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semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

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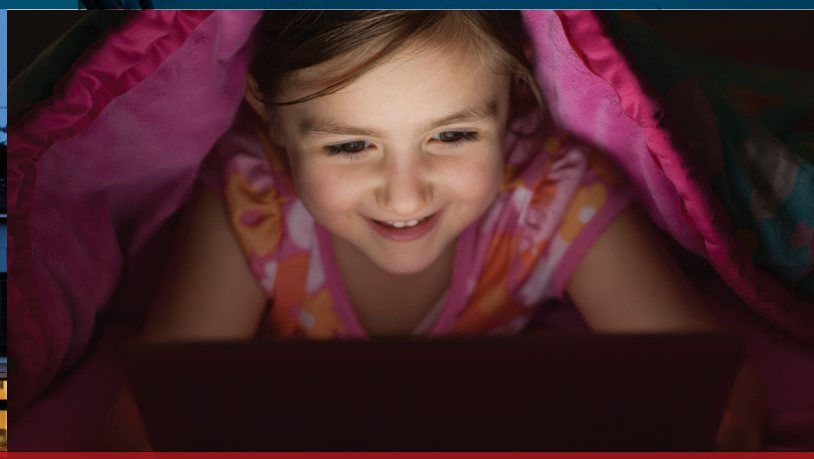
Wide-bandgap semiconductors for power electronics

News from OFC

Cree licenses GaN power patents to Nexperia • IPO for nLIGHT
Plasma-Therm acquires KOBUS • Riber returns to annual profit

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.

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

Veeco's New TurboDisc EPIK700 GaN MOCVD System

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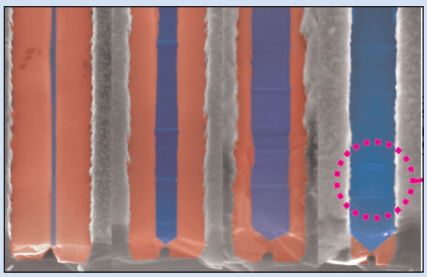
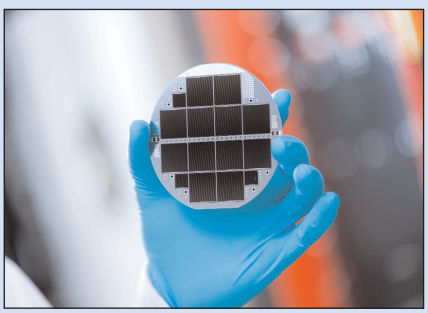
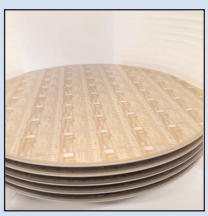


p32 Aspect ratio nano-patterning of a silicon substrate enables a hexagonal-to-cubic phase transition in GaN MOCVD growth.



p50 III-V/Si multi-junction solar cell with record conversion efficiency of 33.3%, developed by Fraunhofer ISE.



Cover: Belgium's imec and US-based Qromis have developed enhancement-mode p-GaN power devices on 200mm engineered CTE-matched substrates, processed on imec's silicon pilot line. The substrates are offered by Qromis as commercial 200mm QST substrates as part of its patented product portfolio. **p12**

editorial

Wide-bandgap prospects widening

On page 8 of this issue we report market research estimating that the gallium nitride device market is rising at a compound annual growth rate (CAGR) of 17.1% from $711.44m in 2017 to $1842.8m in 2023, driven by "growing demand for RF devices, the booming consumer electronics market and the proliferation of electric vehicles (EVs) and photovoltaic inverters". Particular applications cited include wireless electricity charging (WiTricity) and light detection and ranging (LiDAR) in autonomous vehicles. With consumer electronics becoming the largest sector, the Asia-Pacific will grow fastest (becoming the biggest region by 2023), aided by China being one of the largest EV markets and India committing to sell only electric cars by 2030. Emphasizing GaN's commercial promise, Cree has just licensed its GaN power device patents to Netherlands-based Nexperia (formerly the Standard Products business unit of NXP/Philips Semiconductors but now owned by a consortium of China-affiliated investors) — see page 16.

However, GaN's high production cost compared with silicon carbide could hinder market growth, notes the report. Another report by TrendForce estimates that the markets for SiC and GaN substrates will be $180m and $3m, respectively, in 2018 (see page 9). In particular, SiC will be driven by auto makers completing tests on SiC power devices. In addition, it is reckoned that 5G wireless entering commercial operation in 2020 will drive the use of GaN-on-SiC in base-stations as well as more cost-effective GaN-on-Si (on 200mm silicon wafers) in smartphone handsets. Furthermore, imec has shown how GaN-on-Si can be extended to applications operating above 650V by using Qromis' coefficient of thermal expansion (CTE)-matched substrates to enable thicker buffer layers.

This technology can perhaps also be used to create free-standing GaN substrates for vertical GaN power switches and rectifiers (see page 12). Meanwhile, China's Zhejiang University has developed a 1kV vertical GaN-on-GaN Schottky barrier diode featuring a high Baliga figure-of-merit of 825MW/cm^2 and eight-order ON/OFF current ratio at –600V (claimed to be one of the best reported for vertical unipolar GaN power rectifiers) — see page 16. In addition, Toyoda Gosei has achieved high-current (>50A) operation in vertical GaN power transistors (page 17).

The higher performance of devices on existing GaN substrates is currently compromised by the economics of small wafer diameter (2-inches) and high cost. However, an alternative to GaN-based devices is gallium oxide (β-Ga_2O_3), which has the dual advantages of both higher device performance (due to its even wider bandgap energy of 4.5–4.9eV, versus 3.4eV for GaN and about 3eV for SiC) and larger substrate diameter. On pages 64–71 we therefore give a round-up of recent research on Ga_2O_3 for both power electronic devices (field-effect transistors and Schottky barrier diodes) and optoelectronic devices (deep-UV photodetectors). The latter comprised Ga_2O_3 deposited on III-nitride epitaxial layers grown on silicon substrates — rather than existing AlGaN deep-UV devices — precluding the use of smaller-diameter, more costly aluminium nitride or sapphire substrates.

Finally, on page 58–59 we cover developments in improving the efficiency of more conventional AlGaN deep-UV LEDs (on AlN substrate) and on pages 56–57 we report the first observation of room-temperature electrically injected lasing in AlGaN near-UV lasers grown on silicon.

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

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HVM: High Volume Manufacturing

news

Silicon photonics market to grow at a CAGR of 20.8% between 2018 and 2023

The silicon photonics market will grow at a compound annual growth rate (CAGR) of 20.8% between 2018 and 2023, according to a report from Markets and Markets.

Rising demand for silicon photonics in data centers and the growing requirements of high bandwidth and high data transfer capabilities are the key factors contributing to growth. However, the risk of thermal effects remains as a major restraint affecting silicon photonics market growth.

Transceiver sector growing fastest

The silicon photonics market for transceivers is expected to grow at the highest CAGR between 2018 and 2023.

Transceivers are used in applications such as high-performance computing, due to the large demand for high-speed data transmission in data centers. Many tier-1 players are entering this market; for example, Intel began research on silicon photonics in the last decade and launched its first 10Gbps product in partnership with Luxtera.

Further, in May 2017 Intel launched a 100G CWDM4 and QSFP28 optical transceiver that has higher bandwidth capabilities and can support speeds up to 100Gbps.

Demand for silicon photonics in data centers and the growing requirements of high bandwidth and high data transfer capabilities are the key factors contributing to growth

Data-centers/high-performance computing largest sector

Data centers and high-performance computing comprised the largest share of the silicon photonics market in 2017. Due to the rise of cloud computing and several emerging web applications, data centers are experiencing an exponential increase in data traffic. To manage this network load, large data centers are required with thousands of servers interconnected with high-bandwidth switches.

APAC region to grow fastest

The Asia-Pacific (APAC) region is expected to grow at the highest CAGR between 2018 and 2023, due mainly to China, Japan and South Korea. The increasing requirement of high-speed data communication and the increasing focus of international and domestic IT companies on Big Data analytics and cloud-based services in the region should fuel market growth. Also fueling market growth are increasing investment in the development of silicon photonics products, domestic players on the silicon photonics market, and increasing R&D activities in the region.

Major players in silicon photonics are cited as Acacia (Switzerland), Luxtera (USA), Intel (USA), Cisco (USA), Mellanox (Israel/USA), Finisar (USA), STMicroelectronics (Switzerland), Hamamatsu (Japan), IBM (USA), Juniper (USA), GlobalFoundries (USA), Broadcom (USA), Oclaro (USA), Neophotonics (USA), and Ciena (USA).

www.researchandmarkets.com

Luminaire revenue for horticultural applications to reach $3.8bn by 2027

Global luminaire revenue for horticultural applications is expected to reach $3.8bn by 2027, according to a new report from Navigant Research that focuses on LEDs.

By offering greater energy efficiency and better crop yields, improvements in LED technology are providing growers larger profits as well as other benefits, notes the report 'LED Lighting for Horticultural Applications'. Leveraging a growing indoor farming market, lighting manufacturers are providing tunable solutions of LEDs that support plants during different stages of the grow cycle, allowing farmers to monitor every known influence on the crop's well-being, and encouraging further adoption.

"Market growth in horticultural LED applications has helped lower installation costs for luminaires, driving further adoption for LED technology," says research analyst Courtney Marshall. "This feedback loop between more affordable prices and greater adoption rates has created a market environment marked by innovation and experimentation as vendors look to upgrade their offerings with quality research."

While the lack of a one-size-fits-all approach can be a challenge, the diverse horticulture market also presents an opportunity for collaboration among incumbents, startups and universities to provide proven and scalable lighting offerings, notes the report. By taking advantage of the academic space to conduct controlled experiments, vendors can increase credibility and may also discover successful lighting applications that could speak to an audience as diverse as the horticultural market, it concludes.

www.navigantresearch.com

LED packaging market revenue grows from $15.975bn in 2016 to $18.035bn in 2017

China's MLS climbs from seventh to fourth in revenue ranking

Annual LED packaging market revenue has grown steadily over the past year, from $15.975bn in 2016 to $18.035bn in 2017, according to a report from LEDinside.

In 2017, the top three LED package suppliers were Nichia, Osram Opto Semiconductors and Lumileds. However, China's MLS rose from seventh in 2016 to fourth in 2017 following its significant capacity expansion to meet increased demand in the lighting and display market, says LEDinside research director Roger Chu. Seoul Semiconductor remained fifth, benefitting from significant growth in sales of backlight CSP (chip-scale packaged), flash LEDs, lighting, automotive products and UV products. Samsung LED was hence leapfrogged, from fourth in 2016 down to sixth in 2017, while Everlight was pushed down from sixth to seventh. Cree, LG Innotek and Nationstar remained eighth, ninth and tenth, respectively.

Nichia remained the revenue leader in the global LED package market in 2017, but has been challenged by competitors in the blue LED sector. It is therefore actively involved in sectors such as WCG (wide color gamut) backlight LEDs, ultraviolet (UV) LEDs, blue and green lasers and automotive lighting, while maintaining its market share through holding patents.

Top 10 packaged LED suppliers by revenue.

Ranking	2016	2017
1	Nichia	Nichia
2	Osram Opto	Osram Opto
3	Lumileds	Lumileds
4	Samsung LED	MLS
5	Seoul Semiconductor	Seoul Semiconductor
6	Everlight	Samsung LED
7	MLS	Everlight
8	Cree	Cree
9	LG Innotek	LG Innotek
10	Nationstar	Nationstar

Among manufacturers based in Europe and the USA, Osram has the best revenue performance due to its long-term and solid foundation in automotive lighting and recent achievements in infrared sensing. In the general lighting sector, Osram is actively launching new products, and is outsourcing the manufacturing of small- and medium-power products to OEMs in Taiwan and China, as it hopes to increase its share of the LED lighting market. In order to ensure profitability, Lumileds and Cree have begun to focus on niche applications such as automotive lighting, niche lighting and architectural lighting.

Impacted by Chinese LED makers offering lower prices, most Taiwanese LED makers have reduced the proportion of low-profit lighting products in their product mixes, and transited to applications with high gross margin. For example, Everlight has been actively developing automotive lighting, UV/IR lighting, and mini-LED backlight applications.

On the other hand, China LED makers have developed rapidly due to the rise of the domestic market and the increasing demand for general lighting products and displays. Firms such as MLS and Nationstar hence continue to expand their production capacity, resulting in them rising up the revenue ranking.

In addition, in recent years the financial subsidies offered by local governments in China have prompted many Chinese LED makers to increase production capacity.

