieved the best performance for advanced Schottky rectifiers and power transistors."

However, electric (E) fields crowd around sharp corners, leading to premature breakdown. The dry etch techniques used to create trenches tend to result in such sharp corners and rough sidewalls that encourage unwanted current leakage. Although heating the structure can round off trenches and smooth sidewalls, such annealing degrades material quality. Another approach is a second etch using wet solutions, which is slower but can also smooth rough sidewalls.

The researchers etched wafers with n^--GaN layers on 2-inch silicon or n^+-GaN substrates. The trench process was developed using samples on silicon, while trench-based devices were produced on free-standing GaN.

The dry etch part consisted of boron trichloride (BCl_3) and chlorine (Cl_2) inductively couple plasma processing through nickel hard masks, giving trenches of the order 2μm wide and deep. "Compared with conventional oxide masks, the use of a metal hard mask allows for a much smoother etch sidewall, due to the lack of oxide edge erosion under high ion energies," the team writes.

Corner rounding and etch-damage repair was achieved using tetramethylammonium hydroxide (TMAH) wet etching and piranha clean. The 70-minute 85°C TMAH etch was anisotropic, preferring to eat the

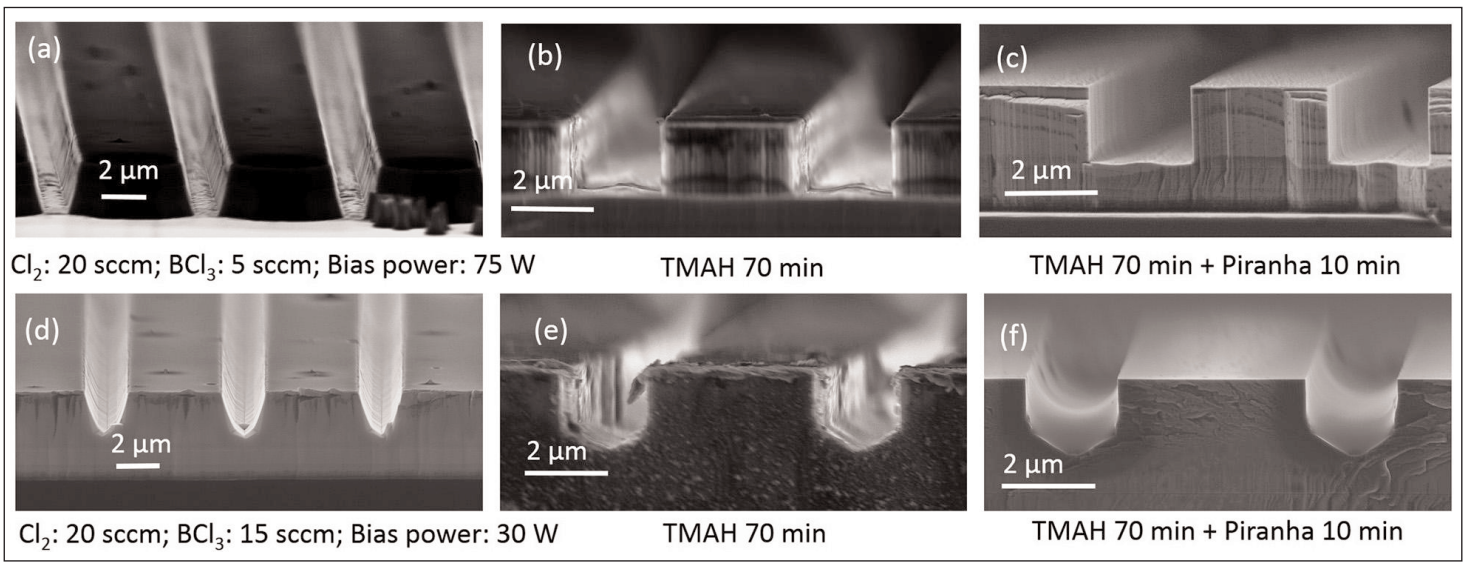

Figure 1. Cross-sectional scanning electron micrographs of trench structures right after dry etching, with following TMAH wet etching, and additional piranha clean, for two different conditions of initial dry etching.

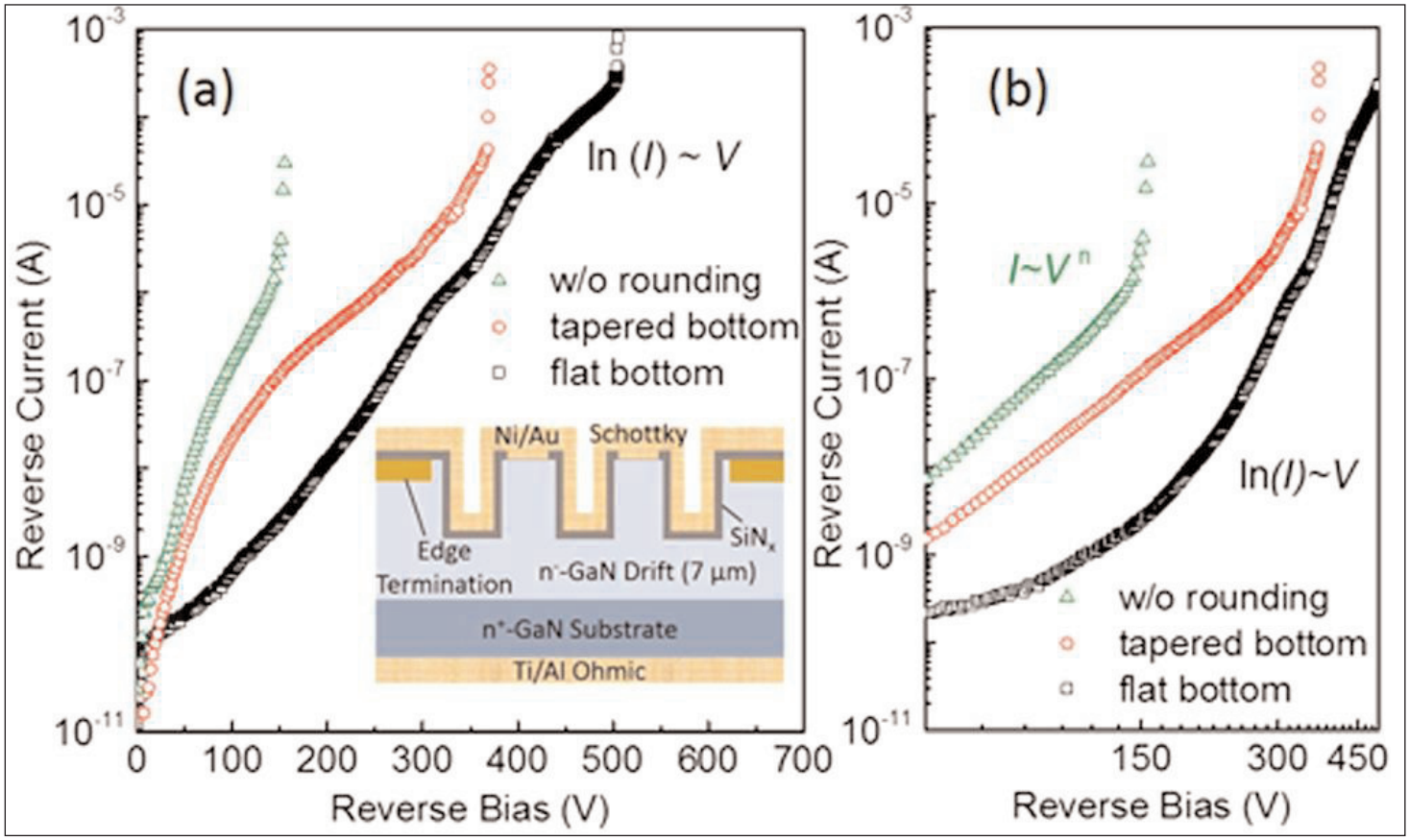

Figure 2. (a) Reverse I–V characteristics of TMBS rectifiers with non-rounded trenches, rounded flat-bottom trenches and rounded tapered-bottom trenches, in semi-log plot. Inset: schematic structure of fabricated GaN TMBS rectifiers. (b) Reverse I–V characteristics in log-log plot.

sidewalls. The researchers found only slight differences in smoothness (~20nm) for trenches aligned to different crystal orientations subjected to TMAH treatment. The 10-minute piranha clean removed nickel mask residues.

The dry etch could also be adjusted to provide either flat-bottom or tapered-angled-bottom trenches (Figure 1). The researchers explain: "A less anisotropic dry etching could enhance the lateral etching, reduce the tapered angle of dry etching sidewalls, and produce a tapered trench bottom after the TMAH wet etching. In the Cl_2/BCl_3-based ICP etching, the less anisotropic etching can be realized by either reducing the bias power or increasing the BCl_3/Cl_2 ratio."

Dry etch with lower bias power and higher BCl_3 flow rate produced a pointed trench bottom that became rounded after wet etch treatment.

Trench metal-insulator-semiconductor barrier Schottky (TMBS) rectifiers were produced with various trench profiles: unrounded, rounded with tapered bottom, and rounded with flat bottom (Figure 1). After etching, the structure was coated with 250nm of plasma-enhanced chemical vapor deposition (PECVD) silicon nitride. The top Schottky contacts consisted of nickel/gold. The backside contact was titanium/aluminium, giving an ohmic contact.

Without rounded trench corners, the device suffered from reverse-bias leakage and breakdown at only −150V (Figure 2). The researchers attribute the leakage mainly to trap-assisted space charge limited current: "The dominant traps are probably located at the etching sidewalls and their interfaces with dielectrics."

The structure with flat-bottom rounded-corner trenches gave the lowest reverse-bias leakage current and highest breakdown at −500V. The leakage is attributed mainly to variable-range-hopping through dislocations. The team comments; "This indicates that, in the TMBS rectifiers with rounded flat-bottom trenches, the leakage current is mostly determined by the peak E-field in bulk GaN rather than dielectrics or dielectrics/GaN interfaces."

The rounded tapered-bottom rectifiers came between the leakage and breakdown (−350V) performance of the previous two devices. The leakage is attributed mainly to a combination of the dominant factors affecting the unrounded and the flat-bottom devices.

The researchers foresee that, by using the optimized trench, further current-blocking improvement could come from "enhancement of dielectric quality, insertion of implanted field rings near the trench bottoms, or introduction of carbon-doped GaN/p-GaN hybrid blocking layers." ■

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Author: Mike Cooke

Building up vertical GaN for high-power technology

Devices where currents flow through the substrate material could change the location of peak fields in high-power devices. Mike Cooke reports on research to enable vertical high-power diodes.

Gallium nitride (GaN) has been developed for some time for high-power and high-frequency electronics beyond its original core applications of light-emitting diodes and laser diodes. Electronic devices on gallium nitride have mainly been restricted to lateral structures where charge flow is restricted to one side of the chip. This can be due to the non-conductive nature of the substrate, particularly where sapphire is used.

Recently more research has focused on vertical devices, where current flows from the top surface layers through the substrate to a contact on the back-side. The vertical structure allows simultaneous high current and high voltage with reduced on-resistance and less performance degradation from surface and interface states, compared with more conventional lateral devices.

Progress to vertical technology has been enable by the fast development of free-standing and bulk GaN substrates with low threading dislocation density. Such substrates are more expensive than conventional sapphire, silicon or silicon carbide (SiC) wafers. However, if the performance can be enhanced sufficiently, this may balance the increased (but hopefully falling) substrate cost.

High material quality is needed to avoid premature breakdown through defects in power electronics. Defect densities of GaN on sapphire or on SiC tend to be more than $10^9/cm^2$. Using free-standing/bulk substrates can reduce the density to around $10^6/cm^2$.

Here we look at some recent research focused on using p-n and Schottky diodes as test vehicles.

High-voltage regrowth

Researchers in the USA have been studying the regrowth of GaN on bulk GaN substrates, claiming the highest breakdown voltage so far for regrown vertical GaN p–n diodes [Zongyang Hu et al, IEEE Electron Device Letters, vol38, p1071, 2017]. "This is the first high-voltage vertical regrown p–n junction ever reported in the GaN system," according to the team from Cornell University, University of Notre Dame, and IQE RF LLC in the USA.

The power performance is comparable to diodes produced without regrowth ('as-grown') on sapphire substrates, the researchers report. They add: "This work serves as an important step towards understanding the conduction mechanism in regrown junctions and improving selective doping technique for high-performance vertical GaN switches."

Selective doping is needed for current apertures formed from lateral p–n junctions or for embedded p–n junctions in vertical switches.

The n-type part of the device was grown by metal-organic chemical vapor deposition (MOCVD) in the form of an 8μm GaN layer with ~$2x10^{16}/cm^3$ silicon doping on commercial bulk GaN. The surface was then cleaned with hydrochloric acid before molecular beam epitaxy (MBE) of 400nm ~$10^{18}/cm^3$ magnesium-doped p-GaN and a 20nm p^{++}-GaN cap.