Aided by their cost advantages, these manufacturers have also received many orders from overseas companies. Chinese LED makers hence continue to climb the ranking. In 2017, market share of Chinese makers in the global LED packaging market reached 35%, up from 30% in 2016, concludes the report.

www.ledinside.com

Mid-power 3030-packaged LEDs in China market see 5.2% price drop in March

Mid-power 3030-packaged LED products in the China market saw a significant price drop in March, and high-power ceramic-substrate LEDs saw a slight price drop, while prices of other products remained stable, according to LEDinside (a division of market research firm TrendForce).

High-power ceramic-substrate LED package products (up to 1000mA) continued to see a slight price drop in March of 0.8%. As for mid-power products, prices of 3030-packaged LED products fell by 5.2% as suppliers focus on product promotion.

In terms of new products, suppliers continued to improve performance, notes LEDinside analyst Terri Wang. For example, Nichia has introduced Optisolis, a new ultra-high-CRI mid-power 3030 LED, with an Ra above 95 and an R9 above 80. Since it emits no UV radiation, it is suitable for lighting in museums and art galleries, which require high-CRI and less UV radiation. Moreover, it can be used in retail lighting etc, notes LEDinside.

www.ledinside.com

GaN device market to grow at 17.1% CAGR from $711.44m in 2017 to $1842.8m in 2023

The gallium nitride (GaN) device market is rising at a compound annual growth rate (CAGR) of 17.1% from $711.44m in 2017 to $1842.8m in 2023, according to a report by Mordor Intelligence.

Major drivers include the growing demand for radio-frequency devices in the semiconductor market, the booming consumer electronics market (particularly LED-based lighting and displays) and the proliferation of electric vehicles and photovoltaic inverters. Demand for smartphones, gaming devices, laptops and TVs will also provide modest growth potential in the consumer electronics sector. Although consumer electronics held the largest share in recent years, the maturing market for smartphones and laptops is expected to reduce the pace, paving the way for the expansion of the aerospace & defense sector.

In addition, the replacement of incandescent lamps with GaN LEDs in automobiles and the growing demand for electric vehicles are augmenting the GaN device market growth rate in the automotive sector. According to the International Energy Agency (IEA), the number of battery electric vehicles in use rose from 113,000 in 2012 to 1,209,000 in 2016.

However, the high production cost of gallium nitride compared to silicon carbide is one of the major factors that could hinder market growth, notes the report.

Growth of new industries to offer opportunities for expansion

Many chipmakers are now using GaN to make devices that support wireless electricity (WiTricity). GaN also enables chipmakers to reduce the cost of integrated circuits, driving broad adoption among semiconductor manufacturing companies. Wireless charging applications include phones, tablets, drones, laptops, industrial robots, appliances and automotive applications.

Autonomous vehicles use eGaN chips in their LiDAR systems to sense their environment. GaN chips are proven to be more accurate than silicon chips, to the scale of inches whereas silicon chips are limited to a range of 10 feet. Hence, with the increasing usage of GaN chips in new applications such as wireless charging and self-driving cars, the GaN device market is expected to grow significantly.

Consumer electronics the biggest sector

Due to growing innovation and adoption in the industry, the price of GaN technology is expected to fall, rapidly boosting adoption. Due to various advantages such as higher efficiency and higher operating frequency, many circuit boards used in day-to-day consumer electronic devices are expected to be replaced with GaN technology. GaN's adoption is expected to revolutionize charging technologies in existing devices, specifically in wireless charging, fast charging and in laptop chargers. For example, Cambridge Electronic Inc has developed transistors for charging purposes that are about 1.5 cubic inches in volume. There are also expected to be many innovations where the charging adapter is included inside the laptop, driving the market for GaN technology in consumer electronics. Due to their operating efficiency and smaller chip size (which aids cost saving and aesthetic appeal), these devices are also being used in LED-based TV screens. Moreover, the reduction in device size, such as in an uninterruptible power supply (UPS), increases the available office space or domestic space that can be used more productively.

Asia-Pacific to see fastest growth

Other crucial factors fueling market growth include the lower labor and production costs in the Asia-Pacific region. Moreover, due to the increasing production and export of consumer electronics products from China and Japan, the Asia-Pacific is expected to hold the highest share of the GaN market by 2023. China is one of the world's biggest EV markets, as well as the largest market for plug-ins (or new energy vehicles, NEV, as they are called in China). Also, in 2017 Tesla Motors announced plans to open its first manufacturing site outside the USA, in Shanghai. These factors are expected to increase demand for GaN in China.

Similarly, under the new government's plans to curb pollution, India has committed to sell only electric cars by 2030. Furthermore, Maruti Suzuki (the country's biggest car manufacturer) has teamed up with Toyota to launch its first electric car by 2019–2020. These factors are expected to increase GaN demand in India. In addition, the Indian government has announced an investment of 2.5% of its GDP in healthcare, starting from 2020 ($57bn, according to 2016's GDP), further increasing demand for GaN semiconductors in the healthcare segment.

Key market developments

In November, Osram and Continental announced plans for a joint venture for intelligent lighting solutions in the automotive sector. The JV will enable Osram and Continental to combine semiconductor-based lighting modules, advanced electronics, optics and software expertise, with access to sensor technology and innovative light sources.

In October, GaN Systems and Taiwan's Ministry of Economic Affairs (MOEA) signed a Letter of Intent to collaborate on expanding the economic and technical benefits of GaN technology to Taiwan's electronics companies. The collaboration is targeted at meeting the global challenges of unsustainable increases in power consumption, combating climate change, implementing cleantech technologies, and meeting green CO_2-reduction initiatives.

www.researchandmarkets.com

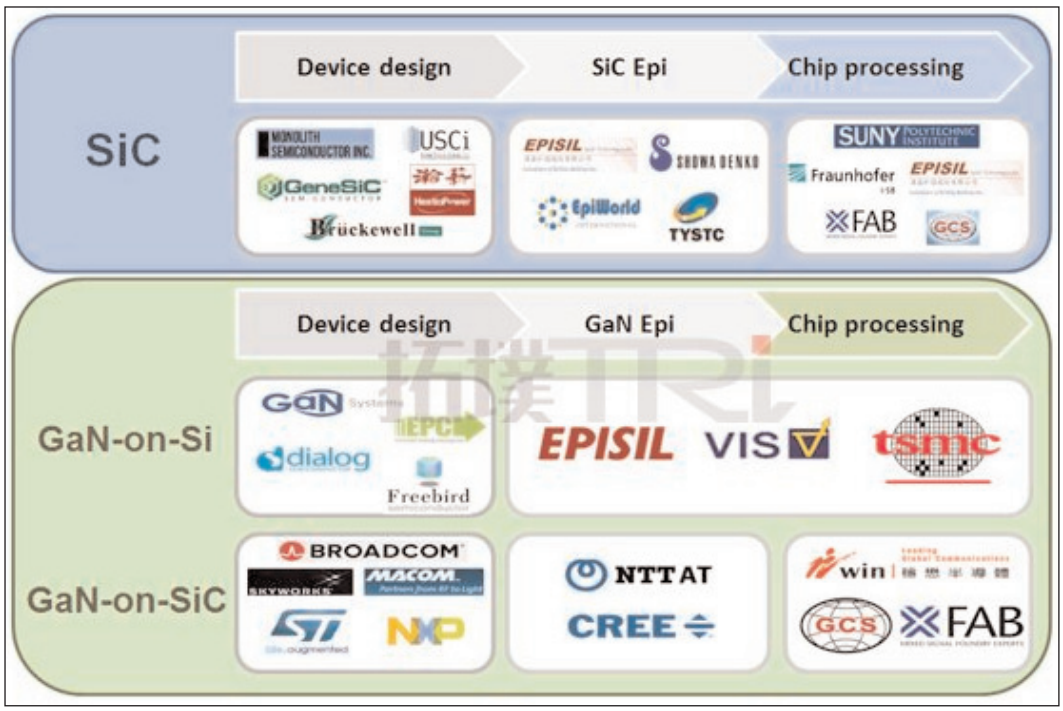
SiC and GaN substrate markets to grow to $180m and $3m respectively in 2018, driven by rapid development of 5G and automotive technology

Development of foundry services encroaching on IDMs in supply chain

5G is expected to enter commercial operation in 2020, while vehicles become more intelligent, networked and electric, driving the substrate market for the 'third-generation' semiconductor materials silicon carbide (SiC) and gallium nitride (GaN) to $180m and $3m, respectively, in 2018, forecasts market research firm TrendForce.

Compared with mainstream silicon-based devices, SiC and GaN devices are more resistant to high-voltage operations. SiC and GaN materials also outperform silicon in high-temperature and high-frequency operation, respectively. In SiC and GaN power devices, the sizes of chips are smaller, while the circuit designs are simplified, so modules, components and cooling systems are also smaller. The entire vehicle can hence become more lightweight. In addition, SiC and GaN's properties of low on-resistance and low switching loss will be key to improving automotive battery life, notes TrendForce, so the development of SiC and GaN power devices is closely associated with the advancement of electric vehicles.

However, SiC materials remain at the stage of testing and introduction. In the automotive area, SiC power devices are currently only applied in race cars, so SiC-based production by area accounts for less than 0.1% of all automotive power devices worldwide, according to TrendForce. Currently, GaN-on-SiC and GaN-on-Si are the two mainstream production approaches for GaN power devices. GaN-on-SiC has excellent heat dissipation performance and is suitable for high-frequency operation, making it commonly used in 5G base stations. It is expected that the SiC substrate market will rise in the next five years after automobile companies complete tests and 5G enters commercial operation in 2020.



Ecosystem of foundry services for products based on third-generation semiconductor materials.

The cost of GaN substrates remains high, so GaN substrate revenue is much smaller than that of SiC substrates currently. However, GaN devices' resistance to high-frequency conditions makes them a point of focus for technology companies, notes TrendForce. GaN-on-SiC technology is now used in high-specification products. On the other hand, GaN-on-Si is more cost effective and has become mainstream in the GaN power device market, with the possibility of greater growth in the sectors of power management chips and charging systems for automobiles and smartphones, reckons the market research firm.

Since these third-generation semiconductor materials show market potential due to the rapid development of 5G and automotive technology, manufacturers have begun providing foundry services for SiC and GaN devices, cutting into the supply chain where integrated device manufacturers (IDMs) like Cree, Infineon, Qorvo etc used to dominate. For example, Taiwan Semiconductor Manufacturing Corporation (TMSC, the world's biggest semiconductor wafer foundry) and Vanguard International Semiconductor (VIS) provide GaN-on-Si foundry services. Taiwan's WIN Semiconductors Corp focuses on GaN-on-SiC sectors and business opportunities arising from 5G base stations. Also, X-Fab, Episil Technologies and Global Communication Semiconductors (GCS) provide SiC and GaN foundry services. The development of foundry services will drive growth of the SiC and GaN materials market, concludes TrendForce.

www.trendforce.com

Guerrilla RF completes $3.8m Series E funding round

Funds to bolster working capital needs as firm nears profitability

Guerrilla RF Inc of Greensboro, NC, USA — a provider of radio-frequency integrated circuits (RFICs) and monolithic microwave integrated circuits (MMICs) for wireless applications — has completed a $3.8m Series E funding round (comprising a combination of equity and debt) with participation from multiple angel investors. Since being founded in April 2013 by Ryan Pratt, the firm has now raised $11.6m in funding and has more than 50 products shipping in production volumes.

Guerrilla RF expects to at least double 2018 revenue over 2017, and to increase staffing from 21 associates currently to 25 by the end of 2018.

"This year is off to a very fast start for us," says founder & CEO Ryan Pratt. "With multiple customer production ramps underway, it was clear we needed additional working capital. This Series E funding round gives us the working capital that we anticipate needing, with quite a lot of margin on top for any upside business," he adds. "Based on the revenue growth we see, we believe we're in striking distance of profitability for the first time."

According to Research and Markets, the overall wireless network infrastructure market will rise at a compound annual growth rate (CAGR) of more than 5% to over $104bn in annually by the end of 2020.

http://guerrilla-rf.com

Custom MMIC expands sales rep coverage into Scandinavia

As part of its global expansion, monolithic microwave integrated circuit developer Custom MMIC of Westford, MA, USA has added sales representation in the Scandinavian region.

Established in 1926, Oslo-based Bredengen AS will represent the firm in Norway. Established in 1968, Amtele Communication AB (which has offices in the Stockholm area, Gothenburg and Helsinki) will represent it in Sweden, Finland, Denmark and the Baltic countries.