MOCVD has problems in regrowth such as high leakage in non-planar structures and strong dependence of impurity incorporation on crystal orientation. There are also problems with forming sharp boundaries between p-type and n-type material due to the magnesium memory/diffusion effect. Further, the presence of hydrogen in MOCVD passivates the effectiveness of magnesium doping in creating p-type conduction.

The fabricated diode was a bevel structure etched down to the n-GaN (Figure 1). The anode was palladium/gold and the cathode was titanium/gold. The device was passivated with spin-on glass (SOG). Edge-termination was achieved with an anode field plate that extended outside the mesa edge.

Capacitance-voltage measurements suggested a reduced built-in voltage of the p–n junction (~2.2V), compared with 'as-grown' junctions (~3.2V). The researchers tentatively attribute the reduction to band-bending, arising from increased defect density.

The regrown diode further suffered from higher leakage before, and lower output current after, turn-on at more than 3.2V. Reverse-bias leakage in the regrown diode was below the measurement capability of the test equipment for voltages less than 1V, giving an on/off current ratio of 11 orders of magnitude. The ideality factor was greater than 2 at all bias voltages.

The 300–600nm emission from electroluminescence was 30 times lower than for as-grown devices. "This is another direct evidence that the regrown interface

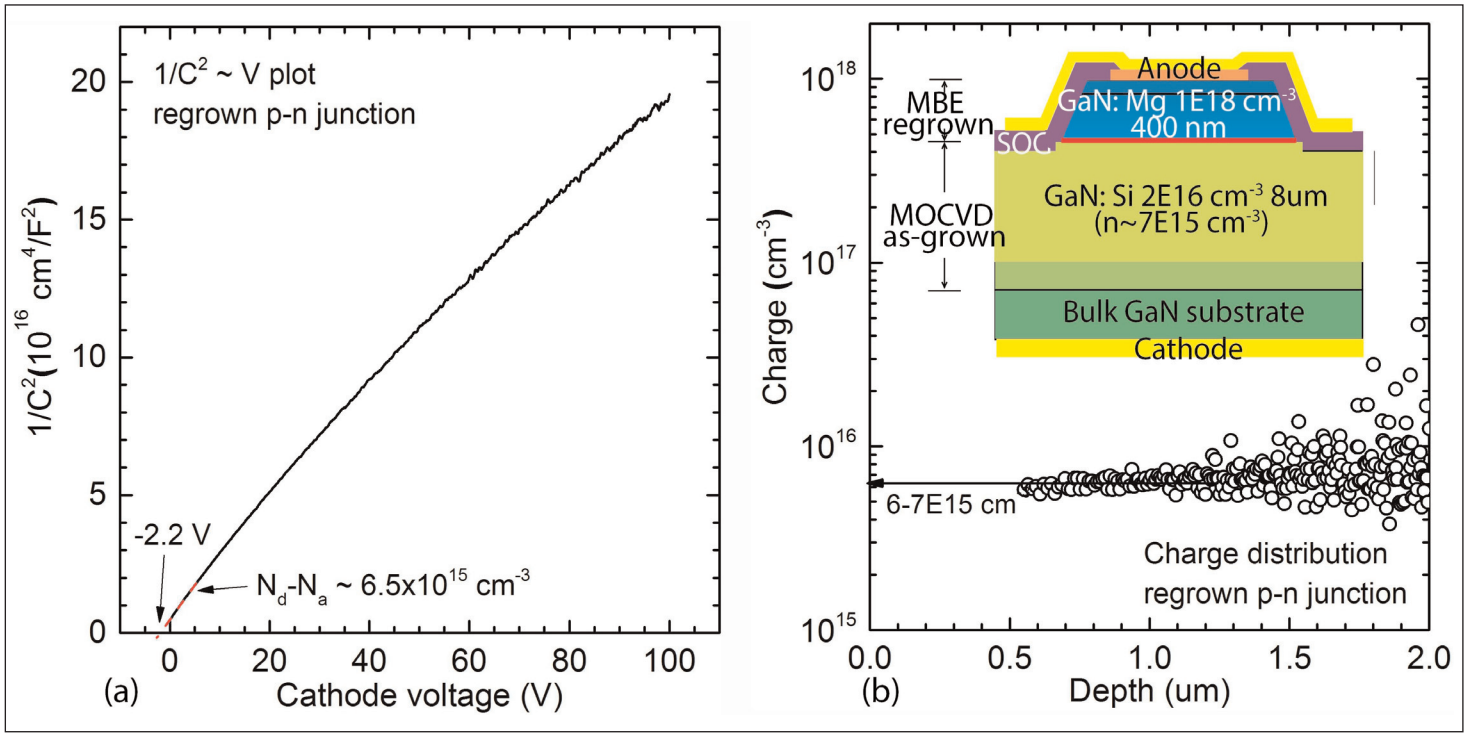

Figure 1. (a) Inverse-square capacitance ($1/C^2$) as function of reverse voltage measured on regrown GaN p–n diodes and (b) extracted net doping concentration in n-GaN drift layer. Inset: schematic cross section of completed device.

contains much more non-radiative recombination centers than the bulk material," the researchers comment.

The researchers also note that the differential on-resistance (R_{on}) increased with temperature from 25ºC to 125ºC. "This trend suggests that the dominant component of R_{on} in the regrown diode is the n-layer resistance (ρ_n), since electron mobility in the lightly doped n-GaN with low dislocation densities is significantly limited by phonon scattering, thus decreasing with increasing temperature," they write.

At 800A/cm^2 current density, the R_{on} was ~3.9mW-cm^2 for regrown diodes and ~0.6mW-cm^2 for as-grown.

The maximum reverse-bias breakdown of the regrown diodes was 1136V for a 107μm-diameter device. The leakage before breakdown was 0.1A/cm^2. "Most breakdown events were destructive and no avalanche breakdown behavior could be measured, unlike in the as-grown p–n diodes," the team reports.

Study of the current–voltage behavior suggests that Frenkel–Poole field-assisted thermionic emission was the dominant leakage mechanism below 160V reverse bias. This changed to variable range hopping in the depletion region as breakdown approached, it is thought.

Comparing the breakdown voltage (BV) and 800A/cm^2 R_{on} (Figure 2) through the ratio BV^2/R_{on} gives 0.33GW/cm^2 for the regrown diode and 4.1GW/cm^2 for the as-grown device.

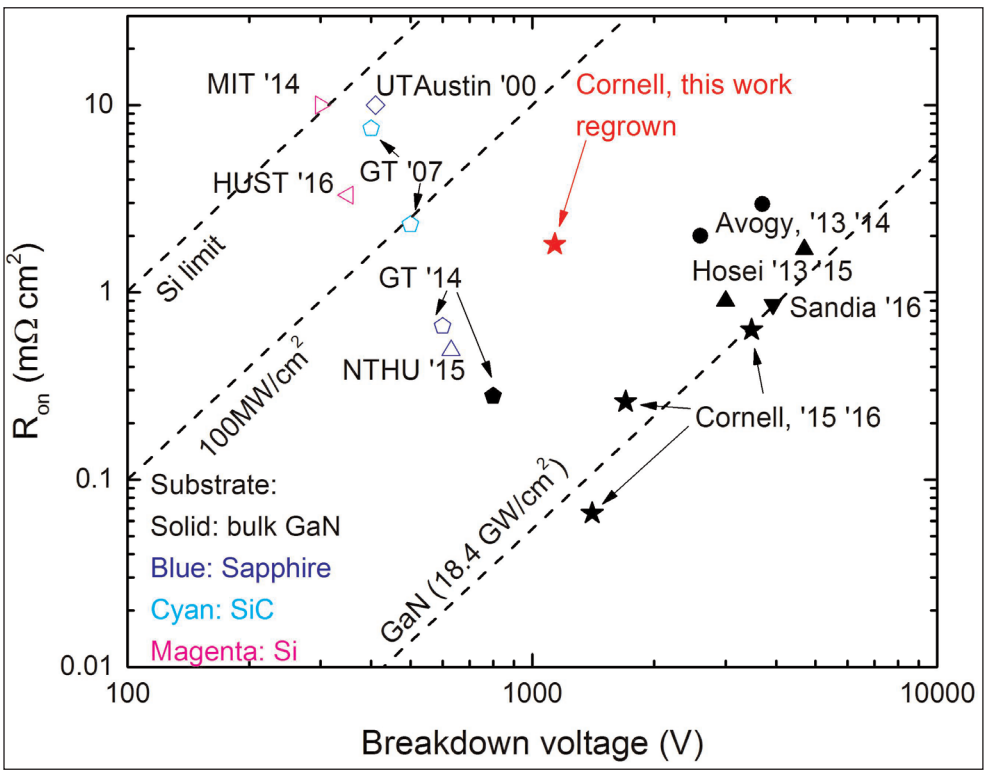

Figure 2. On-resistance versus breakdown voltage benchmark plot of state-of-the-art high-voltage GaN p–n diodes on GaN, SiC, sapphire and silicon substrates.

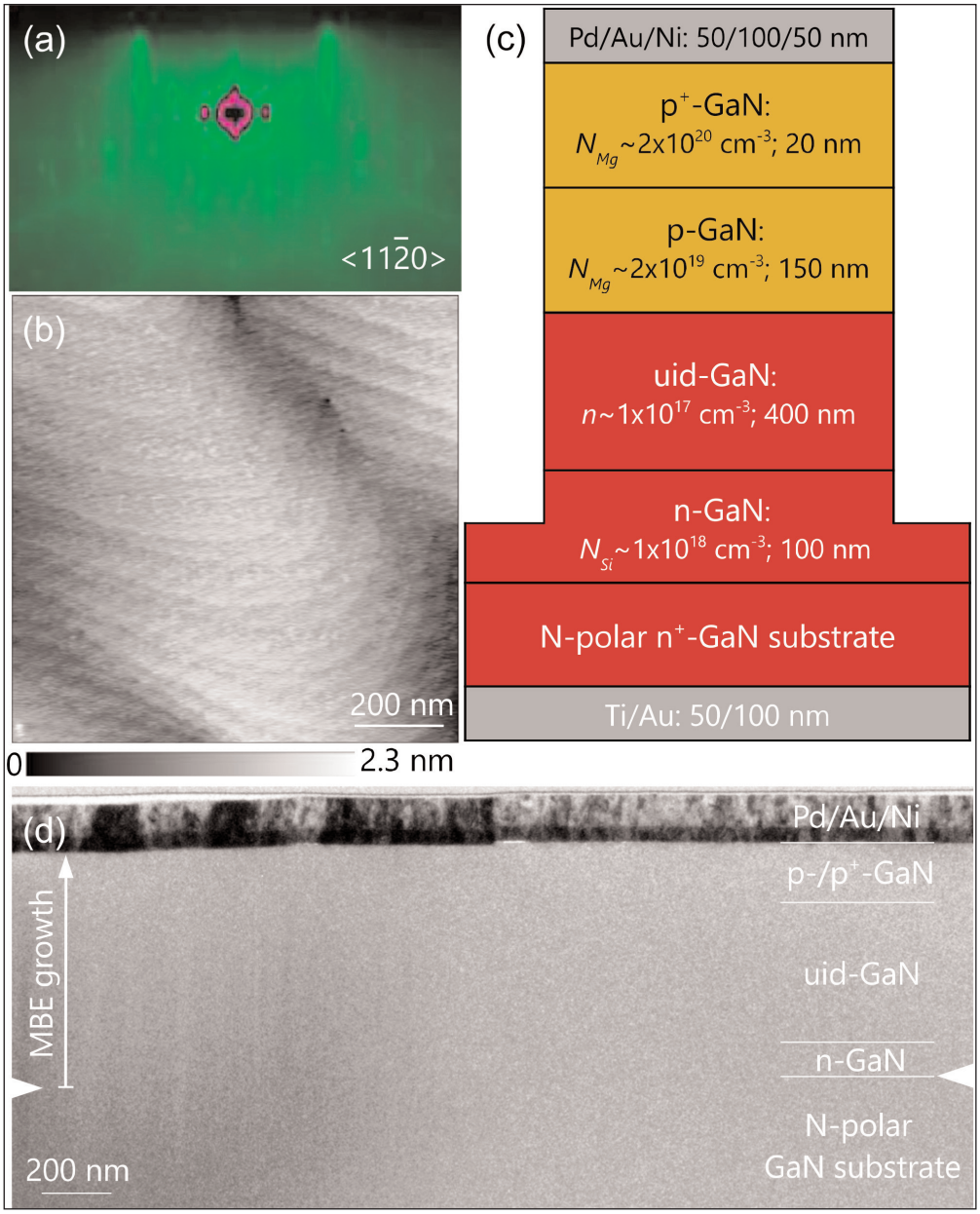

Figure 3. (a) In-situ reflection high-energy electron diffraction (RHEED) pattern showing (3x3) reconstruction characteristic of N-polar surface, and (b) AFM micrograph of MBE-grown N-polar GaN p–n diodes showing atomic steps. (c) Schematic layer structure and (d) cross-section transmission electron micrograph of fabricated vertical p–n diodes. Two white grooves on sides of image highlight the interface between the single-crystal bulk GaN substrate and MBE-grown epi-layers.

Nitrogen polarity

Cornell University in the USA has developed vertical p–n diodes using nitrogen-polar c-plane (000$\bar{1}$) GaN growth [YongJin Cho et al, Appl. Phys. Lett., vol110, p253506, p2017]. The researchers report: "A very low dislocation density leads to a high reverse breakdown electric field of ~2.2MV/cm without field plates — the highest reported for N-polar epitaxial structures." They further claim that their devices are the highest-quality p–n diodes ever demonstrated on N-polar GaN in terms of reverse-bias leakage.

The GaN crystal structure has strong charge polarization in the c-direction due to the ionic nature of the Ga-N chemical bond. The Cornell team suggests that growing material in the N-polar rather than the more common Ga-polar form, reversing the polarization, could lead to new electronic and photonic device opportunities such as ultra-low-power tunneling transistors, buried barrier high-electron-mobility transistors, and interband tunnel junctions. Further polarization engineering is used to create two-dimensional electron gas (2DEG) transistor channel layers and can also be exploited to improve hole densities in p-type regions.

N-polar growth allows higher growth temperatures, since the material is more robust against decomposition. However, bulk GaN substrates are usually prepared in Ga-polar form, and high-quality, low-dislocation, smooth N-polar GaN substrates have only recently become available. The N-polar GaN (000$\bar{1}$) substrate for Cornell's work was supplied by Ammono SA. The n^+ doping in the substrate delivered an electron concentration of about $10^{19}/cm^3$. X-ray diffraction analysis suggested a dislocation density of $5x10^4/cm^2$, much lower than the $10^9/cm^2$ typical of GaN material on alternative substrates. Root-mean-square roughness over a 10μm x 10μm field was ~0.4nm, according to atomic force microscopy (AFM).

The p–n diodes (Figure 3) were grown using Ga-rich plasma-assisted MBE on a Veeco Gen Xplor machine. Excess Ga droplets were removed after growth by hydrochloric acid cleaning. Analysis of the diode material suggested that "the high structural perfection of the single-crystal GaN substrate was largely transferred to the MBE-overgrown p–n diodes," according to the researchers. The diodes were fabricated with 600nm-high mesas for electrical isolation.

A 50μm-diameter device had a 3.5V turn-on voltage, close to that expected from the ~3.4eV bandgap of GaN. At 5V forward bias, the current density was $7.8kA/cm^2$, and the specific differential R_{on} was $0.1m\Omega\text{-}cm^2$ (Figure 4). The resistance was not

corrected for the probe and therefore the actual value is smaller. Under reverse bias down to −6V, the leakage was less than 10^{-5}A/cm^2. The ±5V on/off current ratio was more than 10^9.

Electroluminescence was also observed with photon energy peaks at 3.13eV and 3.39eV with 5V forward bias and 1.5kA/cm^2 current density. The 3.39eV was attributed to near-band-edge (NBE) emission. The 3.13eV emissions were assigned to conduction-band-to-acceptor (CBA) transitions in p-GaN layers. The magnesium doping of p-GaN gives a hole binding energy around 0.25eV.

A very weak broad deep-level transition was also observed around 2.2eV. The team writes: "The presence of the NBE and CBA peaks, and the weak intensity of the broad band peak, indicate a low density of deep point defects in the p–n diodes."

Reverse-bias breakdown was studied using a 20μm-diameter diode. Abrupt breakdown occurred at −76V, just after the current leakage reached 10^{-1}A/cm^2 density. The researchers attribute the breakdown to trap-assisted avalanche effects as opposed to interband Zener tunneling.

Using capacitance–voltage measurements to estimate the electron concentration in the unintentionally doped (uid) GaN layer (9.6×10^{16}/cm^3), the researchers calculated that the peak electric field at breakdown was around 2.2MV/cm, occurring at the edge of the depletion region.

The team comments: "This breakdown electric field, lower than the best Ga-polar GaN p–n diodes of ~4MV/cm, nevertheless indicates the highest value for N-polar GaN p–n diodes and can be significantly improved by sculpting the electric field externally using field-plates as the Ga-polar counterparts. The full performance and true breakdown behavior of the diodes may be accessible by electrically isolating the device regions from edge sidewalls."

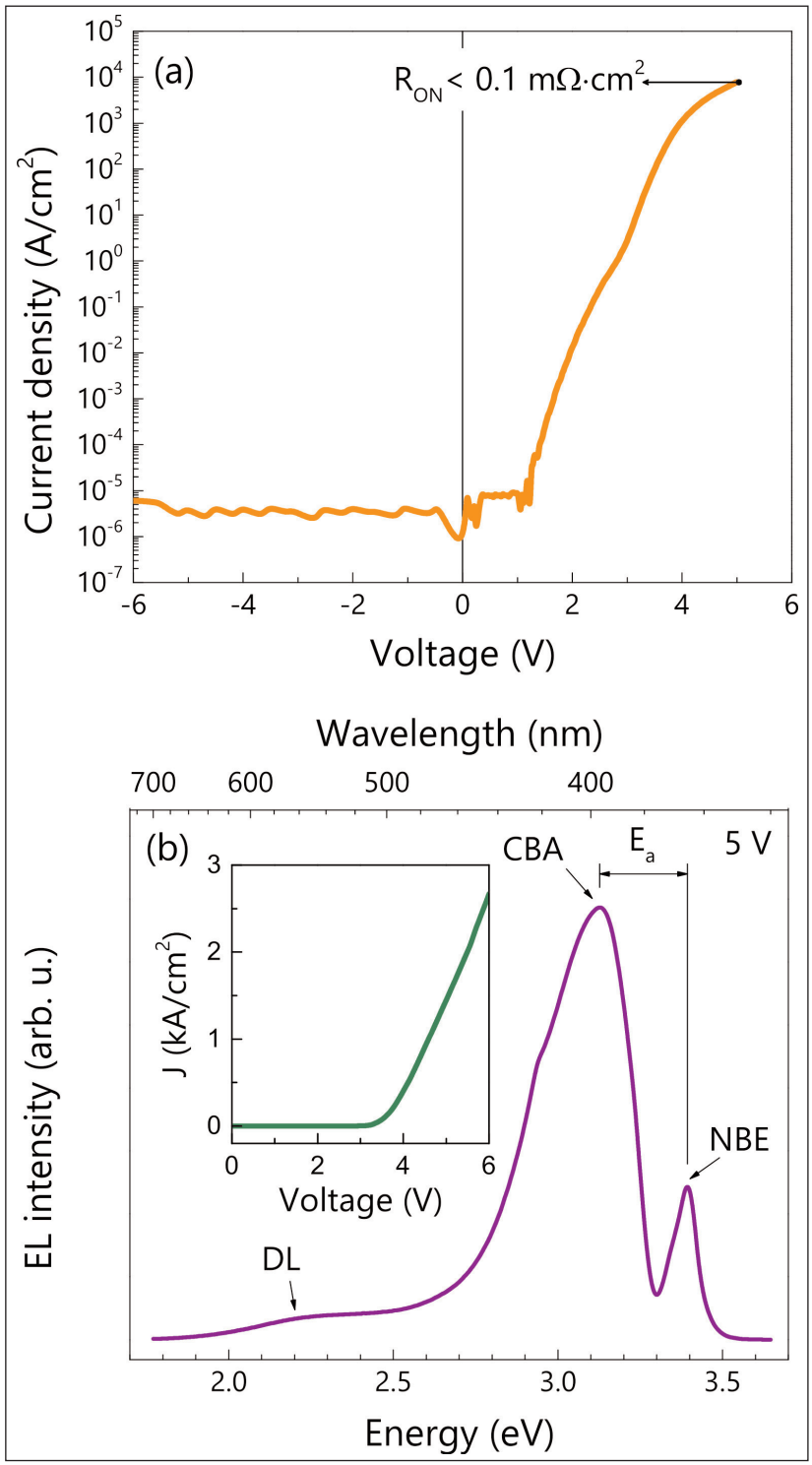

Figure 4. (a) Current density versus voltage characteristics of N-polar GaN single-crystal diodes in semilog scale showing high rectification ratio and low on-resistance. (b) Electroluminescence spectrum measured at 5V forward bias. Inset: linear-scale current density versus forward voltage.

Buffer and drift layer effects

Arizona State University in the USA has been studying the effects of GaN buffer layer thickness and drift layer doping on the material quality and performance of vertical p–n and Schottky barrier diodes [Houqiang Fu et al, IEEE Electron Device Letters, vol38, p763, 2017]. Without passivation or field-plates, some p-n devices reached breakdown voltages of more than 1000V and achieved R_{on} as low as 3mΩ-cm^2.

Samples were created from MOCVD on n-GaN free-standing substrates (Figure 5). The buffer layer was doped with silicon at 2×10^{18}/cm^3 concentration. The buffer thickness was varied at 50nm, 400nm, 1μm, and 1μm for samples labeled A–D, respectively. The 9μm drift layer was unintentionally doped (UID), except for sample D that was lightly doped with silicon (2×10^{16}/cm^3). The p-GaN upper layers were doped with magnesium — 500nm at 10^{19}/cm^3 concentration and 20nm at 10^{20}/cm^3.

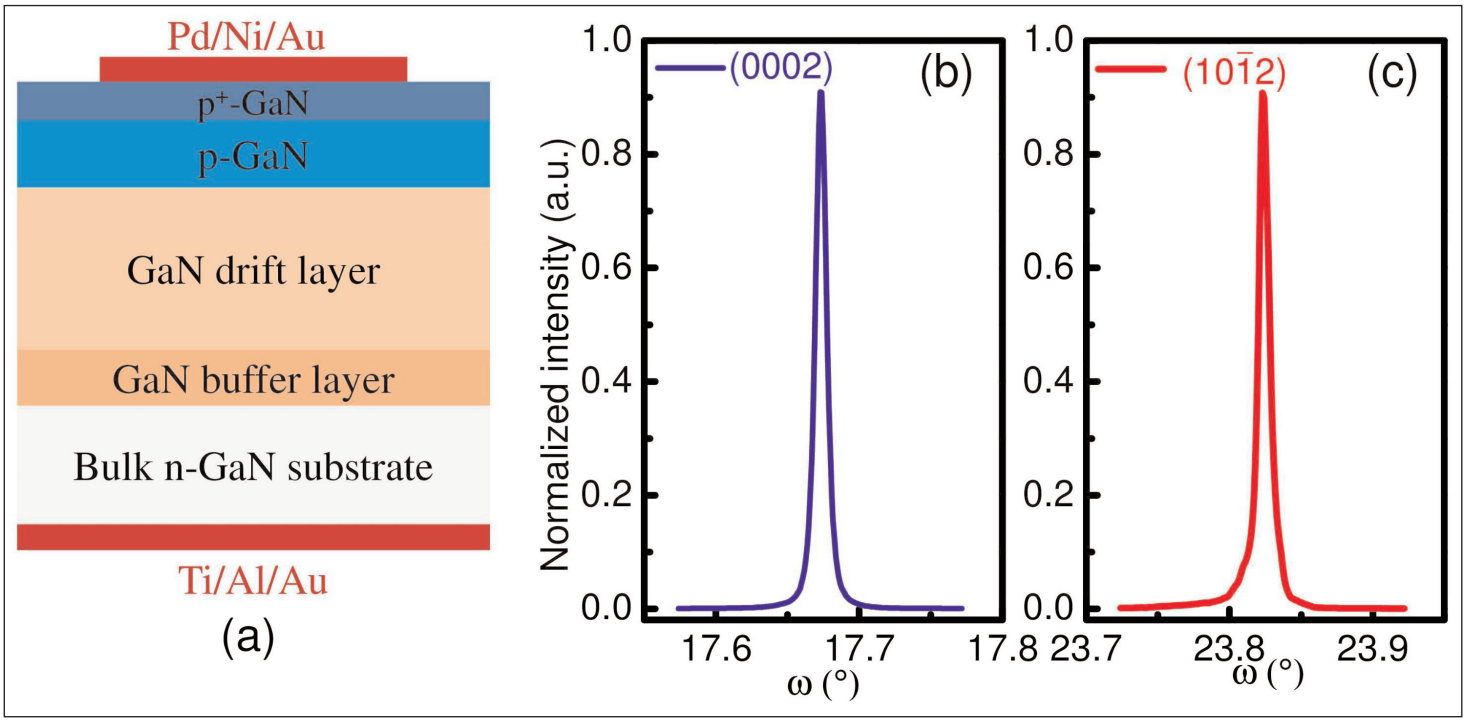

Figure 5. (a) Schematic of GaN p–n diodes on bulk GaN substrate. High-resolution x-ray diffraction rocking curve of (b) (0002) plane and (c) (10$\bar{1}$2) plane for GaN p–n diodes.

As a result of x-ray diffraction analysis, the researchers comment: "All samples have dislocation densities on the order of 10^6/cm^2, which are significantly lower than that of typical GaN devices grown on sapphire (> 10^9/cm^2)." AFM scans gave root-mean-square (RMS) roughness values in the range 0.5–1.5nm over a 10μm x10μm field.