Both firms have strong knowledge of their regions and long experience of selling RF & microwave products.

www.custommmic.com

Anokiwave launches its first intelligent gain blocks in new family of multi-function mmWave ICs

Anokiwave Inc of San Diego, CA, USA — which provides highly integrated silicon core chips and III-V front-end integrated circuits for millimeter-wave (mmW) markets and active antenna-based solutions — has launched its first intelligent gain blocks in a new family of multi-function microwave and millimeter-wave silicon ICs offering complete transmit/receive functionality with active gain and phase control. The new IC family offers versatile RF blocks that can be used in a wide range of applications including SatCom, radar, 5G communications, and sensing.

The AWMF-0117 and AWMF-0116 provide a power amplifier (PA), a low-noise amplifier (LNA), 6-bit gain and phase control and a transmit/receive (T/R) switch, all integrated into a single IC operating in the Ku- and Ka-bands.

The AWMF-0117 operates at 10.5–16GHz, providing +12dBm power output during transmit and 3dB noise figure during receive. The AWMF-0116 operates at 26–30GHz with +12dBm of power output during transmit and 6dB noise figure during receive. Both ICs provide 31.5dB of dynamic range and are packaged in a 2.5mm x 2.5mm wafer-level chip-scale package (WLCSP).

With these new ICs, designers can now use the same IC for multiple functions across the RF signal chain, have increased control using a software interface, and provide equivalent or better performance than traditional discrete gallium arsenide ICs

"Silicon technology allows integration of multiple RF functions into one IC for a very small form factor and low price," says Abhishek Kapoor, associate VP of business development. "With these new ICs, designers can now use the same IC for multiple functions across the RF signal chain, have increased control using a software interface, and provide equivalent or better performance than traditional discrete GaAs ICs," he claims. "We see these as the versatile new intelligent gain blocks of the microwave and millimeter-wave world."

For ease of adoption of the technology and capabilities, Anokiwave offers evaluation kits that include boards with the IC, USB-SPI interface module with drivers, and all required cables.

Pilot-production deliveries are available now.

www.anokiwave.com

AHS awarded UK contract for GaAs-based magnetic imaging of clandestine metallic threats

Award follows proof-of-concept demonstration in 2017

Advanced Hall Sensors Ltd (AHS) of Manchester, UK (which makes magnetic sensor products based on quantum effects in gallium arsenide materials) has been awarded a Phase 2 contract under the UK government's Innovative Research Call (IRC) in Explosives and Weapons Detection (2016) program to develop real-time, high-resolution magnetic imaging of clandestine metallic threats, following a successful proof of concept demonstration in 2017.

The technology is based on a radically new sensor that offers the essential characteristics to realise high-resolution, high-throughput magnetic imaging. GaAs-based quantum-well Hall-effect (QWHE) technology is >100x more sensitive than existing silicon Hall sensor technology, and is key to unlocking multiple benefits in the context of threat detection, i.e. nanoTesla sensitivities in an uncooled format, AC operation enabling 3D inspection, and minimal power consumption for portable implementation.

The superior sensitivity enables visualization of the geometrical characteristics of hidden metallic objects, determination of the type of metallic object (both ferrous and non-ferrous), discrimination of metallic combinations, and 3D profiling of metallic objects. In essence, the technology offers the advantages of x-ray imaging of metallic components without the need for an x-ray source.

The core sensing technology was developed at Manchester University by professor Mohamed Missous, and is being further refined for multiple applications under the UK Engineering and Physical Sciences Research Council (EPSRC) Future Compound Semiconductor Manufacturing Hub, in partnership with the Compound Semiconductor Centre.

The IRC in Explosives and Weapons Detection is a cross-government program sponsored by a number of Departments and Agencies under the UK Government's CONTEST strategy in partnership with the US Department of Homeland Security, Science and Technology Directorate.

AHS has supplied in excess of 15 million sensors to customers in industrial, medical, aerospace and the oil & gas industries.

The Compound Semiconductor Centre was founded in 2015 as a joint venture between Cardiff University and epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK, with the mission of accelerating the commercialization of compound semiconductor materials and device research. The centre is also key towards developing a compound semiconductor cluster in South Wales.

Core sensing technology was developed at Manchester University and is being further refined for multiple applications

The Future Compound Semiconductor Manufacturing Hub is a £10m EPSRC-funded initiative between Cardiff University (lead), Manchester University, Sheffield University and University College London, with support from 24 industry partners. The hub's vision is to establish the UK as the global leader in future compound semiconductor materials and device research.

www.ahsltd.com
www.compoundsemiconductorcentre.com/irc-2016-phase-2-contract

IN BRIEF

SEMI award honors RF-SOI pioneers

At the SEMI Industry Strategy Symposium (ISS Europe 2018) in Dublin, Ireland (4–6 March), industry association SEMI honored Bernard Aspar and Jean-Pierre Raskin with the annual European SEMI Award (established nearly 30 years ago to recognize individuals and teams that make significant contributions to the European semiconductor and adjacent industries).

Aspar and Raskin are recognized for their seminal work with radio frequency silicon-on-insulator substrates, involving pioneering research and collaboration with academia and industry that led to "major advances in RF switches and ushered RF-SOI technology from concept to worldwide adoption".

www.semi.org/eu

Skyworks joins ETSI

Skyworks Solutions Inc of Woburn, MA, USA has become a member of the European Telecommunications Standards Institute (ETSI), an independent, non-profit organization that sets global standards for telecommunications, broadcasting and other electronic communication networks and services.

ETSI is a channel through which the 3GPP organization submits contributions for 5G requirements. Membership consists of over 800 organizations from more than 60 countries across five continents.

As a member of ETSI, Skyworks is actively participating in the development of 5G standards critical to ensuring interoperability among systems and networks, compliance with legislation, security, and other needs of the industry. Skyworks is also a key contributor to the 3GPP body for Radio Access Network (RAN4) technical specifications.

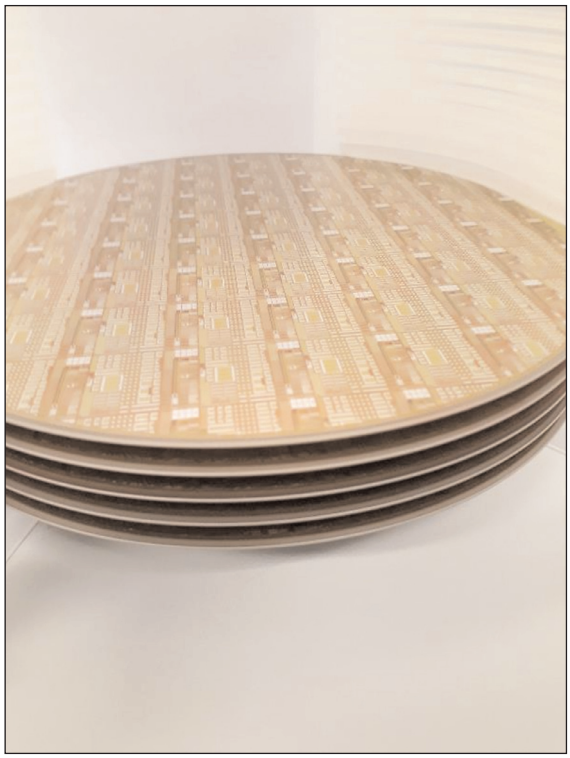
www.etsi.org
www.skyworksinc.com/Sky5

Imec and Qromis present p-GaN HEMTs on 200mm CTE-matched substrates

Thick GaN buffer layers pave way to GaN power technology operating above 650V

Nanoelectronics and photovoltaics research centre imec of Leuven, Belgium and fabless firm Qromis Inc of Santa Clara, CA, USA (formerly Quora Technology Inc, spun off from Micron Technology in March 2015) have developed high-performance enhancement-mode p-GaN power devices on 200mm engineered coefficient of thermal expansion (CTE)-matched substrates, processed on imec's silicon pilot line. The substrates are offered by Qromis as commercial 200mm QST substrates as part of its patented product portfolio.

Gallium nitride on silicon (GaN-on-Si) technology is currently the industry-standard platform for commercial GaN power switching devices for wafer diameters up to 150mm/6". Imec has developed GaN-on-Si power technology for 200mm/8" wafers and qualified enhancement-mode high-electron-mobility transistor (HEMT) and Schottky diode power devices for 100V, 200V and 650V operating voltage ranges, paving the way to high-volume manufacturing applications. However, for applications beyond 650V such as electric cars and renewable energy, it has become difficult to further increase the buffer thickness on 200mm wafers to the levels required for higher breakdown and low leakage levels, because of the mismatch in CTE between the GaN/AlGaN epitaxial layers and the silicon substrate. One can envisage using thicker silicon substrates to keep wafer warp and bow under control for 900V and 1200V applications, but practice has shown that, for these higher voltage ranges, mechanical strength is a concern in high-volume manufacturing, and the ever thicker wafers can cause compatibility issues in wafer handling in some processing tools.



Carefully engineered and CMOS-fab-friendly QST substrates with a CTE-matched core (with a thermal expansion that very closely matches the thermal expansion of the GaN/AlGaN epitaxial layers) are paving the way to 900–1200V buffers and beyond, on a standard semi-spec thickness 200mm substrate. Moreover, QST substrates open perspectives for very thick GaN buffers, including the realization of free-standing and very low-dislocation-density GaN substrates by >100µm-thick fast-growth epitaxial layers. These unique features enable the long-awaited commercial vertical GaN power switches and rectifiers, suitable for high-voltage and high-current applications presently dominated by silicon IGBTs and silicon carbide (SiC) power FETs and diodes.

"QST is revolutionizing GaN technologies and businesses for 200mm and 300mm platforms," claims Qromis' president & CEO Cem Basceri. "I am very pleased to see the successful demonstration of high-performance GaN power devices by stacking leading-edge technologies from Qromis, imec and Aixtron," he adds.

In this specific collaboration, imec and Qromis developed enhancement-mode p-GaN power-device-specific GaN epitaxial layers on 200mm QST substrates, with buffers grown in Aixtron's G5+ C 200mm high-volume manufacturing metal-organic chemical vapor deposition (MOCVD) system. Imec then ported its p-GaN enhancement-mode power device technology to the 200mm GaN-on-QST substrates in their silicon pilot line and demonstrated high-performance power devices with a threshold voltage of 2.8V.

"The engineered QST substrates from Qromis facilitated a seamless porting of our process of reference from thick GaN-on-Si substrates to standard-thickness GaN-on-QST substrates using the AIX G5+ C system, in a joint effort of imec, Qromis and Aixtron," says Stefaan Decoutere, program director for GaN power technology at imec. The careful selection of the material for the core of the substrates, and the development of the light-blocking wrapping layers resulted in fab-compatible standard-thickness substrates and first-time-right processing of the power devices.

Imec acknowledges funding from the Electronic Component Systems for European Leadership Joint Undertaking under grant agreement No 662133, designated as PowerBase.

www.imec.be
www.qromis.com
www.imec.com

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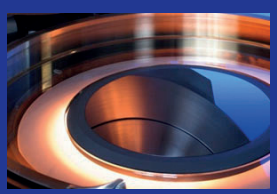

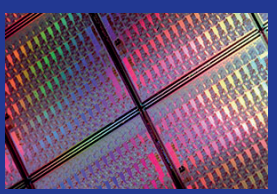

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Curious? For further information, please contact us at **NAsP.de**

GaN Systems first to surpass 10,000 hours of qualification testing for GaN E-HEMT devices

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) has surpassed 10,000 hours of qualification testing for its GaN E-HEMT devices. This is 10x the 1000-hour requirement to meet JEDEC qualification. As the power electronics industry increases adoption of GaN power transistors, the need for high confidence in the technology is imperative, states the firm.

Electronics are expected to last a long time. For computers and cell phones this may be a couple of years for some, but 5–10 years for others. For our homes, offices and factories, 20+ years are routinely expected. While nearly all automobiles are on the road for only a few years, expectations are that some will last for 20 years or more. End-users and power equipment makers want long-lifetime equipment. Also, power system manufacturers want to make sure that the semiconductors in their products last far longer than the expected life of the system. With long lifetime in mind, semiconductor manufacturers perform accelerated testing at elevated temperature, voltage and current to prove these long durations. The longer the duration of the accelerated reliability tests, the longer the lifetime of the semiconductors in the real world.

The industry standard of 1000 hours of JEDEC testing equates to 10+ years of lifetime at normal operating conditions. Extend that testing by 10x to 10,000 hours (1.5 years) and the lifetime jumps to >1000 years. This is what the power system makers want: GaN semiconductors that outlast the rest of the system.

"One and a half years of testing at accelerated conditions takes a lot of ovens, a large number of test equipment and a lengthy amount of time," says CEO Jim Witham. "For GaN Systems, this is a notable achievement," he adds. "Our customers from consumer electronics to automotive electric vehicles are pleased to see GaN transistor long lifetime clearly demonstrated."