The p–n diode fabrication began with inductively coupled plasma etch to 1.5μm depth of 260μm-diameter circular mesas. Annealed 200μm-diameter p-GaN ohmic contacts of palladium/nickel/gold (Pd/Ni/Au) were created with electron-beam evaporation. The backside n-GaN contacts comprised titanium/aluminium/gold (Ti/Al/Au).

The p–n diode turn-on voltage for all samples was around 3.1V. The on/off current ratio was of the order 10^{10}. Variations between devices are not believed to be intrinsic, but rather due to inhomogeneous p-contact resistance. The R_{on} was of order 3mΩ-cm^2 at 4V.

Electroluminescence was detected with spectral peaks at 2.2eV, 3.2eV and 3.4eV photon energies. "The strong EL suggests the radiative recombination in GaN p–n diodes and is an indication of high material quality," the researchers write.

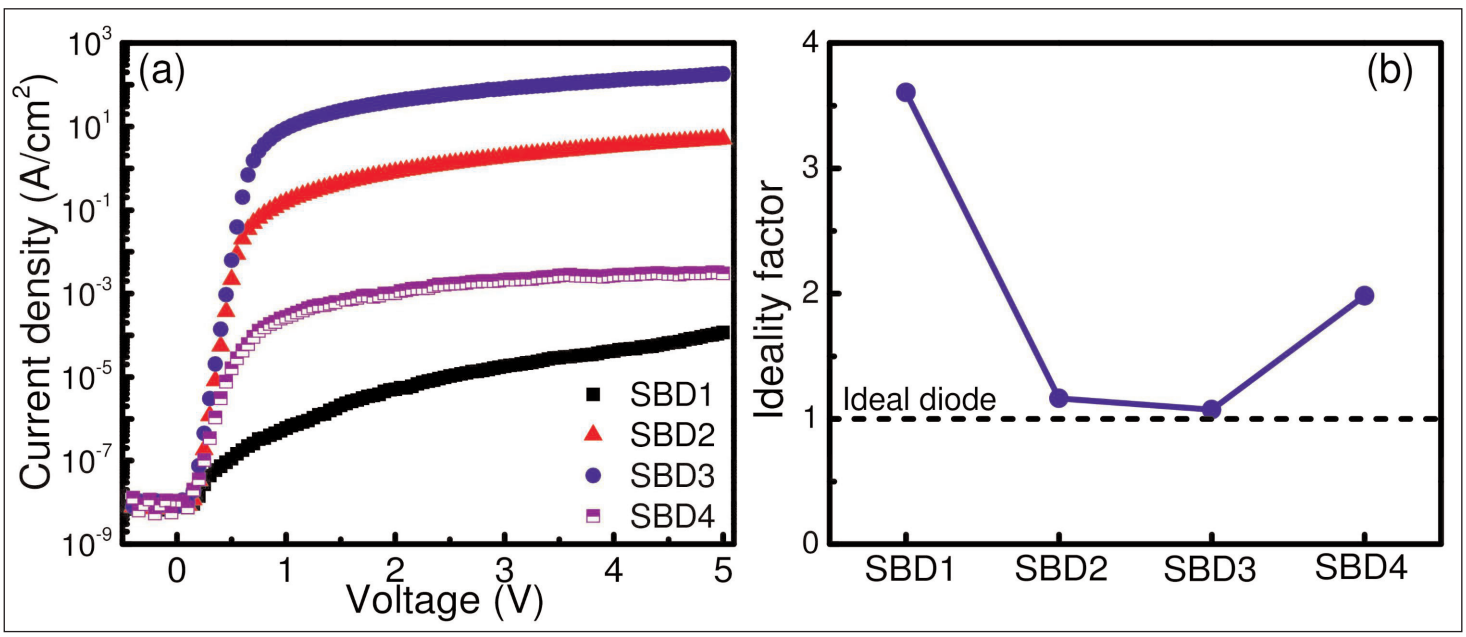

Figure 6. (a) Forward current–voltage I–V characteristics and (b) ideality factor of GaN Schottky diodes.

The reverse bias breakdown voltage was highest at more than 1000V for the p–n diode on sample C. The other samples in order of decreasing breakdown voltage were B at 772V, D at 687V, and A at 647V. The sample C device had a thicker buffer layer and low drift layer doping.

Some Schottky barrier diodes were also produced with Pd contacts on samples where the MOCVD growth ended with the drift layer. The buffer layer thicknesses were 20nm, 100nm, 400nm and 400nm for SBDs1–4, respectively. The buffer silicon doping was at $2x10^{18}/cm^3$, as before. The 9μm drift layer was unintentionally doped, except for SBD4 with light silicon doping ($2x10^{16}/cm^3$).

The SBDs showed much more variation in on-current, with SBD3 demonstrating the highest (Figure 6). Also, the ideality for SBD3 was near unity at 1.07, indicating high material quality of the drift layer, according to the team. The researchers comment: "With the same UID drift layer, the ideality factor decreases with increasing buffer layer thickness, indicating thicker buffer layer results in better material quality which can result from reduced defect density."

Thinner buffers and intentional drift layer doping gave idealities deviating from near-unity.

Thicker buffers were also found to increase the critical electric field, and hence breakdown voltages. However, the critical electric field was smaller than previous work by University of Notre Dame and Cornell University. The Arizona team attributes the lower performance to insufficient mesa isolation and larger contacts.

The breakdown characteristics of the SBDs followed the trends of the p–n diodes, with the best performance coming from thicker buffers and lower drift layer doping.

One negative side-effect of having thicker buffers was to increase the net doping in the overlying drift layer, which potentially could impact performance, according to capacitance–voltage studies on the SBDs. However, the researchers found that drift layer material quality was more important than doping concentration in achieving high breakdown voltages.

Table 1. Growth conditions, growth rate, root-mean-square (RMS) surface roughness, and thickness of grown GaN.

Sample	TMG (sccm)	NH_3 (slm)	V/III	Growth rate (μm/h)	RMS (nm)	Thickness (μm)
A	30	10	4057	2.61	0.11	4.36
B	60	10	2028	4.72	0.62	7.95
C	90	15	2028	7.78	1.19	7.78
D	90	10	1352	8.08	—	8.08

Schottky barriers

Japan's National Institute for Materials Science (NIMS) and Shanghai University in China have developed vertical GaN Schottky barrier diodes (SBDs) with a combination of low turn-on voltage and low R_{on} [Bing Ren et al, Appl. Phys. Express, vol10, p051001, 2017]. The low turn-on voltages obtained are claimed as "the lowest values ever reported for the vertical GaN SBD".

The team used a lowered growth rate to improve the GaN drift layer. The researchers see the technique as a route to high-performance vertical GaN SBDs with low conduction loss and high switching speed suitable for high-power applications.

The GaN drift layer was grown by MOCVD at 950ºC on free-standing substrates with $4x10^6/cm^2$ threading dislocation density and $1x10^{18}/cm^3$ donor concentration. The precursors were trimethyl-gallium (TMG) and ammonia (NH_3) in a carrier gas that was a mix of nitrogen and hydrogen.

The growth rate was controlled by varying the TMG flow rate between 30 standard cubic centimeters (sccm) and 90sccm (Table 1). The ammonia flow was fixed at 10 standard liters per minute (slm), except for sample C. The NH_3/TMG (V/III) molar ratio was between 1352 and 4057.

Schottky barrier diodes were formed with sputtered Ti/Al/Au ohmic metals on the substrate back-side and evaporated Ni/Au as Schottky contact.

The researchers studied the surface of the grown GaN with AFM. Samples A–C, grown with flow rates 2.6–7.81μm/h, had surfaces with aligned, atomic-level steps. By contrast, the 8.08μm/h fast growth rate of sample D resulted in valley-like defects. The researchers suggest these defects could arise from a three-dimensional growth mode or from the relatively low V/III ratio.

The researchers comment: "Although the step-flow growth was achieved in an optimized growth rate range, the RMS roughness was still rising from 0.11 to 1.19nm with increasing growth rate."

X-ray analysis produced narrow peak rocking curves

Table 2. Key diode parameters extracted from current–voltage (I–V) and capacitance-voltage C–V curves.

Sample	n	Φ I–V (eV)	Φ C–V (eV)	Free carrier density ($/cm^3$)	V_{on} (V)	R_{on} (mΩ-cm²)	Mobility [cm^2/V-s]
A	1.04	0.97	0.97	$6.35x10^{15}$	0.73	0.72	1370
B	1.03	0.93	0.95	$2.30x10^{15}$	0.68	2.62	975
C	1.04	0.85	0.91	$3.10x10^{15}$	0.66	2.90	628
D	1.59	0.69	0.71	$4.59x10^{16}$	0.67	0.86	239

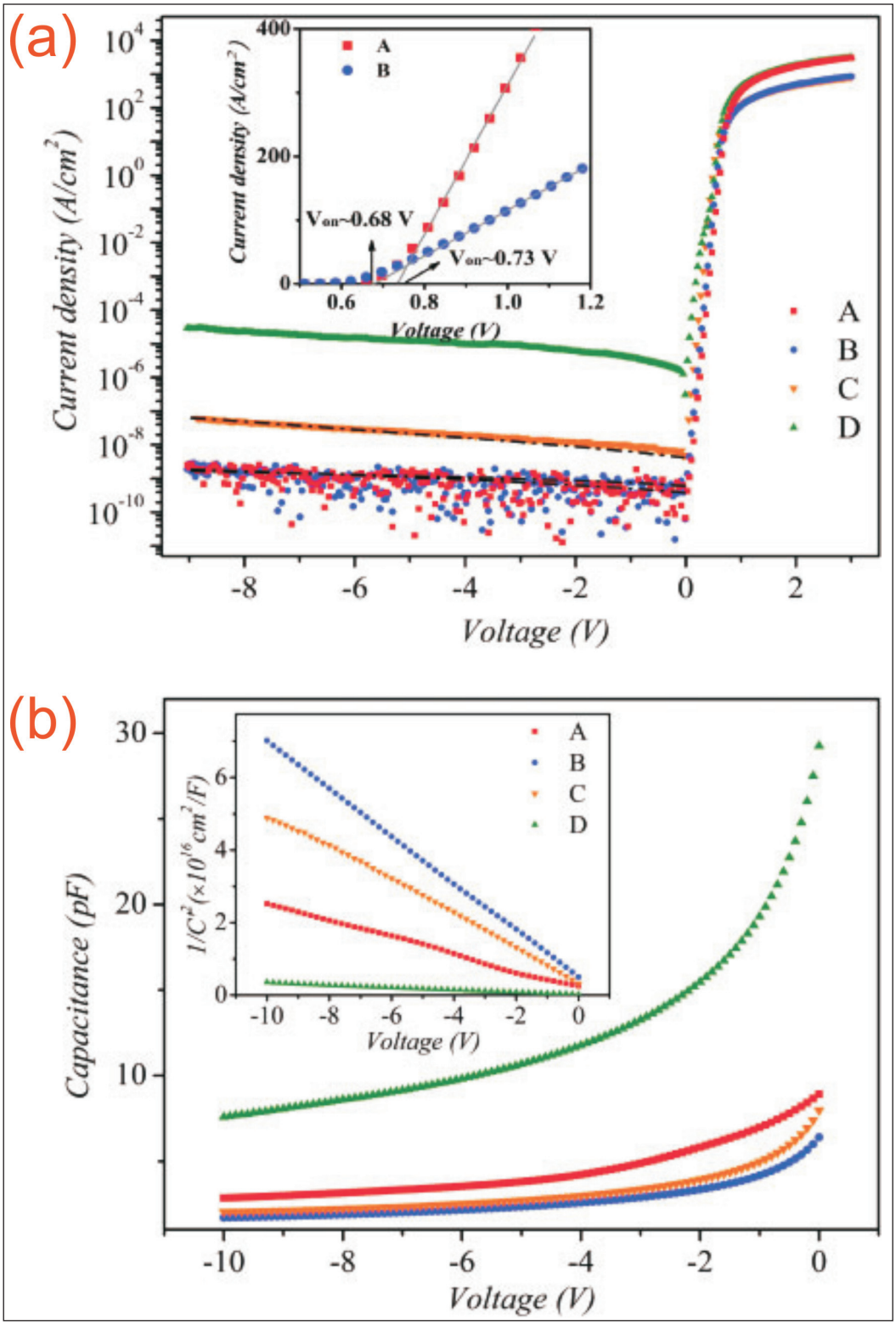

Figure 7. (a) Current density versus voltage, and (inset) detail near turn-on point for samples A and B. (b) Capacitance–voltage measurements at 1MHz, and (inset) inverse-square capacitance versus voltage.

with full-width at half-maximum (FWHM) values similar to that of the underlying substrate. Photoluminescence measurements showed sharp 3.4eV NBE emission and broad ~2.2eV defect-related 'yellow' luminescence. The ratio of NBE to yellow emissions trended downward with growth rate — around 60 for the bulk GaN substrate, and in the range 30 to 5 for samples A–D.

The researchers attribute this to increased carbon incorporation, presumably from the organic TMG precursor. The low carbon incorporation of samples A and B improved the mobility of the SBD drift layer.

Electrical characteristics (Figure 7 and Table 2) were extracted from SBDs with 60μm-diameter contacts. "Although the SBD devices have large Schottky barrier heights, the turn-on voltages were still kept at a low level (0.66–0.73V), which are the lowest values ever reported for the vertical GaN SBD," the team writes.

The SBD based on sample A material gave a combination of low 0.72mΩ-cm^2 R_{on} and high 1370cm^2/V-s mobility, at the cost of a slightly higher turn-on voltage compared with the other devices. Sample A's R_{on} is described as "among the lowest ever reported". "It should be noted that this is the first report of such a low R_{on} together with a low turn-on voltage," the researchers add.

The sharpness of the turn-on, as given by the ideality, is close to 1 (the ideal) for SBDs on samples A–C. The higher 1.59 ideality of sample D is attributed to the poor Schottky contact of the rough surface. Also, SBD sample D suffered from a higher reverse-bias leakage of 10^5A/cm^2, due to trap-assisted tunneling, according to the researchers. The Schottky barrier heights (Φ) from current–voltage and capacitance–voltage analysis of the devices on samples A and B are close to the Ni/GaN theoretical value of 1.0eV. ■

Author:
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RF power semiconductor market growing at 9.8% CAGR to $2.5bn in 2022

Gallium nitride is taking over LDMOS' market share as 5G reshapes the RF technology landscape, says Yole Développement.

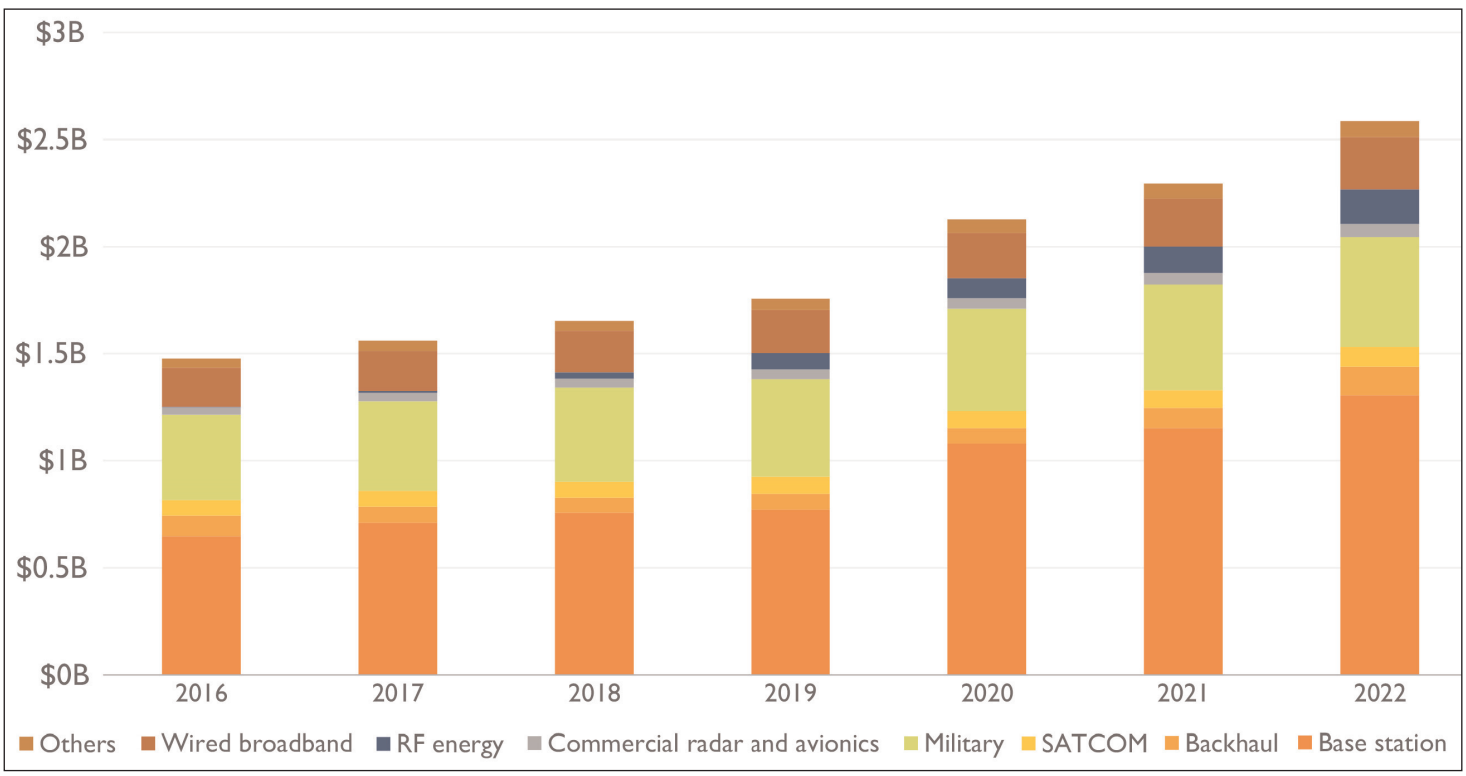
Yole Développement's 'RF Power Market and Technologies 2017: GaN, GaAs and LDMOS Report' forecasts that, after shrinking in 2015 and 2016 as telecom operators invested less, the total RF power semiconductor market (for applications above 3W) is now rising again at a compound annual growth rate (CAGR) of 9.8% over 2016–2022, growing by 75% from $1.5bn in 2016 to more than $2.5bn in 2022. Growth is being driven by increasing demand for telecom base-station upgrades and small-cell implementations.

"The revolutionary transition toward 5G implementation in the next five years is dramatically reshaping the RF technology landscape," says technology & market analyst Zhen Zong. This is not only for smartphones application but also for RF telecommunication infrastructure applications above 3W, and 5G is offering enormous business opportunities for compound semiconductors in this RF power market.

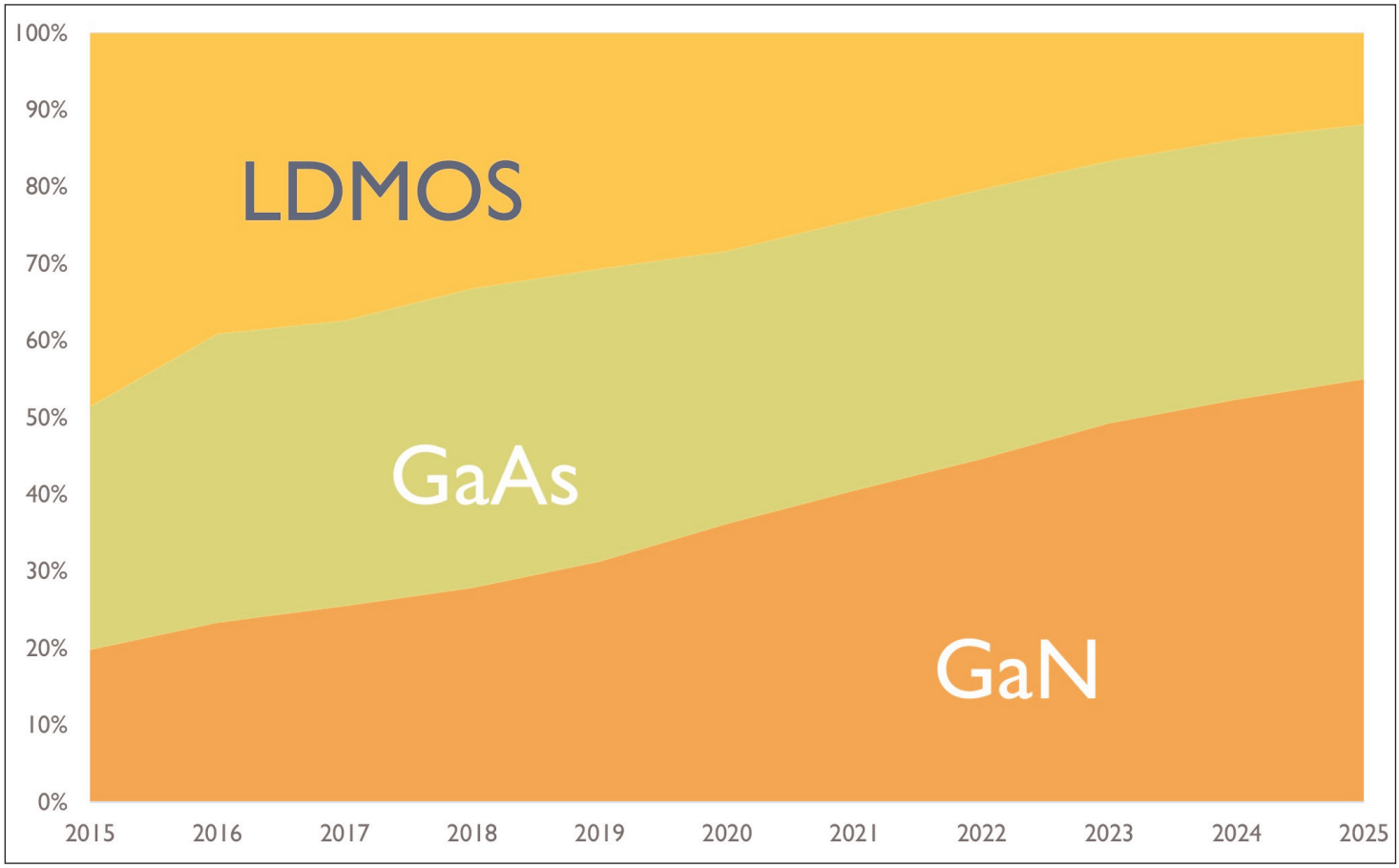
The market is currently standing at the threshold of completion of 4G networks and the beginning of the transition to 5G, but there is still a lot to be settled and established, says Yole. However, some things are sure: the new radio network will require more devices and higher frequencies. There is therefore a tremendous opportunity for chip suppliers, especially those of RF power semiconductors, reckons Yole.

"The market size of telecom infrastructure including base stations and wireless backhaul accounts for about half of the total market," notes technology & market analyst Dr Hong Lin. "It will continue growing fast at an expected 12.5% CAGR for base stations and 5.3% CAGR for telecom backhaul over 2016–2022," she adds.

Meanwhile, defense applications are also providing good opportunities for RF power devices, as there is a trend for replacing old vacuum tube designs with solid-state technologies exploiting gallium arsenide (GaAs) and gallium nitride (GaN), notes Yole. In various applications,



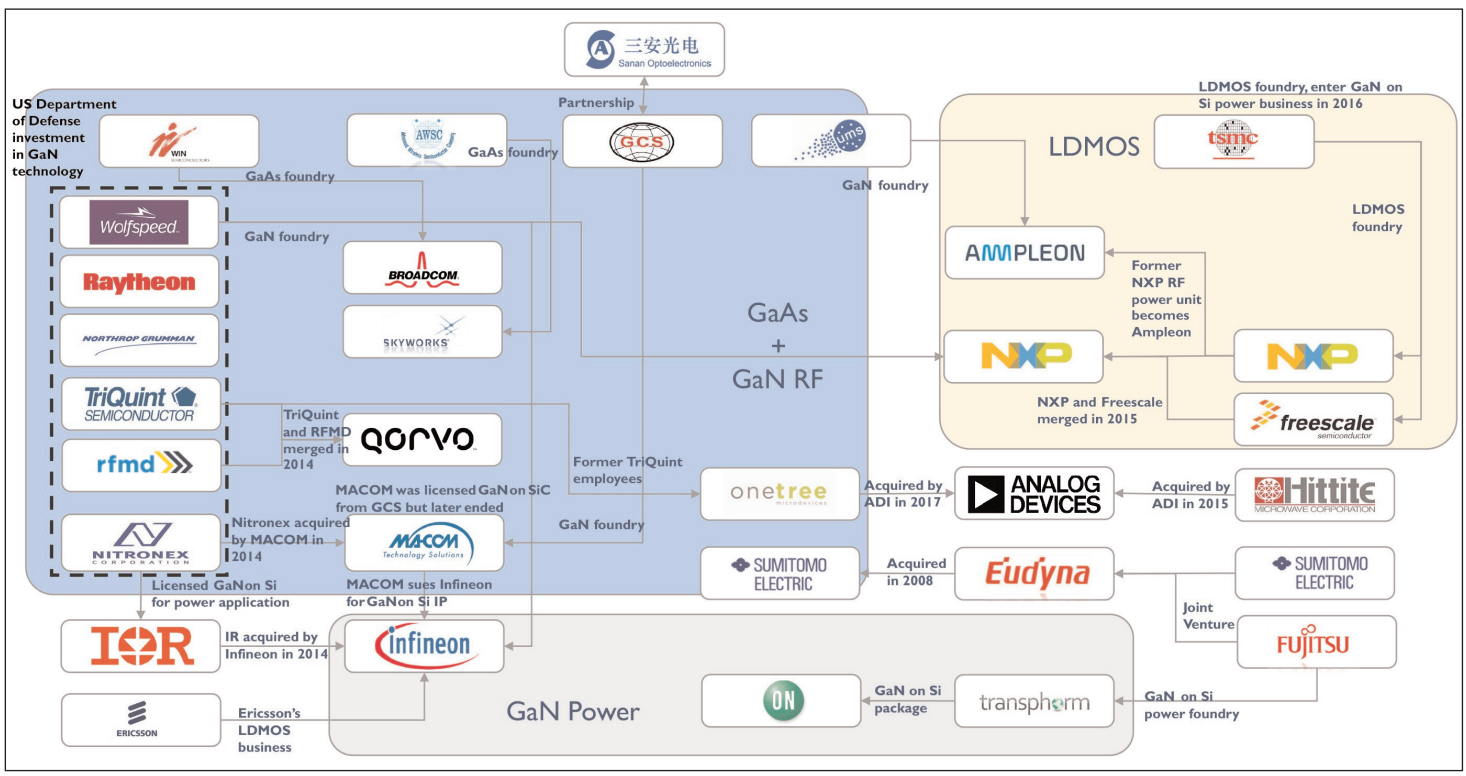
RF power market from 2016 to 2022



RF power device market, in value — breakdown by technology (only considering RF power semiconductors above 3W, excluding such applications as mobile power amplifiers).

these new technologies provide better performance, reduced size as well as robustness, so they are gradually taking more market share. This market segment is growing at a CAGR of 4.3% over 2016–2022 (up 20% by 2022).

www.yole.fr/PowerRF_Devices_Applications.aspx



Evolution of the RF power industry supply chain.