NuCurrent partners to extend wireless charging to 150W

In partnership with GaN Systems, Chicago-based firm NuCurrent has developed 150W wireless power systems designed for industrial and consumer applications with high power needs. This builds on NuCurrent's achievements in wireless power and wireless charging, including the development of what is claimed to be the thinnest and most efficient (highest Q) 15W wireless charging antennas for smartphones.

"Following the rapid adoption of wireless charging for devices that need a few watts of power, customers are demanding solutions that deliver higher levels of power," says NuCurrent's VP of sales & marketing Tim Tumilty. "Our new solutions solve the most important challenges for product categories that need 150W or more."

Smartphones and small electronic devices typically require less than 15W of power and are well suited for silicon-based transistors. However, for wireless charging applications needing 150W or more, existing silicon-based transistors can heat up and become inefficient. To address this challenge, NuCurrent selected a 150W gallium nitride-based power amplifier from GaN Systems.

NuCurrent antennas with patented MLMT technology enable wireless power transfer from sub-1W to 150W.

"These solutions open up wireless charging to new categories like power tools, autonomous robots, drones, and more," says GaN Systems' VP strategic marketing Paul Wiener. "With NuCurrent's technology and system design capabilities and our high-power transistor and amplifier capabilities, the possibilities for wireless charging at high power levels have been expanded in some really important directions."

Demonstrations of the 150W wireless charging solutions will be given in booth #511 (hall 9) at the Power Conversion and Intelligent Motion (PCIM 2018) conference in Nuremberg, Germany (5–7 June).

www.mesago.de/en/PCIM
www.gansystems.com
www.nucurrent.com

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Zhejiang University develops kilovolt vertical GaN Schottky barrier diode with 825MW/cm² figure-of-merit

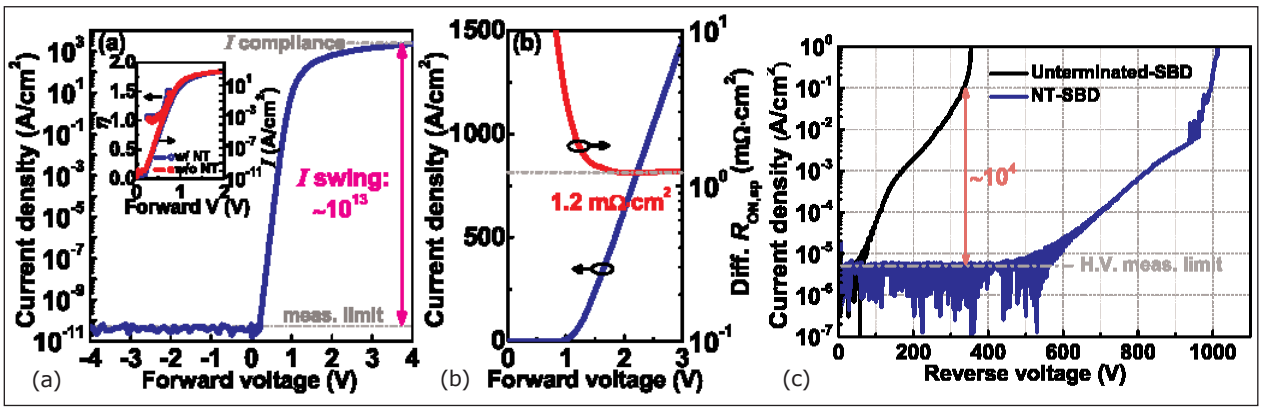
China's Zhejiang University (ZJU) has developed a 1kV/1.2mΩcm² vertical GaN-on-GaN Schottky barrier diode (SBD) featuring a high Baliga figure-of-merit (BFOM) of 825MW/cm² and eight-order ON/OFF current ratio at –600V, which is claimed to be one of the best reported for vertical unipolar GaN power rectifiers ('High-voltage and high-I_{ON}/I_{OFF} vertical GaN-on-GaN Schottky barrier diode with nitridation-based termination' by Shaowen Han, Shu Yang and Kuang Sheng; IEEE Electron Device Letters, vol39, no4, p572).

To overcome electric field crowding-induced leakage at the junction edge and premature breakdown, the ZJU team has developed a simple planar nitridation-based termination (NT) technique for favorably modifying the GaN surface condition, which can effectively suppress the reverse leakage by over 10^4 and boost the breakdown voltage up to 1kV.

Furthermore, by using ultraviolet photoemission spectroscopy (UPS) characterization and TCAD simulations, the researchers have revealed the mechanism of leakage suppression by NT. It is experimentally verified that the NT structure yields an enlarged barrier height and/or effective barrier thickness at the junction edge and, consequently, electron transport via thermionic field emission or tunneling can be suppressed, leading to significantly suppressed edge leakage. This is believed to be the first report revealing the physical mechanism of termination technology that is well suited for high-voltage vertical GaN power devices.

Breakdown voltage is boosted from 335V for an unterminated-SBD to 995V after the planar nitridation-based termination. With a differential specific ON-resistance of 1.2mΩcm², a high ON/OFF current ratio (I_{ON}/I_{OFF} at –600V) of ~10^8 is realized. The 1kV/1.2mΩcm² vertical GaN SBD exhibits a high current swing of ~10^{13}, large forward current density over kA/cm², and nearly ideal Schottky contact with a low ideality factor of 1.01–1.04, showing great potential for high-power and high-frequency applications, says the researchers.

http://ieeexplore.ieee.org/document/8300629
http://ee.zju.edu.cn/english



(a) Current–voltage characteristics of the NT-SBD on a semi-log scale at a temperature of 25°C. Inset: comparison of I–V characteristics and ideality factor η between unterminated-SBD and NT-SBD. (b) Forward I-V characteristics of NT-SBD in linear scale and extracted differential $R_{ON,sp}$ of the NT-SBD. (c) Reverse I-V characteristics of the unterminated-SBD and NT-SBD.

Cree licenses GaN power device patents to Nexperia

Cree Inc of Durham, NC, USA has signed a non-exclusive, worldwide, royalty-bearing patent license agreement that provides discretes, logic and MOSFET device maker Nexperia BV of Nijmegen, The Netherlands, with access to its gallium nitride (GaN) power device patent portfolio, which includes over 300 issued US and foreign patents that describe aspects of high-electron-mobility transistor (HEMT) and GaN Schottky diode devices. The portfolio addresses novel device structures, materials and processing improvements, and packaging technology. The patent license involves no transfer of technology.

"Cree was founded to develop novel compound semiconductor materials like GaN and SiC and to create devices that capitalize on their unique properties," says John Palmour, co-founder of LED chip, lamp and lighting fixture maker Cree and chief technology officer of its Wolfspeed business (which makes power & RF devices and silicon carbide materials). "Cree's decades of innovation are now yielding devices that enable market introductions of new power management and wireless systems. To help facilitate the growth of these new markets, Cree is licensing its GaN power device patents for GaN power-management systems."

www.cree.com/About-Cree/Licensing/Licensees
www.wolfspeed.com
www.nexperia.com

Toyoda Gosei achieves high-current operation with vertical GaN power semiconductors

Toyoda Gosei Co Ltd of Kiyosu, Aichi Prefecture, Japan has achieved high-current operation in vertical gallium nitride (GaN) power semiconductor devices.

Power semiconductors are widely used in power converters such as power sources and adaptors for electronic devices. However, simultaneous achievement of both high breakdown voltage and low loss (low conduction loss and switching loss) at high levels has been difficult using conventional silicon due to its material properties.

In contrast, GaN has material properties of high breakdown voltage and low loss, and Toyoda Gosei's power semiconductors employ a vertical device structure in which electrical current flows vertically from or to the substrate. These changes have enabled a GaN power transistor chip with operating current of more than 50A (claimed to be the highest ever reported for vertical GaN transistors) and high-frequency operation (several megahertz).

Toyoda Gosei says that it will continue development of the power semiconductors for improved reliability, aiming to achieve practical applications in cooperation with semiconductor and electronics manufacturers. Prospective applications include more compact, lighter-weight and higher-efficiency power converters (e.g. DC–DC converters and power control units for automobiles etc) and higher-output high-frequency power sources (e.g. in wireless power supplies).

The new vertical gallium nitride power transistors (MOSFETs) and Schottky barrier diodes (SBDs) were presented on panel displays at the Techno-Frontier 2018 Advanced Electronic & Mechatronic Devices and Components Exhibition at Makuhari Messe, Chiba, Japan (18–20 April). Also demonstrated were the first full vertical-GaN DC–DC converter equipped with these devices.

www.jma.or.jp/tf/en
www.toyoda-gosei.com

L-band GaN amplifiers from Integra

Integra Technologies Inc of El Segundo, CA, USA (which designs and manufactures high-power RF and microwave transistors and power amplifiers) has launched two new L-band gallium nitride (GaN)-based amplifiers.

The IGNP0912L1KW is a 50Ω-matched GaN-based high-power pulsed pallet amplifier for L-band avionics systems operating over the instantaneous bandwidth of 0.960–1.215GHz. Supplying minimum peak pulse power of 1000W under the conditions of 2.5ms pulse width and 20% duty cycle, the new pallet amplifier is suitable for Class AB operation with what is claimed to be excellent thermal stability. The IGNP0912L1KW has a gain of 12.0dB, frequency of 0.1–1.0GHz and a voltage of 28V.

Also, the IGNP1214M1KW-GPS is a single-supply 50Ω-matched GaN-based pulsed power pallet amplifier for L-band radar systems, operating in the 1.2–1.4GHz instantaneous frequency band. The high-efficiency, low-input/output VSWR pallet amplifier supplies a minimum of 1000W of peak pulsed output power under the conditions of 300μs pulse width and 10% duty cycle. The pallet contains bias sequencing and RF-activated gate biasing circuitry to simplify system integration.

All devices are 100% screened for large-signal RF parameters.

www.integratech.com

AXT lowers Q1 revenue forecast from $26–27m to $24–24.5m after China government-ordered factory shutdown days

First phase of new factory completed in Dingxing, China

AXT Inc of Fremont, CA, USA — which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials — has lowered its first-quarter 2018 revenue forecast from $26–27m to $24–24.5m, due to government-ordered mandatory factory shutdowns in Beijing caused by severe air pollution that occurred late in the quarter. From 27 February to 31 March over 300 manufacturing companies were intermittently shut down for a total of ten days (30% of the calendar days in this period).

"We were disappointed that air quality conditions in Beijing triggered mandatory shutdowns late in the quarter, which prevented AXT from meeting our guidance expectations," says CEO Morris Young. "We were working hard to narrow the gap but the last week of March alone had three shutdown days," he adds.

"The demand environment, however, remains solid as AXT substrates continue to perform well, particularly in applications where customer requirements are most stringent," continues Young. "We are optimistic about our business opportunity in 2018, and believe we are well-positioned to take advantage of positive trends in a number of applications, including high-end LED lighting, infrared and other sensors requiring low-EPD [etch-pit density] wafers, passive optical networks, data-center connectivity and satellite solar cells."

AXT also says it has completed the first phase of facilitization of its new manufacturing facility in Dingxing, China (about 90 miles south of its Beijing factory) and is progressing well on its staged relocation.

"We have installed wafer processing equipment and have produced initial wafers at this site that can be used for qualification," Young says. "With the continued solid execution by our team, we are on schedule with our plans and pleased with our progress to date," he adds. "This new technically advanced facility gives us the opportunity to plan our business for our next stage of growth and to support the longer-term capacity requirements of our customers."

www.axt.com

AKHAN's Miraj diamond technology awarded Taiwan patent and US trademark

AKHAN Semiconductor Inc of Gurnee, IL, USA, which specializes in the fabrication and application of lab-grown, electronics-grade diamond as functional semiconductors, has obtained official notifications from both the United States Patent and Trademark Office (USPTO) and Taiwan Intellectual Property Office (TIPO) for the Miraj Diamond trademark registration and patent allowance.

The official registration of the Miraj Diamond mark by the USPTO (Registration No. 5,438,740) follows nearly six years of completed filings fulfilled by firm following its launch in December 2012. The TIPO issued patent I615943 is the second AKHAN patent to be granted by the country. The patent is a foreign counterpart of other issued and pending patents owned by AKHAN that are used in its Miraj Diamond products. The firm says that the claims protect uses far beyond the existing applications, including microprocessors. Covering the base materials common to nearly all semiconductor components, the intellectual property can be realized in everything from diodes, transistors and power inverters to fully functioning diamond chips such as integrated circuitry.

"The official declarations from both the USPTO and TIPO significantly add to the critical protections of the Miraj Diamond intellectual property portfolio and brand," says founder & CEO Adam Khan. "Less than six years after our founding, the Miraj Diamond trademark is not only gaining global attention from the consumer electronics and semiconductor market places, but is also synonymous for next-generation performance, breakthrough capability, and flagship technology with diamond," he adds.