Gallium oxide transistor radio-frequency measurements

Researchers claim record-high transconductance and frequency characteristics.

Researchers in the USA and Germany have claimed the first radio frequency (RF) measurements on β-crystal gallium oxide (β-Ga_2O_3) metal-oxide-semiconductor field-effect transistors (MOSFETs) [Andrew J. Green et al, IEEE Electron Device Letters, published online 19 April 2017].

The team from Air Force Research Laboratory (AFRL) in the USA, Leibniz Institute for Crystal Growth in Germany, and George Mason University and KBRwyle in the USA further claim record-high transconductance and frequency characteristics. "The RF result is achieved through the reduction of contact resistance, due to a highly doped cap layer, and through the use of a gate recess, allowing for gate length scaling," the researchers comment.

The team believes that the MOSFETs point the way to monolithic or heterogeneous integration of power switch and other RF devices on β-Ga_2O_3. Such devices benefit from the ultra-wide 5eV bandgap that theory suggests could lead to critical fields for breakdown as high as 8MV/cm. The breakdown fields for gallium nitride (3.4eV bandgap) and silicon carbide (~3eV) are up to 5MV/cm. Greater critical fields should lead to higher breakdown voltages in devices.

The team comments: "These early results indicate promising RF potential for β-Ga_2O_3 MOSFETs as crys-

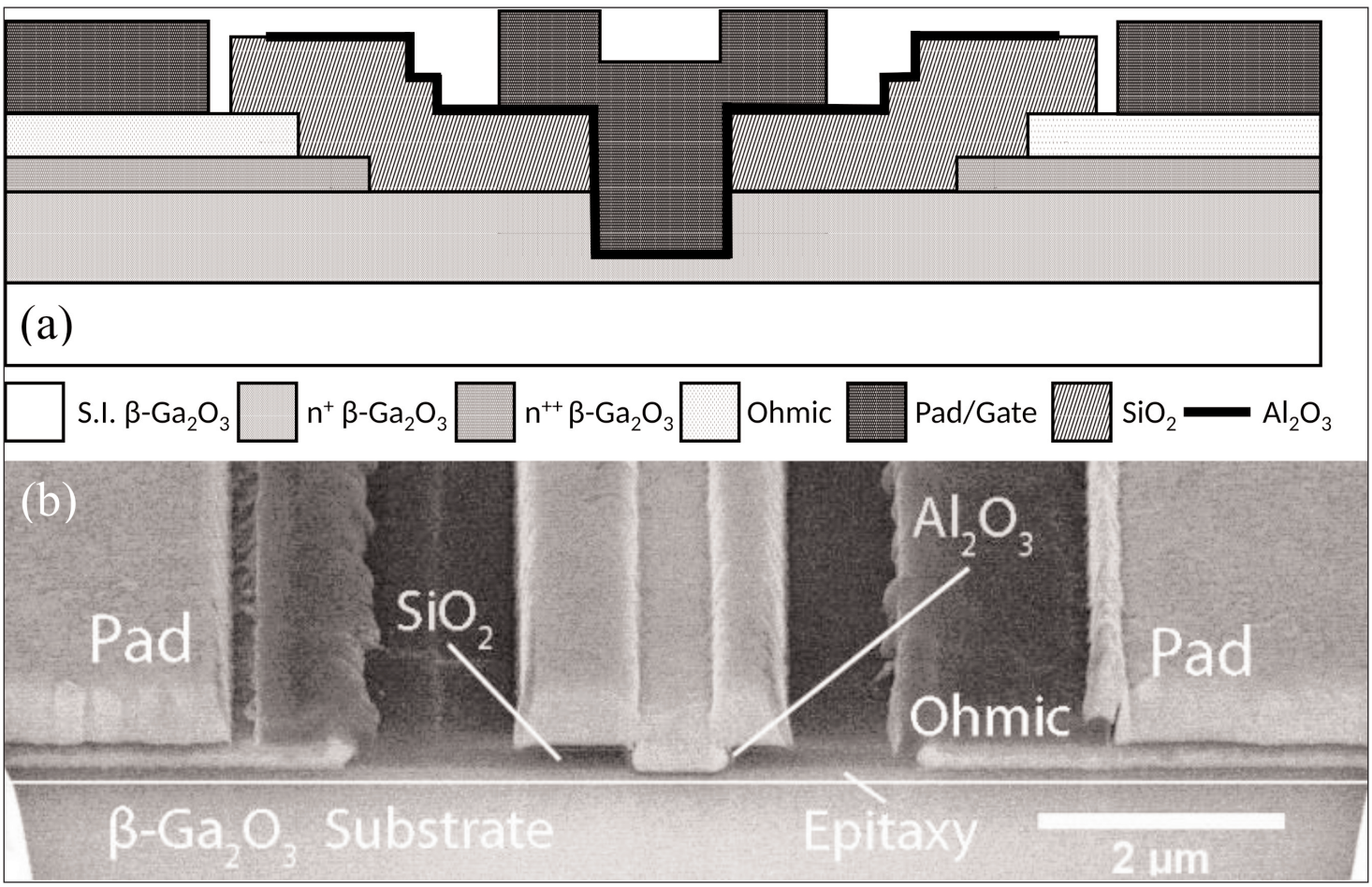


Figure 1. (a) Cross-sectional schematic for β-Ga_2O_3 MOSFET. (b) Focused ion beam cross-sectional image showing bottom finger of 2x50μm split finger gate.

tallinity improves and device scaling techniques are implemented. Additionally, dramatic improvements are expected with heterostructure development."

The device material was grown by metal-organic vapor phase epitaxy (MOVPE) on 2-inch semi-insulating (100) β-Ga_2O_3. The wafer was offcut 6° from the (100) plane to encourage step-flow growth, reducing planar defects. The epitaxial layers were silicon doped with $1x10^{18}/cm^3$ concentration for 180nm and $1x10^{19}/cm^3$ for 25nm to give the channel and ohmic contact, respectively.

Device fabrication began with mesa isolation etch with boron trichloride inductively coupled plasma. The ohmic source and drain contacts were evaporated and annealed titanium/aluminium/nickel/gold.

Gate formation began with boron trichloride inductively coupled plasma reactive-ion etch to expose the channel layer. The device was then coated with 200nm silicon dioxide (SiO_2) for passivation and for field-plate separation. The SiO_2 was etched to give a 0.7μm-wide gate trench. The etch was continued ~90nm into the channel layer to give a gate recess.

The gate dielectric was 20nm atomic layer deposition (ALD) aluminium oxide (Al_2O_3). Nickel/gold was used for local interconnection and gate electrodes. Extra current handling was enabled by the use of 2μm-thick titanium/gold interconnections.

Hall-effect measurements using van der Pauw structures on post-processed material with the ohmic cap layer removed gave a carrier concentration of $1.3x10^{18}/cm^3$ and $96cm^2/V\text{-}s$ mobility. Transfer length measurements gave contact resistance of 3.3Ω-mm and 4850Ω/square sheet resistance.

The final MOSFETs (Figure 1) had a 3.8μm source–drain spacing. The gate–drain distance was 1.6μm.

The devices achieved an on/off current ratio of 10^6 and 150mA/mm maximum drain current at 40V drain bias and 0V gate potential. The threshold voltage was estimated at −10.1V through linear extrapolation of the transconductance curve.

The peak transconductance was 21.2mS/mm. The researchers claim that this is 7x the group's previously reported β-Ga_2O_3 MOSFET performance and is also "higher than any other published result for β-Ga_2O_3".

With the drain biased at 40V and the gate potential at −3.5V (the position of the peak transconductance), the small-signal cut-off frequency (f_T) was 2.7GHz and the maximum oscillation (f_{max}) was 12.9GHz. Varying the drain bias allowed f_T to reach 3.3GHz. By contrast, the highest f_{max} occurred at 40V, after saturation at 35V.

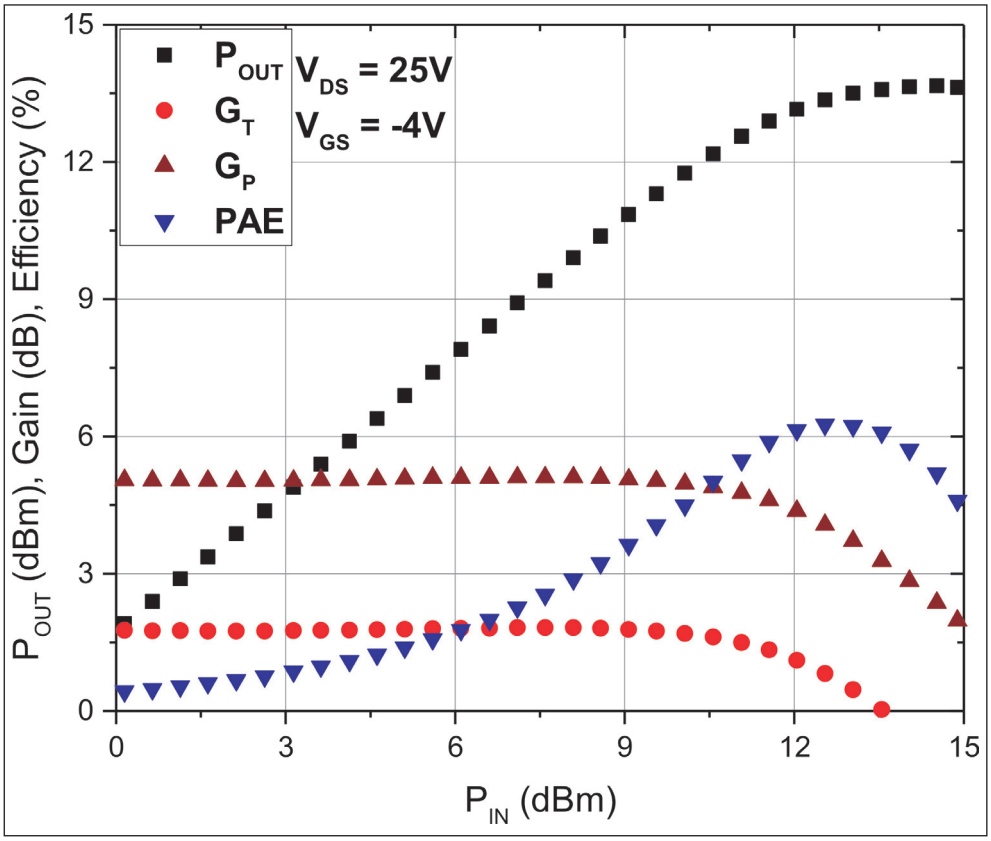


Figure 2. 800MHz Class-A power sweep of a 2x50μm β-Ga_2O_3 gate recessed MOSFET.

Large-signal continuous-wave 800MHz performance was also measured with 25V drain bias and −4V gate potential (see Figure 2). A passive source was used with load tuning for maximum output power, giving approximate Class A operation. The output power reached 0.23mW/mm (13.7dBm).

The team reports: "Both small- and large-signal measurements had significant reflected power due to a large high input impedance (small device periphery of 100μm coupled with a large sheet resistance of 4850Ω/square) of the device which could not be properly matched at the source side."

The effect was measured and corrected for by suitably reducing the input power value to give maximum transducer and power gain figures of 1.8dB and 5.1dB, respectively. The maximum power-added efficiency (PAE) was 6.3%.