"The notices of these issuances are very timely as we complete the construction of our cleanroom pilot production facility in northern Illinois," notes president & chief operating officer Carl Shurboff, who highlights the targeted 2019 launch of Miraj Diamond Glass products for Smartphone devices and the concurrent development of Miraj Diamond electronics products for aerospace and defense.

"Safeguarding the technology and trademark from infringement, improper use and other challenges benefits not only our OEM customers, by preserving their market value and time-based exclusivity, but also our shareholders, corporate development partners, and technology partners around the world," says Jeffrey G. Miller, sales advisor to the board.

www.akhansemi.com

Riber returns to annual profit

Year-on-year revenue growth of at least 15% targeted for 2018

For full-year 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 growth of 86% from 2016's €16.5m to €30.6m (49% from Asia, 33% from Europe and 18% from North America). Growth was driven by sales of evaporators (cells and sources) for the screen and photovoltaic industries, as well as sales of services and accessories.

Revenue for MBE systems was €7.2m, down 19% on 2016's €8.8m due to a lower level of billings: five systems (including two production units) in 2017 versus six machines (including two production units) in 2016.

Revenues for services & accessories were €7.2m, up 56% on 2016's €4.6m, supported by the reactivation of production capacity by industrial customers.

Revenues for evaporators (cells and sources) were €16.2m, up 435% on 2016's €3m, driven by major contracts to supply evaporators for the photovoltaic and screen industries.

Gross margin rose from 36.4% in 2016 to 44.5% in 2017

Net income was €4.1m, compared with a net loss of –€1.1m in 2016, benefiting from €1m of tax income linked to the capitalization of losses carried forward.

The increase in funds collected on billing and the advance payments received on orders has contributed to a stronger cash position, up by €4.9m during 2017 from €2.5m to €7.4m.

Shareholders' equity is up by €4.3m to €19.8m. The firm says that it hence has the financial resources needed to finance its development.

The order book has risen by 44% during 2017 from €18m to €25.8m.

Systems order are up 121% from €5.5m to €12.2m, including seven MBE systems (of which five are production machines).

Services & accessories orders are up 34% €3.7m to €4.9m, reflecting the robust development of production and research MBE activities.

Order for evaporators (cells and sources) remains roughly unchanged at €8.7m.

In view of this order book, plus orders received since the start of 2018 (for major accessories for Asia; a research MBE system for the USA; and a production MBE system for China, all for delivery this year), Riber is targeting year-on-year revenue growth of at least 15% for 2018.

Riber's executive board will be submitting a proposal for approval at the General Meeting on 21 June for a dividend of €0.05 per share (deducted from the share premium account), to be released for payment on 28 June.

www.riber.com

Riber receives order from China for research MBE systems

Riber says that it has received an order from a Chinese research institute for two fully automated MBE412 research systems, to be delivered in 2019 and used for developing solar cells.

Enabling epitaxial deposition on either a 4"-diameter wafer or on multiple 2" wafers, Riber says that its MBE412 systems are used mainly for the development of new microelectronic or opto-electronic devices, as well as qualification before going into full production.

www.riber.com

ON Semiconductor orders Veeco Propel HVM MOCVD system for GaN power electronics manufacturing

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that, based on a beta evaluation, ON Semiconductor of Phoenix, AZ, USA — which supplies power management, analog, sensors, logic, timing, connectivity, discrete, system-on-chip (SoC) and custom devices — has ordered its production-level Propel High-Volume Manufacturing (HVM) metal-organic chemical vapor deposition (MOCVD) system, to be used for gallium nitride (GaN) power electronics manufacturing.

As what is described as the industry's first single-wafer cluster platform, the Propel GaN MOCVD system is specifically designed for high-voltage power-management devices used in data centers; automotive, information and communication technology; defense; aerospace and power distribution systems, among other applications.

"Our prior learning with Veeco's K465i GaN MOCVD system drove us to investigate the Propel HVM platform for our production ramp," says Marnix Tack PhD, senior director of corporate R&D and Open Innovation at ON Semiconductor. "The beta-test results demonstrated superior device performance with high uniformity and within-wafer and wafer-to-wafer repeatability, while meeting our cost-of-ownership targets for 6- and 8-inch wafers," he adds. "As such, the Propel HVM system proved to be the most suitable platform for our power electronics manufacturing needs."

Veeco's Propel HVM MOCVD system.

Introduced recently for high-volume production of power electronics, laser diodes, RF devices and advanced LEDs, the Propel HVM platform is based on Veeco's single-wafer system with proprietary IsoFlange and SymmHeat technologies that provide homogeneous laminar flow and uniform temperature profile across the entire wafer.

"The Propel HVM platform is rapidly gaining traction in the industry as innovative companies like ON Semiconductor recognize the benefits of GaN-on-silicon, which will partially replace current silicon technology for power electronics," says Peo Hansson PhD, senior VP & general manager of Veeco MOCVD operations. "With its highly controlled doping, run-to-run stability, superior wafer uniformity, high productivity and uptime, Propel HVM extends the benefits of our TurboDisc platform to a unique single-wafer architecture," he adds. "These capabilities benefit customers that seek a superior solution for manufacturing while providing a path for scaling to 8-inch wafers and expansion to RF and other advanced applications."

www.onsemi.com
www.veeco.com

Azur Space adds customized Aixtron AIX 2800G4 8x6" system to expand production of space and CPV solar cells

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany is providing its latest metal-organic chemical vapor deposition (MOCVD) technology to aerospace supplier Azur Space Solar Power GmbH of Heilbronn, Germany (a long time user of Aixtron's planetary technology).

The customized AIX 2800G4 series system with an 8x6"-wafer configuration (delivery in second-quarter 2018) will further expand production of highly efficient multi-III-V space and concentrator solar cells, which are mainly used in the solar panels of satellites.

The AIX 2800G4 system follows the predecessor models of the G3 series and enables the production of 6" epitaxial wafers from gallium arsenide (GaAs) on germanium (Ge). Azur Space benefits not only from the homogeneity of the processed wafers but also from the economic advantages of the AIX 2800G4 - with maximum throughput and yield combined with the most efficient use of resources, the system is claimed to set standards in the semiconductor industry regarding the lowest cost per wafer.

"Applications in the aerospace industry have special requirements regarding the longevity and performance of solar cells," notes Azur Space's managing director Jürgen Heizmann. "With the introduction of the AIX 2800G4, we have deliberately set a very decisive, long-term course to continue to be able to supply competitive high-performance solar cells for the construction of space satellites in the future," he adds.

www.azurspace.com
www.aixtron.com

Edwards Vacuum breaks ground on new Technology Innovation Center & North American HQ in Hillsboro

After completing the purchase of an 8-acre site (a collaborative effort with Avison Young), Edwards Ltd of Crawley, UK (a manufacturer of vacuum products and abatement systems and a provider of related services) has begun construction of a new 75,000ft^2 Technology Innovation Center in Hillsboro, OR, USA (due to open in second-quarter 2019) that will serve as the firm's North American semiconductor headquarters.

"This project spanned two years of due diligence, analysis, and negotiation that included the collaboration of half a dozen firms and experts," notes Ed English, senior VP at Avison Young, whose team worked closely with Edwards to lead the real-estate strategy and implementation. "Edwards originally planned to lease the facility, but ultimately chose to purchase it."

Edwards held a ground-breaking ceremony at the site (on NE Century Boulevard) attended by company officials and local dignitaries, including Hillsboro City mayor Steve Callaway and Hillsboro Chamber of Commerce president Deanna Palm.

"Edwards has many options for global investment, and our community greatly appreciates Edwards and its commitment to Hillsboro," comments Callaway. "As a city, we will continue to support Edwards employees when the new high-tech facility opens," he adds.

"Our state-of-the-art innovation center and manufacturing facility is strategically located close to some of our key accounts in the Pacific Northwest, and will enable us to work closely with them, as well as other customers in North America, on R&D and continuous improvement programs," says Scott Balaguer, VP & general manager, Semiconductor Division North America. "This proximity will also enable us to provide rapid service & support, as well as serve as our regional training center.

Edwards has about 100 staff at its current Hillsboro locations and, with consolidation, expects to double in size at the new facility.

"Edwards is fully committed to the Northwest Region, creating jobs and participating in the local growth, as environmentally conscious corporate stewards in the neighbourhood," says Balaguer. "We anticipate continued expansion on site, as we plan to design & manufacture our integrated vacuum & abatement production solutions, as well as other world-class products in our portfolio," he adds.

www.edwardsvacuum.com

Groundbreaking for Edwards' new innovation center and North American semiconductor headquarters in Hillsboro.

Plasma-Therm acquires KOBUS

Fast Atomic Sequential Technology pulsed CVD provides alternative to ALD for thick, conformal layers

Plasma-Therm LLC of St Petersburg, FL, USA (which makes plasma etch, deposition and advanced packaging equipment for specialty semiconductor and nanotechnology markets) has acquired plasma deposition firm KOBUS of Montbonnot, France, which enables FAST (Fast Atomic Sequential Technology), an alternative to atomic layer deposition where thick and conformal films are required.

As a unique deposition method at the intersection between ALD and CVD, FAST is enabled by a proprietary chemical vapor deposition (CVD) reactor design combined with pulsing capability and, while capable of depositing in traditional ALD mode, it is optimal for thick and conformal layer deposition and offers new solutions for 3D integration challenges, Plasma-Therm says.

KOBUS offers a unique portfolio of equipment for both mature and advanced materials deposition, expanding Plasma-Therm's plasma-based deposition and etch suite of products for all silicon and emerging compound semiconductor applications.

Plasma-Therm reckons that the acquisition will allow it to establish a solid base in Europe and conduct R&D in Grenoble's 'Silicon Valley', a region fueled with R&D, startups and large semiconductor corporations.

www.kobus-tech.com/technologies/fast
www.plasmatherm.com

CORIAL appoints Innodys as new sales rep in Europe

Plasma etch and deposition equipment maker CORIAL of Bernin, France has expanded its sales network in Europe by signing a new representation contract with Innodys of Mennecy, France. Innodys and CORIAL will work together with the teams at each of Innodys' local offices in France, Germany and UK.

Since 1989, Innodys has been a European distributor and manufacturer's representative for semiconductor systems and components. Offering complete equipment solutions for process steps including wet processing, photolithography, dry processing and metrology, team members have experience in sales and support of plasma etch and deposition tools.

According to the agreement, Innodys will take on sales, marketing and technical support locally for CORIAL in France, Switzerland, Germany, BENELUX, and UK.

www.innodys.com/france
www.corial.com

SPTS awarded 'Supplier of the Year – Customized Frontend Equipment' by Infineon

Orbotech Ltd of Yavne, Israel says that its company SPTS Technologies Ltd of Newport, Wales, UK — which manufactures etch, physical vapor deposition (PVD) and chemical vapor deposition (CVD) and thermal wafer processing solutions for the MEMS, advanced packaging, LED, high-speed RF on GaAs, and power management device markets — has been awarded 'Supplier of the Year — Customized Frontend Equipment' at Infineon Technologies' Supplier Day in Singapore for its "outstanding support and the performance of its plasma etch and physical vapor deposition equipment".

Infineon's global operational and management teams rated and ranked suppliers against stringent criteria. SPTS was selected for supporting Infineon's Power and MEMS business with its etch and deposition solutions. The award was presented to Kevin Crofton (corporate executive VP at Orbotech and president of SPTS Technologies) by Pantelis Haidas (senior VP operations) and Achim Janker (senior director – head of purchasing Frontend). SPTS was specifically recognized for being an "excellent long-term and reliable partner to Infineon", highlighting the collaborative development of special process and hardware solutions to meet Infineon's current and future needs.

"We continually strive to achieve a high level of customer satisfaction, and receiving this third Supplier Excellence Award is a real testament of the quality and performance of our engineering, operations and support teams across the company," says Crofton. "As a long-time trusted partner of Infineon's Power and MEMS businesses, we look forward to many more years of innovating together."

Infineon is the market leader in power semiconductors, retaining the top spot for both discrete power semiconductors and power modules, according to last August's 'Annual Power Semiconductor Market Share Report 2017' by IHS Inc. SPTS is a preferred supplier and partner to Infineon, and provides etch, deposition and thermal wafer processing equipment to its fabs in Villach, Dresden, Regensburg and Kulim.

www.spts.com
www.infineon.com

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Eulitha nano-lith system for Lund's nanowire research

Eulitha AG of Kirchdorf, Switzerland (a spin-off of the Paul Scherrer Institute in Villigen that offers lithographic equipment and services for nanotechnology, photonics and optoelectronic applications) has received an order for a PhableR 100 DUV photolithography systems from Sweden's Lund University, a leader in the materials science and applications of nano-structured semiconductors.