Increasing the drain bias to 50V gave an output power of 0.25W/mm, but a low power-added efficiency of 1.4%. Catastrophic failure occurred for this high bias with the operating temperature reaching 300°C due to self-heating thermal effects, degrading device performance. ■

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Author: Mike Cooke

Indium gallium arsenide quantum well transistors on 300mm silicon

Researchers claim record effective mobility for 15nm-channel-thickness devices.

Researchers in South Korea and the USA claim record 2190cm^2/V-s effective mobility for indium gallium arsenide (InGaAs) quantum well (QW) metal-oxide-semiconductor field-effect transistors (MOSFETs) on 300mm-diameter (100) silicon substrates [Seung-Woo Son et al, IEEE Electron Device Letters, published online 19 April 2017].

InGaAs MOSFETs are being developed for the n-channel part of next-generation low-power logic complementary MOS circuits. InGaAs benefits from higher electron mobility and injection velocity compared with silicon. This should allow a reduction of operation voltages to below 0.5V, reducing power dissipation.

Kyungpook National University and Samsung Electronics of South Korea, University of Texas at Austin in the USA and Ulsan University in South Korea grew their semiconductor material by metal-organic chemical vapor deposition (MOCVD). The transistor structure (Figure 1) used GaAs and indium phosphide (InP) layers to create a strain relaxation buffer (SRB) on the silicon wafer. This was followed by indium aluminium arsenide ($In_{0.52}Al_{0.48}As$) buffer and an ultra-thin-body $In_{0.53}Ga_{0.47}As$ channel. The device layers were completed with an InP etch stop and $In_{0.53}Ga_{0.47}As$ cap.

The MOSFETs were fabricated with mesa isolation, molybdenum/titanium/platinum/gold ohmic source–drain electrodes, plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide passivation, aluminium oxide/hafnium dioxide gate dielectric, atomic layer deposition (ALD) titanium nitride gate metal, and titanium/gold gate contact.

With a 5nm channel thickness and 3μm gate length,

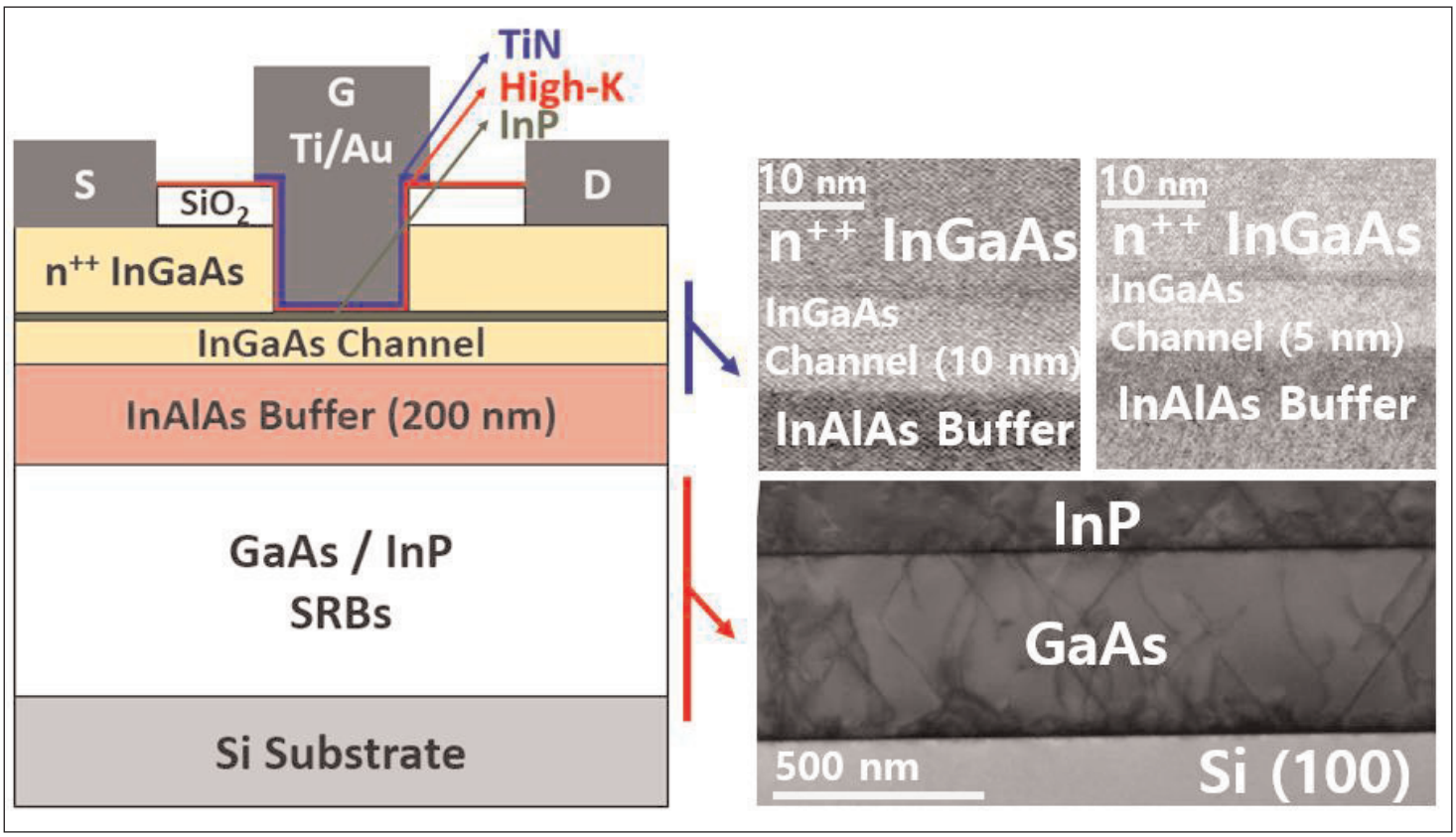

Figure 1. (a) Schematic of InGaAs QW-MOSFET, and (b) cross-sectional transmission electron micrographs with channel thicknesses of 10nm and 5nm.

the transistor achieved 50μA/μm maximum drain current and 6000Ω-μm on-resistance. With drain bias at 0.5V, the maximum transconductance was 100μS/μm. The subthreshold swing was 75mV/decade, while the drain-induced barrier lowering (DIBL) was 8mV/V.

The researchers studied devices with varying channel thickness (15–5nm), finding that thinner channels reduced drive current and transconductance performance, as expected. The thinner channels also suffered from reduced effective mobility (Figure 2). The researchers attribute this to increased surface roughness and Coulomb scattering in the thin channel devices.

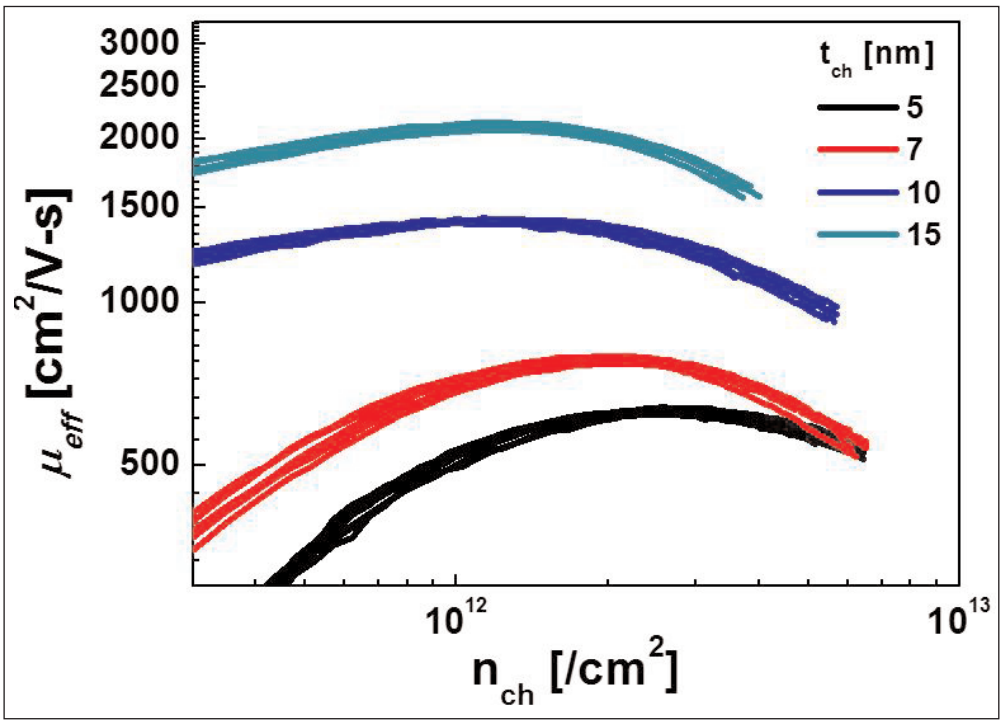

Figure 2. Effective mobility (μ_{eff}) plotted against channel carrier concentration (n_{ch}) for InGaAs MOSFETs on silicon from 10μm to 4μm, with different values of channel thickness (t_{ch}).

The root-mean-square roughness was assessed at close to 1nm, according to atomic force microscopy (AFM). This is rougher than what has been achieved in InGaAs/InAlAs QW MOSFETs on InP substrates. Coulomb scattering is associated with interface states that trap charges.

The team suggests that process optimization should aim at "defect-free growth of InGaAs/InAlAs QW MOSFETs on silicon with smooth surface morphology".

With a 15nm channel thickness, the researchers achieved what they consider to be the best combination of high effective mobility (2140cm^2/V-s) and low subthreshold swing (90mV/decade), beating the results of other group's InGaAs QW MOSFETs in both respects. ■

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31 rue Casimir Périer, BP 70083,
95873 Bezons Cedex, France
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Fax: +33 (0) 1 39 47 45 62
www.riber.com

SVT Associates Inc
7620 Executive Drive,
Eden Prairie, MN 55344, USA
Tel: +1 952 934 2100
Fax: +1 952 934 2737
www.svta.com

Veeco Instruments Inc
100 Sunnyside Blvd.,
Woodbury, NY 11797,
USA
Tel: +1 516 677 0200
Fax: +1 516 714 1231
www.veeco.com

Veeco is a world-leading supplier of compound semiconductor equipment, and the only company offering both MOCVD and MBE solutions. With complementary AFM technology and the industry's most advanced Process Integration Center, Veeco tools help grow and measure nanoscale devices in worldwide LED/wireless, data storage, semiconductor and scientific research markets—offering important choices, delivering ideal solutions.

7 Wafer processing materials

Air Products and Chemicals Inc
7201 Hamilton Blvd.,
Allentown, PA 18195, USA
Tel: +1 610 481 4911
www.airproducts.com/compound

MicroChem Corp
1254 Chestnut St. Newton,
MA 02464, USA
Tel: +1 617 965 5511
Fax: +1 617 965 5818
www.microchem.com

Praxair Electronics
(see section 5 for full contact details)

8 Wafer processing equipment

EV Group
DI Erich Thallner Strasse 1,
St. Florian/Inn, 4782,
Austria
Tel: +43 7712 5311 0
Fax: +43 7712 5311 4600
www.EVGroup.com
Technology and market leader for wafer processing equipment.
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Logitech Ltd
Erskine Ferry Road,
Old Kilpatrick,
near Glasgow G60 5EU,
Scotland, UK
Tel: +44 (0) 1389 875 444
Fax: +44 (0) 1389 879 042
www.logitech.uk.com

Oxford Instruments Plasma Technology
(see section 6 for full contact details)

Plasma-Therm LLC
(see section 6 for full contact details)

SAMCO International Inc
532 Weddell Drive,
Sunnyvale,
CA,
USA
Tel: +1 408 734 0459
Fax: +1 408 734 0961
www.samcointl.com

SPTS Technology Ltd
Ringland Way,
Newport NP18 2TA,
UK
Tel: +44 (0)1633 414000
Fax: +44 (0)1633 414141
www.spts.com

SUSS MicroTec AG
Schleißheimer Strasse 90,
85748 Garching,
Germany
Tel: +49 89 32007 0
Fax: +49 89 32007 162
www.suss.com

Veeco Instruments Inc
(see section 6 for full contact details)

9 Materials & metals

Goodfellow Cambridge Ltd
Ermine Business Park,
Huntingdon,
Cambridgeshire
PE29 6WR,
UK
Tel: +44 (0) 1480 424800
Fax: +44 (0) 1480 424900
www.goodfellow.com
Goodfellow supplies small quantities of metals and materials for research, development, prototyping and specialised manufacturing operations.