The PhableR 100 DUV exposure tool incorporates Eulitha's proprietary Displacement Talbot Lithography technology that enables robust printing of very high-resolution periodic patterns at low cost. The system ordered by Lund operates with a 193nm ArF excimer laser that enables printing of features much smaller than 100nm.

The new tool will be installed at the Lund Nano Lab (LNL) nanofabrication facility, which is operated by NanoLund, the Center for Nanoscience at Lund University. LNL has over 80 installed processing tools, including epitaxial systems, patterning tools and characterization equipment, serving more than 150 users from academic research groups and industry.

"We are grateful to both the university's Faculty of Engineering (LTH) and NanoLund for granting us the funding to purchase the PhableR 100 DUV system," says Lund Nano Lab's operations manager Dr Maria Huffman. "Also, we are very pleased that the technical leadership of Hexagem AB shared with us their data on gallium nitride (GaN) nanowires grown on substrates patterned on the Eulitha tool, which enabled us to evaluate the tool in a very efficient and effective manner," she adds. "This Displacement Talbot Lithography system will be useful to a variety of research projects and applications within the NanoLund research community. It will not only provide added capabilities currently lacking at the LNL but will also be a unique tool within Sweden… Such a capability will attract various researchers, both locally and nationally."

The PhableR 100 DUV system can expose periodic patterns with feature sizes well below 100nm, rivaling the performance of much more expensive state-of-the-art steppers, claims Eulitha. "This equipment will let us address the feature size range of 90–100nm, which makes it very attractive to all nanowire growers within the research community, in particular those working on LED and solar cell development," says Huffman.

"One key advantage is the fact that this is a non-contact technique, perfectly suitable for sensitive substrates," she adds. Patented focus-free imaging enables uniform printing on non-flat substrates often employed in photonic and optoelectronic sectors.

Eulitha has previously announced the delivery of lithography systems to the University of Bath in the UK and Waterford Institute in Ireland.

www.eulitha.com

BluGlass appoints VP of business development, leading expansion of custom services subsidiary EpiBlu

BluGlass Ltd of Silverwater, Australia has appointed Brad Siskavich to a full-time role as VP of business development, based in the USA and leading the expansion of BluGlass' custom services business EpiBlu Pty Ltd, amongst other things.

BluGlass is commercializing its proprietary low-temperature remote-plasma chemical vapor deposition (RPCVD) process for manufacturing indium gallium nitride (InGaN)-based LEDs, power electronics and solar cells, offering benefits including higher performance and lower cost, it is claimed.

"As our commercialization plans around RPCVD continue to become firmer, and as we continue to add to and expand on our joint venture partnerships, it's essential that we develop and prepare our export expertise ahead of time," says managing director Giles Bourne.

Siskavich has more than 20 years' experience in developing, marketing and commercializing new technologies in start-up and high-growth environments in the compound semiconductor, solar photovoltaic, laser, photonics and optoelectronics industries. He previously worked in senior research and business development roles at companies including Emcore, Oxford Instruments and Masimo Semiconductor.

The subsidiary EpiBlu is BluGlass' service arm and offers specialized custom epitaxy, foundry and characterization at its facility in Sydney, Australia. EpiBlu will continue to expand its operations, providing both MOCVD and BluGlass' unique low temperature RPCVD services. This revenue-generating business also creates new opportunities to introduce RPCVD to customers in the optoelectronics industry.

The appointment represents "a new commitment to building our custom service revenues," says Bourne. "He brings significant industry expertise to BluGlass, with deep research and business development experience across the sector. His role has a global focus for the EpiBlu service business; and provides us with a dedicated resource based in the US to develop export markets."

RPCVD will become "a key enabler in developing new technologies and market opportunities," says Siskavich. "Specialist compound semiconductor markets, including micro-LED, UV LED, laser diode and power semiconductor markets, are showing rapid growth. These new technologies will require advanced flexibility and performance, and this is where the RPCVD technology will have a competitive edge."

www.bluglass.com.au

UV LED curing firm Phoseon investing in factory and global business expansion

UV LED curing firm Phoseon Technology of Hillsboro, OR, USA has announced its continued business expansion and growth plan.

"The positive investment atmosphere for corporations in the US and the continuing need for innovative LED solutions demanded by the markets we serve have created the need for further expansion of our Hillsboro, Oregon, facility," says president & CEO Bill Cortelyou. "Operating as a global supplier to the industry, the latest move by the US government to support a competitive corporate tax structure will make us even more competitive."

Phoseon will expand its headquarters by more than 50%, including added space for manufacturing, design and its new Life Sciences division. Phoseon has exceeded 25% annual growth for the past five years and the expansion is targeted at enabling the firm, with 175 staff, to accelerate its growth. In addition to this US expansion, Phoseon recently established a wholly owned entity in Shanghai.

"The UV LED market is still in its infancy," comments Avinash Matani, research analyst at The Insight Partners. "As the technology grows and matures, and market leaders like Phoseon Technology amplify its capabilities, we expect this market to continue to grow at greater than 25% annually."

The UV LED market is expected to exceed $1.3bn by 2025. A rise in the number of firms offering UV LED packages, and expansion of UV technology in various applications (curing, purification, analytical instruments and medical phototherapy) will have the biggest impact on UV LED adoption, it is thought.

"Phoseon is encouraged by the progress and market presence we've attained over the past 16 years," says chief financial officer Chris O'Leary. Since 2002, the firm has shipped more than 100,000 lamps for applications ranging from packaging solutions for consumer goods to disinfection of laboratory samples. "With a strong balance sheet, we will continue to invest heavily in research and development to enable high-value solutions to lead this market transition. Phoseon currently offers the broadest portfolio of innovative LED solutions across the industrial curing and life sciences market," he claims.

www.phoseon.com

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FBH presents UV LED chip and module developments at ICULTA-2018

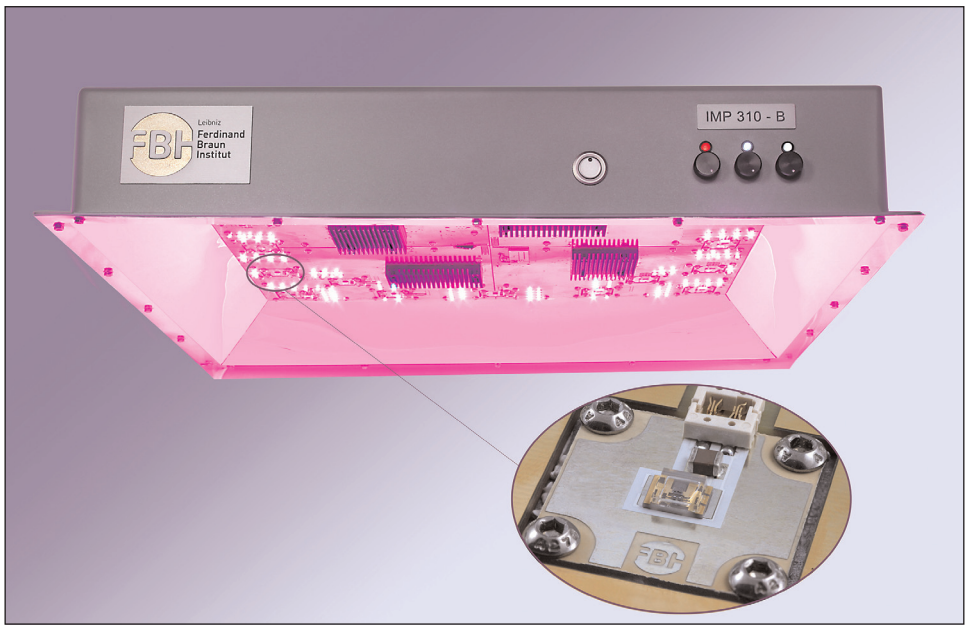
At the International Conference on UV LED Technologies & Applications (ICULTA-2018) in Berlin, Germany (22–25 April), the Berlin-based Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH) and its spin-off UVphotonics NT GmbH gave several invited talks as well as being present in booths at the accompanying exhibition.

Progress in development for industrial applications

Increased efficiency and output power are making UV LEDs more attractive for a constantly growing number of applications including disinfecting water, air and surfaces, detecting pathogenic germs and curing of synthetic materials.

FBH and UVphotonics report on progress in UV LED efficiency and reliability. This includes identifying a degradation mechanism that points to operation-induced electro-migration of hydrogen in the UV-B LED structure during the first hours of operation, which is accompanied by a drop in optical output power. After respective design adjustments, UV-B LEDs with L50 lifetimes of 8000 hours can be demonstrated. Optimization of the devices has led to further improvements in reliability, with much longer L50 lifetimes expected. In addition, their output power at 350mA can be increased to 30mW. Methods to increase internal quantum efficiency and for efficient light extraction have also been investigated in detail.

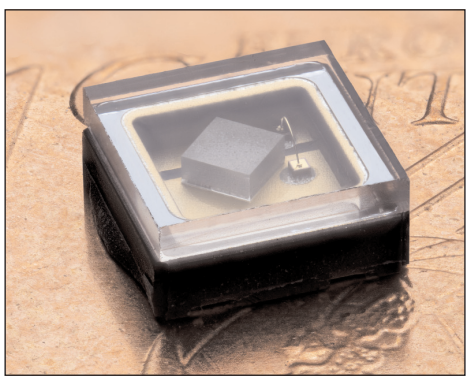
At the conference, FBH is also presenting a compact diode laser-based light source for the deep UV spectral range with an emission wavelength of 222nm, and hence in a region difficult to access with LEDs. The device converts the light of a GaN-based high-power diode laser into the UV spectral range via frequency doubling (single pass) and offers the potential for miniaturization. The wavelength-stabilized, narrow-band light source is particularly suited to spectroscopy applications, such as absorption and Raman spectroscopy applied in medical diagnostics but also in substance analysis.



UV-B LED module for plant illumination, providing LED light of three different wavelengths. Brightness and irradiation intensity can be adjusted individually to determine optimum irradiation for structurally diverse vegetable secondary metabolites. Inset: UV-B LED.

From customized housings to ready-to-use modules

FBH also develops the optimum package for each application and, supported by its Prototype Engineering Lab, even complete modules tailored precisely to fit the range of use. For one of its research partners, for example, FBH has developed and realized several illumination systems that irradiate plants with LED light of specific wavelengths. The proportion of health-promoting secondary plant metabolites can hence be systematically enhanced. For use in greenhouses, UV LEDs need to be protected by special packages against enhanced degradation caused by the warm and humid environment. At its exhibition booth, FBH displayed one of these plant illumination modules along with a small water disinfection system.

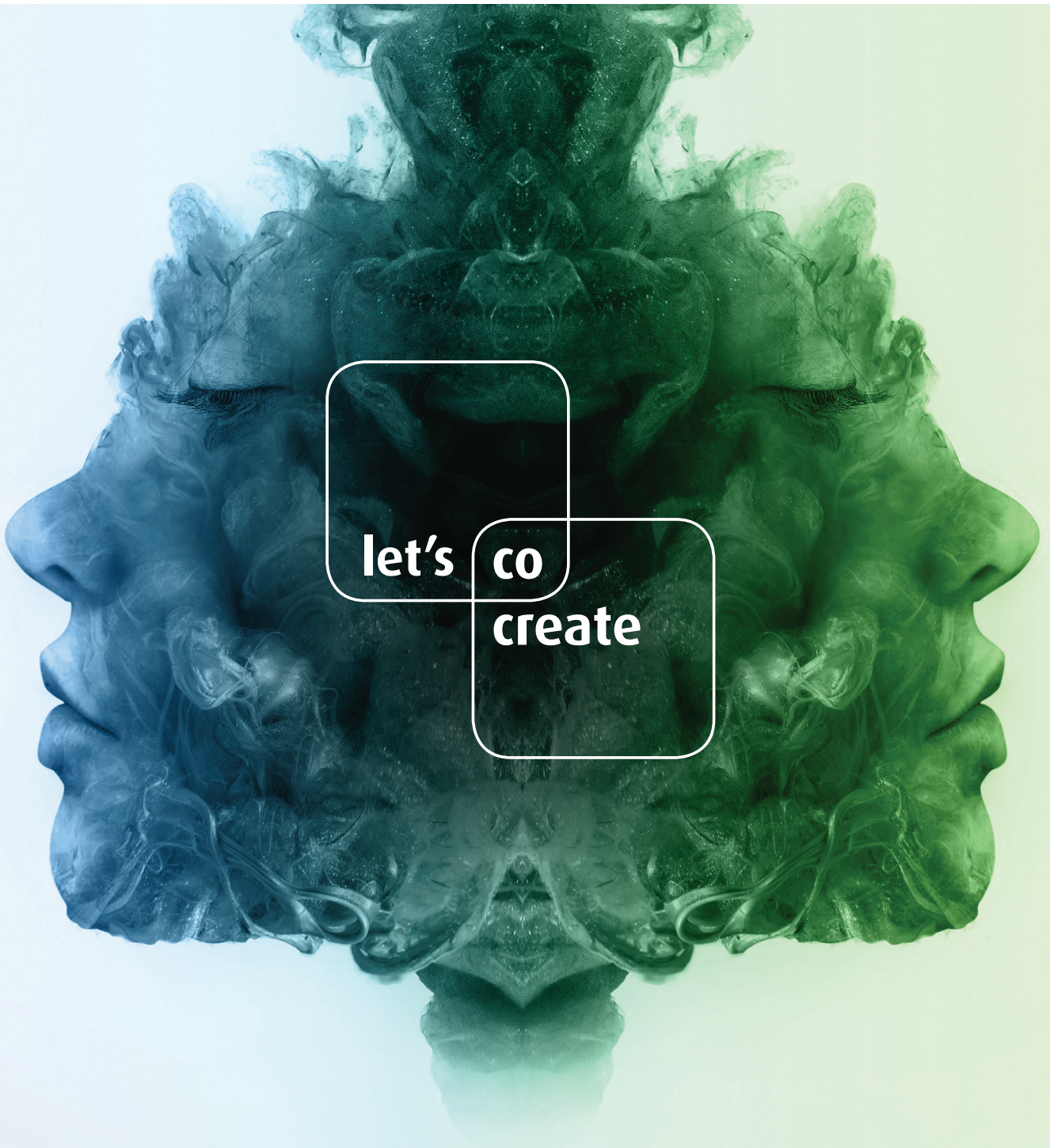


High-power UV-B-LED in package, containing a 1mm x 1mm LED chip.

FBH involvement in conference

ICULTA-2018 was jointly organized by the International Ultraviolet Association and 'Advanced UV for Life', an FBH-managed consortium bringing together 50 partners from research and industry. Conference co-chair was professor Michael Kneissl, who is head of the Joint Lab GaN Optoelectronics (jointly operated by FBH and TU Berlin). The chair of the program committee was professor Markus Weyers, head of FBH's Materials Technology Department.

www.advanced-uv.de/conference
www.fbh-berlin.com



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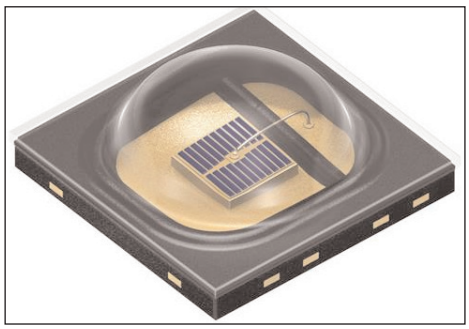
Osram adds to Oslon Black infrared LED family for automotive applications, boosting pulsed current to 5A

Osram Opto Semiconductors GmbH of Regensburg, Germany is expanding its Oslon Black family with six new infrared LEDs (IREDs) for automotive use.

The 850nm versions are intended for exterior applications, enhancing advanced driver assistance systems (ADAS) such as night vision, pedestrian protection and lane detection technologies. The new 940nm versions are better suited for interior applications like driver monitoring, interior cabin monitoring and gesture recognition. Due to a dynamic range of wavelengths and lenses, these products cover a wide array of customer requirements and can be operated at up to 5A in pulsed mode (compared with 3A previously).

The IREDs are intense, with an optical output of up to 2W in continuous operation, and deliver various wavelengths and beam angles.

The SFH 4715AS A01, SFH 4716AS A01 and SFH 4717AS A01 all have a wavelength of 850nm and beam angles of ±45°, ±75° and ±25°.



New members of the Oslon Black family offer pulse handling capability of up to 5A.

The SFH 4725AS A01, SFH 4726 A01 and SFH 4727AS A01 all have a wavelength of 940nm and beam angles of ±45°, ±75° and ±25°.

A high-refractive-index silicone is used for each lens, giving the IREDs a particularly low profile so that only very little light is lost from the sides. The maximum operating temperature of the IREDs is 125°C.

The high optical pulse outputs and wide range of integrated lens options allow system designers to select the right IRED for virtually any application without installing secondary optics, says Osram. Infrared light sources with a wavelength range <900nm are perceived by the human eye as a red glow. This is largely suppressed at 940nm. Like the rest of the Oslon Black family, the new IREDs offer what is claimed to be outstanding performance, long lifetime and excellent thermal properties.

"With this product line within the Oslon Black family we can cover all IRED-based lighting applications inside and outside the car," says Walter Rothmund, marketing manager ELS at Osram Opto. "The exemplary performance and compact dimensions of the IREDs give engineers maximum freedom of design, and end customers benefit from a new level of road safety."

www.osram-os.com

Osram and Continental sign contract to form 50:50 joint venture

Semiconductor-based lighting firm Osram GmbH and automotive technology firm Continental AG in Germany have completed negotiations on their joint venture (in which each of the partners has a 50% stake), which is expected to begin operations in second-half 2018, aiming to combine their respective expertise in lighting, light control and electronics. Leading the joint venture are chief executive officer Dirk Linzmeier from Osram and chief financial officer Harald Renner from Continental.

"Digitalization is creating new possibilities in automotive lighting applications and, in turn, tremendous opportunities that we want to leverage with Continental," says Hans-Joachim Schwabe, CEO of Osram's Specialty Lighting division. "By joining forces, we will be in an even better position to drive innovations by working closely with the automotive industry, seamlessly integrating lighting, sensor technology and electronics in a single application. This will allow us to advance new intelligent light functions, such as the combination of lighting and sensor technology in a module or light-based communication between the driver, other road users and the vehicle's surroundings," Schwabe adds.

"The joint venture puts us in a unique position to drive technological change in the automotive lighting market and to develop intelligent lighting solutions by combining our expertise in software and electronics with Osram's automotive lighting expertise," comments Andreas Wolf, head of Continental's Body & Security business unit. "The innovations Osram and Continental bring to this joint venture will allow us to offer our customers an unrivaled and unprecedented portfolio in the lighting market."

The joint venture will be based within the region of Munich, but will operate globally to target rapid development cycles with customers in their local areas.

The US operations of Osram Continental will be based in Hendersonville, Tennessee. The product portfolio will feature semiconductor-based lighting modules such as LED modules for front and rear headlights, laser modules and light control units.

www.osram.com
www.continental-corporation.com

Hexagonal-to-cubic phase transition in GaN via aspect ratio nano-patterning of silicon substrate

Elimination of polarization doubles emission efficiency

A research team led by professor Bayram of the University of Illinois at Urbana-Champaign (UIUC) Department of Electrical and Computer Engineering's Innovation COmpound semiconductoR (ICOR) Laboratory has used aspect ratio nano-patterning of a silicon substrate to enable a hexagonal-to-cubic phase transition in the metal-organic chemical vapor deposition (MOCVD) growth of gallium nitride (Richard Liu, Richard D. Schaller, ChangQiang Chen, and Can Bayram, 'High internal quantum efficiency ultraviolet emission from phase-transition cubic GaN integrated on nanopatterned Si(100)', ACS Photonics (2018); volume 5, issue 3, p955).

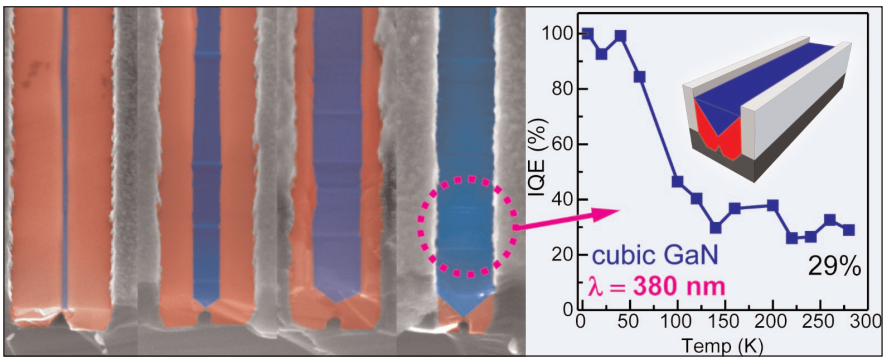


Figure 1. Phase transition of hexagonal GaN (red) to cubic GaN (blue) through the composite scanning electron microscopy images of these nano-grooves on the left. Temperature-dependent internal quantum efficiency (IQE) of the UV band-edge emission (λ = 380nm) from the right-most nano-groove (magenta circle), which has pure cubic GaN on the surface, is shown on the right with a 3D drawing of the nano-groove as the inset. Room-temperature IQE of phase-transition cubic GaN is 29% (double of that of the conventional hexagonal GaN).

For light-emitting diodes, compared with incumbent hexagonal-phase GaN (which has an energy bandgap of 3.42eV), cubic-phase GaN has a 0.2eV lower bandgap of 3.22eV. This reduces by ~10% the indium content necessary in InGaN to achieve the wavelength required. Cubic-phase material can also quadruple radiative recombination dynamics by virtue of the zero polarization.

Due to its polarization-free nature, the room-temperature internal quantum efficiency (IQE) of optimized cubic GaN is measured to be ~29% (at an ultraviolet emission wavelength of 380nm), in sharp contrast to about 12%, 8% and 2% for conventional hexagonal GaN-on-sapphire, hexagonal free-standing GaN, and hexagonal GaN-on-Si, respectively.

The demonstration of high internal quantum efficiency from phase-transition cubic GaN is reckoned to be a critical step towards bridging the 'green gap' in the visible spectrum.

Furthermore, cubic-phase GaN materials can serve as enablers in polarization-free photonics, room-temperature ferromagnetism, high-temperature spintronics, normally-off transistors, and single-photon emitters, add the researchers.

http://pubs.acs.org/doi/abs/10.1021/acsphotonics.7b01231
http://icorlab.ece.illinois.edu

KAUST's Xiaohang Li wins Manasevit Young Investigator Award for research on III–nitrides and III–oxides

Professor Xiaohang Li, head of the Advanced Semiconductor Research Group and assistant professor of electrical engineering in the Computer, Electrical and Mathematical Sciences & Engineering (CEMSE) Division of Saudi Arabia's King Abdullah University of Science and Technology (KAUST), has won the biennial 2018 Harold M. Manasevit Young Investigator Award for his "significant and innovative contributions in the MOCVD growth of state-of-the-art deep UV lasers,

B-III–N alloys, III–oxides, and blue and green emitters". Before joining KAUST, Li conducted research projects at Georgia Institute of Technology and Lehigh University in the USA.

The award was initiated in 2012 in honor of Dr Manasevit for his groundbreaking work in III–V, II–VI and IV–VI compound semiconductors, and is sponsored by the American Association of Crystal Growth (AACG) in conjunction with the 19th International Conference on Metalorganic Vapor Epitaxy (ICMOVPE XIX) Nara, Japan (3–8 June), where Li will receive the honor.

Prior to the award ceremony at ICMOVPE XIX, Li will present an overview of his work on MOCVD.

www.icmovpe.jp
https://semiconductor.kaust.edu.sa

IBELIVE project to develop compact, low-profile multi-functional optical components for data visualization or illumination

Osram Opto coordinating project with Fraunhofer IOF, TEMICON and Continental

Together with Germany's Fraunhofer Institute for Applied Optics and Precision Engineering (IOF), TEMICON and Continental, Osram Opto Semiconductors GmbH of Regensburg, Germany has been working since October 2017 on the development of extremely compact and low-profile multi-functional optical components for data visualization or illumination.

Set to run for three years and funded by Germany's Federal Ministry for Education and Research (BMBF), the research project IBELIVE (Innovative Hybrid Diffusers for Low-Profile Lighting Systems with Tailored Light Distribution) aims to deliver universal, flexible design and manufacturing processes for space-critical applications. The project partners directly address different markets, including compact and powerful head-up projection displays, ultra-thin camera flashes, and selective direct display backlighting.

The background to the research work is the absence of any significant ways of further reducing the profile of the LED chips currently used as light sources. In contrast, there is still great potential for miniaturizing the optics.

The planned reduction in the thickness of the optical elements and the combinability of various optical functionalities in a microstructure should give designers much greater flexibility in integrating the components in the devices. Another benefit is an improvement in energy efficiency, as a much greater proportion of the generated light can be used for the applications.