10 Gas and liquid handling equipment

Air Products and Chemicals Inc
(see section 7 for full contact details)

Cambridge Fluid Systems
12 Trafalgar Way, Bar Hill,
Cambridge CB3 8SQ,
UK
Tel: +44 (0)1954 786800
Fax: +44 (0)1954 786818
www.cambridge-fluid.com

CS CLEAN SOLUTIONS AG
Fraunhoferstrasse 4,
Ismaning, 85737,
Germany
Tel: +49 89 96 24000
Fax: +49 89 96 2400122
www.csclean.com

SAES Pure Gas Inc
4175 Santa Fe Road,
San Luis Obispo,
CA 93401,
USA
Tel: +1 805 541 9299
Fax: +1 805 541 9399
www.saesgetters.com

11 Process monitoring and control

Conax Technologies
2300 Walden Avenue,
Buffalo, NY 14225, USA
Tel: +1 800 223 2389
Tel: +1 716 684 4500
E-mail: conax@conaxtechnologies.com
www.conaxtechnologies.com
Ideas. Solutions. Success.
Conax Technologies is a designer and manufacturer of standard and custom-engineered temperature sensors, compression seal fittings and feedthroughs, probes, wires, electrodes and fiber-optic cables. The company is headquartered in Buffalo, New York, with locations on the US West Coast, Canada, Europe and Asia.

k-Space Associates Inc
2182 Bishop Circle East, Dexter,
MI 48130,
USA
Tel: +1 734 426 7977
Fax: +1 734 426 7955
www.k-space.com
k-Space Associates Inc specializes in in-situ, real-time thin-film process monitoring tools for MBE, MOCVD, PVD, and thermal evaporation. Applications and materials include the research and production line monitoring of compound semiconductor-based electronic, optoelectronic, and photovoltaic devices.

KLA-Tencor
One Technology Dr,
1-2221I, Milpitas, CA 95035, USA
Tel: +1 408 875 3000
Fax: +1 408 875 4144
www.kla-tencor.com

LayTec AG
Seesener Str. 10–13,
10709 Berlin,
Germany
Tel: +49 30 89 00 55 0
Fax: +49 30 89 00 180
www.laytec.de

LayTec develops and manufactures optical in-situ and in-line metrology systems for thin-film processes with particular focus on compound semiconductor and photovoltaic applications. Its know-how is based on optical techniques: reflectometry, emissivity corrected pyrometry, curvature measurements and reflectance anisotropy spectroscopy.

WEP (Ingenieurbüro Wolff für Elektronik- und Programmentwicklungen)
Bregstrasse 90, D-78120
Furtwangen im Schwarzwald,
Germany
Tel: +49 7723 9197 0
Fax: +49 7723 9197 22
www.wepcontrol.com

12 Inspection equipment

Bruker AXS GmbH
Oestliche Rheinbrueckenstrasse 49,
Karlsruhe, 76187, Germany
Tel: +49 (0)721 595 2888
Fax: +49 (0)721 595 4587
www.bruker-axs.de

13 Characterization equipment

J.A. Woollam Co. Inc.
645 M Street Suite 102,
Lincoln, NE 68508, USA
Tel: +1 402 477 7501
Fax: +1 402 477 8214
www.jawoollam.com

Lake Shore Cryotronics Inc
575 McCorkle Boulevard,
Westerville, OH 43082, USA
Tel: +1 614 891 2244
Fax: +1 614 818 1600
www.lakeshore.com

14 Chip test equipment

Keithley Instruments Inc
28775 Aurora Road,
Cleveland, OH 44139, USA
Tel: +1 440.248.0400
Fax: +1 440.248.6168
www.keithley.com

15 Assembly/packaging materials

ePAK International Inc
4926 Spicewood Springs Road,
Austin, TX 78759,
USA
Tel: +1 512 231 8083
Fax: +1 512 231 8183
www.epak.com

Gel-Pak
31398 Huntwood Avenue,
Hayward, CA 94544, USA
Tel: +1 510 576 2220
Fax: +1 510 576 2282
www.gelpak.com

Wafer World Inc
(see section 3 for full contact details)

Materion Advanced Materials Group
2978 Main Street,
Buffalo, NY 14214,
USA
Tel: +1 716 837 1000
Fax: +1 716 833 2926
www.williams-adv.com

16 Assembly/packaging equipment

Ismeca Europe Semiconductor SA
Helvetie 283, La Chaux-de-Fonds,
2301, Switzerland
Tel: +41 329257111
Fax: +41 329257115
www.ismeca.com

Kulicke & Soffa Industries
1005 Virginia Drive,
Fort Washington,
PA 19034,
USA
Tel: +1 215 784 6000
Fax: +1 215 784 6001
www.kns.com

Palomar Technologies Inc
2728 Loker Avenue West,
Carlsbad, CA 92010,
USA
Tel: +1 760 931 3600
Fax: +1 760 931 5191
www.PalomarTechnologies.com

TECDIA Inc
2700 Augustine Drive, Suite 110,
Santa Clara, CA 95054,
USA
Tel: +1 408 748 0100
Fax: +1 408 748 0111
www.tecdia.com

17 Assembly/packaging foundry

Quik-Pak
10987 Via Frontera,
San Diego, CA 92127, USA
Tel: +1 858 674 4676
Fax: +1 8586 74 4681
www.quikicpak.com

18 Chip foundry

Compound Semiconductor Technologies Ltd
Block 7, Kelvin Campus,
West of Scotland, Glasgow,
Scotland G20 0TH, UK
Tel: +44 141 579 3000
Fax: +44 141 579 3040
www.compoundsemi.co.uk

United Monolithic Semiconductors
Route departementale 128,
BP46, Orsay, 91401,
France
Tel: +33 1 69 33 04 72
Fax: +33 169 33 02 92
www.ums-gaas.com

19 Facility equipment

MEI, LLC
3474 18th Avenue SE,
Albany, OR 97322-7014,
USA
Tel: +1 541 917 3626
Fax: +1 541 917 3623
www.marlerenterprises.net

20 Facility consumables

W.L. Gore & Associates
401 Airport Rd, Elkton,
MD 21921-4236,
USA
Tel: +1 410 392 4440
Fax: +1 410 506 8749
www.gore.com

21 Computer hardware & software

Ansoft Corp
4 Station Square,
Suite 200,
Pittsburgh, PA 15219,
USA
Tel: +1 412 261 3200
Fax: +1 412 471 9427
www.ansoft.com

Crosslight Software Inc
121-3989 Henning Dr.,
Burnaby,
BC, V5C 6P8,
Canada
Tel: +1 604 320 1704
Fax: +1 604 320 1734
www.crosslight.com

Semiconductor Technology Research Inc
10404 Patterson Ave.,
Suite 108, Richmond, VA 23238,
USA
Tel: +1 804 740 8314
Fax: +1 804 740 3814
www.semitech.us

22 Used equipment

Class One Equipment Inc
5302 Snapfinger Woods Drive,
Decatur,
GA 30035,
USA
Tel: +1 770 808 8708
Fax: +1 770 808 8308
www.ClassOneEquipment.com

23 Services

Henry Butcher International
Brownlow House, 50–51
High Holborn,
London WC1V 6EG,
UK
Tel: +44 (0)20 7405 8411
Fax: +44 (0)20 7405 9772
www.henrybutcher.com

M+W Zander Holding AG
Lotterbergstrasse 30,
Stuttgart,
Germany
Tel: +49 711 8804 1141
Fax: +49 711 8804 1950
www.mw-zander.com

24 Consulting

Fishbone Consulting SARL
8 Rue de la Grange aux Moines,
78460 Choisel, France
Tel: + 33 (0)1 30 47 29 03
E-mail: jean-luc.ledys@neuf.fr

25 Resources

Al Shultz Advertising Marketing for Advanced Technology Companies
1346 The Alameda,
7140 San Jose, CA 95126, USA
Tel: +1 408 289 9555
www.alshuktz.com

SEMI Global Headquarters
3081 Zanker Road,
San Jose, CA 95134, USA
Tel: +1 408 943 6900
Fax: +1 408 428 9600
www.semi.org

Yole Développement
45 rue Sainte Geneviève,
69006 Lyon, France
Tel: +33 472 83 01 86
www.yole.fr

event calendar

If you would like your event listed in *Semiconductor Today*'s Event Calendar, then please e-mail all details to the Editor at mark@semiconductor-today.com

6–10 August 2017
SPIE Optics + Photonics 2017
San Diego Convention Center, CA, USA
E-mail: customerservice@spie.org
http://spie.org/optics-photonics1

10–12 August 2017
International Conference on Microelectronics Devices, Circuits and Systems (ICMDCS 2017)
VIT University, Vellore, India
E-mail: icmdcs2017@gmail.com
www.icmdcs2017.com

23–25 August 2017
IEEE 14th International Conference on Group IV Photonics (GFP 2017)
Berlin, Germany
E-mail: m.figueroa@ieee.org
www.gfp-ieee.org

7–9 September 2017
22nd International Conference on Simulation of Semiconductor Processes and Devices (SISPAD 2017)
Kamakura, Japan
E-mail: sispad2017@or.knt.co.jp
www.sispad.info

11–14 September 2017
47th European Solid-State Device Research Conference (ESSDERC 2017)
43rd European Solid-State Circuits Conference (ESSCIRC 2017)
Leuven, Belgium
E-mail: essxxrc@sistemacongressi.com
www.esscirc-essderc2017.org

13–15 September 2017
SEMICON Taiwan 2017
Taipei Nangang Exhibition Center, Taipei, Taiwan
E-mail: semicontaiwan@semi.org
www.semicontaiwan.org

17–21 September 2017
ECOC 2017: 43rd European Conference on Optical Communication
Svenska Mässan (The Swedish Exhibition & Congress Centre), Gothenburg, Sweden
E-mail: ecoc2017@meetx.se
http://ecoc2017.org

17–22 September 2017
ICSCRM 2017: International Conference on Silicon Carbide and Related Materials
Wardman Park Marriott, Washington DC, USA
E-mail: info@mrs.org
www.mrs.org/icscrm-2017

24–30 September 2017
2nd International Workshop 'Atomic Layer Deposition Russia 2017'
Saint-Petersburg, Russia
E-mail: ALD2017@onlinereg.ru
http://onlinereg.ru/ALD2017

advertisers' index

1–5 October 2017
2017 IEEE Photonics Conference (IPC), 30th Annual Conference of the IEEE Photonics Society
Orlando, FL, USA
E-mail: i.donnelly@ieee.org
www.ipc-ieee.org

9–10 October 2017
12th European Microwave Integrated Circuits Conference (EuMIC 2017), part of European Microwave Week (EuMW 2017)
Nuremberg, Germany
E-mail: friedel.gerfers@tu-berlin.de
www.eumweek.com/conferences/eumic.html

22–25 October 2017
IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS 2017)
Miami, FL USA
E-mail: l.lelong@ieee.org
https://csics.org

24–26 October 2017
BIT's 7th Annual World Congress of Nano Science & Technology (Nano S & T-2017)
Hilton Fukuoka Sea Hawk Hotel, Japan
E-mail: linhui@bitlifesciences.com
www.bitcongress.com/Nano2017

26–28 October 2017
International Conference on Advanced Materials and Nanotechnology
Osaka, Japan
http://advancedmaterials.conferenceseries.com/events-list/photonics-and-semiconductor-nanophysics

30 October – 1 November 2017
5th IEEE Workshop on Wide Bandgap Power Devices and Applications (WiPDA 2017)
Hyatt Regency Tamaya Resort, Albuquerque, NM, USA
E-mail: rjkapla@sandia.gov
www.wipda.org

14–17 November 2017
SEMICON Europa 2017
Messe München, Germany
E-mail: SEMICONEuropa@semi.org
www.semiconeuropa.org

4–6 December 2017
63rd IEEE International Electron Devices Meeting (IEDM 2017)
San Francisco, CA USA
E-mail: info@ieee-iedm.org
www.ieee-iedm.org

6–9 December 2017
48th IEEE Semiconductor Interface Specialists Conference (SISC 2017)
San Francisco, CA USA
E-mail: pmcintyre@ieeesisc.org
www.ieeesisc.org

13–15 December 2017
SEMICON Japan 2017
Tokyo Big Sight, Tokyo, Japan
E-mail: jcustomer@semi.org
www.semiconjapan.org

27 January – 1 February 2018
SPIE Photonics West 2018
Moscone Center San Francisco, California, USA
E-mail: customerservice@spie.org
http://spie.org/SPIE-PHOTONICS-WEST-conference

4–8 February 2018
IEEE International Solid-State Circuits Conference (ISSCC 2018)
San Francisco, CA, USA
E-mail: melissa@widerkehr.com
www.isscc.org

4–8 March 2018
IEEE Applied Power Electronics Conference and Exposition (APEC 2018)
Henry B. Gonzalez Convention Center, San Antonio, TX, USA
E-mail: apec@apec-conf.org
www.apec-conf.org

14–16 March 2018
LASER World of PHOTONICS CHINA 2018
Shanghai New International Expo Centre, China
E-mail: info@world-of-photonics-china.com
www.world-of-photonics-china.com

15–19 April 2018
SPIE Defense + Commercial Sensing
Gaylord Palms Resort & Convention Center, Orlando, Florida, USA
Abstracts deadline: 9 October 2017
E-mail: customerservice@spie.org
http://spie.org/conferences-and-exhibitions/defense--commercial-sensing

13–17 May 2018
IEEE 30th International Symposium on Power Semiconductor Devices and ICs (ISPSD 2018)
Chicago, IL USA
www.ispsd2018.org

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