The project spans the entire value-added chain from the development of optics and volume production to testing of the new technology in sample applications, and the consortium partners have years of experience in optics simulation, microstructuring of surfaces and opto-electronic system integration. In addition to coordinating the project, Osram Opto is responsible for the system concept and for the design of two application-based demonstrators, and is also researching installation and testing concepts. Continental is designing and developing two compact head-up displays with different projection light sources. The hybrid diffusers to be developed play a central role in creating images and making efficient use of light in the head-up displays (targeting image quality as perceived by the driver). The Fraunhofer Institute for Applied Optics and Precision Engineering is developing methods and algorithms for designing hybrid diffuser optics, as well as technologies for generating deterministic surface structures. The tasks assigned to TEMICON include using interference lithography to overlay nano-scale structures and developing injection stamping and molding technologies for replicating thin two-sided hybrid diffuser optics as series products.

"The IBELIVE research project brings together a powerful consortium with many years of experience in photonic materials and the necessary know-how," says Ulrich Streppel, Key Expert Modelling at Osram Opto Semiconductors.

www.osram.com

Laser manufacturer nLIGHT files for $86.25m IPO

nLIGHT Inc of Vancouver, WA, USA (which was founded in Seattle in 2000 to provide high-power semiconductor and fiber lasers) has filed a registration statement with the US Securities and Exchange Commission (SEC) to raise $86.25m in a proposed initial public offering of its common stock (to be listed on the Nasdaq Global Market under the ticker symbol LASR).

The firm has previously raised $170m. Existing investors include Menlo Ventures (21.5%), Oak Investment Partners (20%), Mohr, Davidow Ventures (18.9%), Hadley Harbor Master Investors (12.1%) and Greenover Group affiliates (5.8%).

Vertically integrated operations include a semiconductor laser manufacturing facility in Vancouver, plus an optical fiber manufacturing facility in Lohja, Finland, and laser packaging & assembly facilities in Vancouver, Washington; Hillsboro, Oregon; and Shanghai, China. Staffing exceeds 1000.

Revenue rose 36% from $101.3m in 2016 to $138.6m in 2017, consisting of $56.6m from industrial, $60.9m from microfabrication and $21.1m from aerospace & defense markets. With over 300 customers (including Samsung, BAE and Raytheon), about 66% of revenue came from outside North America, including 40% from China. Gross margin rose from 22.9% to 31.9%, driven by high-value new products as well as manufacturing efficiencies and cost reductions for raw materials. Profit was $1.8m, compared with a loss of $14.2m in 2016. Compound annual growth rate (CAGR) is about 30% for 2014–2017.

Net proceeds of the IPO will be used for "working capital, capital expenditures and other general corporate expenses".

www.nlight.net

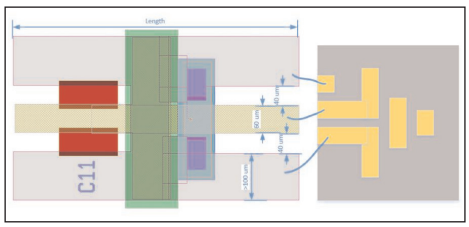
CST Global proves multi-gigabit transmission feasibility with detuned 1270nm DFB lasers facilitating 5G 60GHz radio over fiber

Work with sister firm Sivers IMA to optimize combined radio over fiber, optical and millimeter-wave solution

III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK says that it has proven the feasibility of multi-gigabit data transmission at a 1270nm carrier wavelength.

The feasibility came as part of the European Union (EU) Horizon 2020 research project iBROW (Innovative ultra-Broadband Ubiquitous Wireless Communications Through Tera-hertz Transceivers), led by the University of Glasgow and managed within CST Global by research engineer Horacio Cantu.

"The objective of the iBROW project is to establish the best millimetre-wave (mmWave), ROF (radio over fiber) ultra-broadband solution," says Cantu. "The performance characteristics of 1270nm detuned, in-plane, ridge-waveguide distributed feedback (DFB) laser diodes demonstrated it is an ideal ROF carrier wavelength," he adds.



A 60GHz Tx antenna.

"We previously showed that 1310nm was an effective, transmission wavelength. We are confident that this new technology will also be feasible at 1550nm, which will deliver an ultra-broadband, low-latency solution, extending transmission distances up to 25km."

ROF requires light to be modulated with radio-data, for optical transmission. It offers a huge bandwidth increase over existing solutions and requires no digital-to-analog (DAC) conversion, resulting in a low-latency solution.

CST Global has also begun concurrent development of a wireless-to-optical link as part of the Innovate UK project 'WiPhi' (high-performance wireless/photonic interfaces for 60GHz radio-over-fiber applications) with partners Optocap Ltd and the University of Glasgow.

The mmWave signal base-band is transmitted over the fiber-optic connection from an indium phosphide (InP) mmWave transceiver to the system core. "We are working with our sister company Sivers IMA, a mmWave specialist, to optimize a combined ROF, optical and mmWave solution," notes Cantu. "This will offer ultra-broadband in the V-band frequencies, within the mmWave spectrum, at 60GHz, which is one of the designated 5G network bands for telecommunication infrastructures," he adds. "More development is needed to establish a commercial, ultra-broadband ROF solution that is low-cost, energy-efficient, compact, operates at room temperature, and integrates with 5G fiber-optic network requirements."

www.CSTGlobal.uk

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FerroTec

POET partners with 8" silicon foundry SilTerra Malaysia to develop and manufacture Optical Interposer Platform

POET Technologies Inc of Toronto, Canada and San Jose, CA, USA — a designer and manufacturer of opto-electronic devices, including light sources, passive waveguides and photonic integrated circuits (PIC) for the sensing and datacom markets — has announced a master collaboration agreement with SilTerra Malaysia Sdn Bhd (a wafer foundry offering fabrication and design support services in CMOS logic, high-voltage, mixed-signal, RF, BCD, power and MEMS technologies) for the co-development of fabrication processes and the manufacturing of POET's Optical Interposer Platform. The partnership is expected to accelerate the path to commercial production of the Optical Interposer, which will enable optical engines for single-mode transceiver modules and other high-bandwidth devices.

Together, the companies will bring up critical waveguide processes previously developed by POET for its Optical Interposer, and implement the process flows on new equipment at SilTerra's 8" silicon foundry in Kulim Hi-Tech Park (which began commercial production in 2001, and has a capacity of 46,000 wafers per month). In support of this, SilTerra has agreed to assist financially with the purchase of fabrication and testing equipment, as well as to share certain costs associated with facilities enhancements and installation of equipment for manufacturing the Optical Interposer. The collaboration also includes a wafer purchase agreement for the manufacturing of prototype, initial production and volume production wafers.

"Following several months of preliminary collaborative work together, this agreement with SilTerra represents a significant milestone toward our goal of commercializing POET's Optical Interposer Platform," says POET's CEO Dr Suresh Venkatesan. "The combined resources and investments of the two companies enables us to establish a unique manufacturing process as well as a reliable supply of wafers for our Optical Interposer," he adds. "SilTerra offers POET a truly unique combination of advanced 90nm lithography, cost-effective 8" silicon processing copper metallization and MEMS capabilities, all of which are needed for our Optical Interposer… POET has now secured a key element in the commercialization process, allowing us to establish more engagements with prospective customers."

SilTerra regards the partnership as "a key strategic engagement to address the increasing need for cost-effective solutions for data-center interconnects through the innovative use of silicon in photonics," says SilTerra's CEO Firdaus Abdullah. "POET's Optical Interposer is a major advance over other approaches to optical interconnects and facilitates the co-packaging of electronics and photonics devices in a single multi-chip module (MCM)," he comments. "POET's 'photonics-in-a-package' solution has the potential to address even larger markets in the future for the integration and co-optimization of ASICs and DSPs with photonics at the interposer and chip level. We at SilTerra look forward to a long and prosperous relationship between our two companies and our teams."

The agreement includes provisions for multiple co-development projects, consignment by POET of newly purchased equipment to be installed in SilTerra's Malaysian foundry, various support services to be provided by SilTerra, and the purchase of wafers containing Optical Interposer devices from SilTerra over an initial three-year term.

www.silterra.com

POET's Bill Ring receives PIC Technologist Award

At the PIC International conference in Brussels, Belgium (10 April), POET's senior VP Dr William S. Ring received the 2018 PIC Technologist Award, which recognizes "experts in translating PIC technologies towards commercial reality and product qualification, including the filing of IP/patents and publications".

"Since joining the company in 2016 as part of our acquisition of BB Photonics [where he was CEO & president], his deep experience and expertise in photonics have been instrumental toward advancing POET's technology development," comments CEO Suresh Venkatesan. "Capabilities provided by the dielectric waveguide technology developed by Bill while at BB Photonics are a key enabler for POET's Optical Interposer platform, which is now serving to revolutionize the platform method for integrating photonics in data communication applications," he adds. "The meaningful contributions Bill has made to both the company and the industry merit this well-deserved recognition, and we are very pleased to have him as a key part of our leadership team as we work to bring the next generation of optoelectronic and photonic solutions to market."

Ring was previously Tyco Electronics' director of operations and director of development for devices and transceivers. Before Tyco, he was a principle engineer at HP, responsible for design and development of 1310nm FP, 1480nm pump and DFB lasers for its fiber-optics group. In 1995, he introduced the first strained MQW laser into production at HP's UK facility (later deployed in the firm's 1300nm SFF/SFP transceivers).

www.poet-technologies.com

SMART Photonics and Lumerical make available compact model library for InP integrated photonics platform

Time- and frequency-domain CML and SMART's MPW runs enable prototyping of PIC designs

Independent pure-play indium phosphide (InP) foundry SMART Photonics of Eindhoven, The Netherlands has announced the availability of a new compact model library (CML) for its InP integrated photonics platform and the associated process design kit (PDK) resulting from collaboration with photonic simulation software provider Lumerical Inc of Vancouver, British Columbia, Canada.

The CML enables circuit designers to reliably model behavior and performance of photonic integrated circuits (PICs) within Lumerical's photonic integrated circuit simulator INTERCONNECT, reducing design errors and accelerating time-to-market. Combined with SMART Photonics' frequent multi-project wafer (MPW) shuttle run, this provides designers with a platform to prototype and refine new circuit designs quickly and efficiently, say the firms.

"It's exciting to see two recognized industry leaders like Lumerical and SMART Photonics working together towards industry standardization," comments Francois Menard, chief technology officer & co-founder of AEPONYX Inc, a developer of a silicon planar optical MEMS platform that supports the development of III-V components optimized for efficient hybrid integration. "Having a reliable set of parametrized compact models on a powerful platform like INTERCONNECT is a game-changing development to achieve first-time-right designs."

The new CML contains more than 25 parametrized compact models, which have been carefully calibrated with a combination of experimental data, provided by SMART, and high-accuracy 3D physical simulations using Lumerical's suite of component-level modeling tools. The library includes passive and active devices such as phase modulators, amplifiers and photodetectors, providing an extensive and flexible set of building blocks for creating complex PIC designs. Each model in the library enables both frequency- and time-domain circuit simulation, equipping designers with a complete set of analysis tools to design PICs for any application.

"We are very pleased by the collaborative work done by our partners at Lumerical to rapidly develop a comprehensive compact model library for our InP-based integration platform," comments SMART Photonics' chief technology officer Luc Augustin. "This CML is especially unique in its design, as it brings together simulated data from trusted tools and real, measured performance for increased reliability," he adds. "PIC designers around the world will be able to confidently use a schematic-driven layout flow for a pure-play InP PIC foundry."

With applications including high-speed data communications and biological and environmental sensing in fast-moving fields like Internet of Things (IoT) and automotive, SMART's MPW shuttle runs enable designers to iterate through design-manufacture-test cycles to optimize PIC performance.

"Through this collaboration, we have deployed the leading 3D photonic simulation tools to help SMART enhance their PDK with the most advanced models available for both time- and frequency-domain simulation," claims Lumerical's chief technology officer Dr James Pond. "These accurate models are critical for PDK-driven design and enable engineers to focus on circuit performance rather than individual components."

http://smartphotonics.nl/mpw-runs-2018
www.lumerical.com

Leti silicon photonics PDK available for Synopsys PhoeniX OptoDesigner PIC design suite

Design rules and building blocks for multi-project wafer and custom runs on Leti's Si310 platform

Micro/nanotechnology R&D center CEA-Leti of Grenoble, France says that its silicon photonics process design kit (PDK) for photonic circuits is now available in the PhoeniX OptoDesigner suite of Synopsys Inc (which provides software, IP and services used to speed chip and electronic system design).

Leti's integrated silicon photonics platform has been developed for high-speed optical transceivers and highly integrated optical interposer applications. The PDK contains the design rules and building blocks for multi-project wafer (MPW) and custom runs on Leti's Si310 platform. It also includes a catalog of components available at Leti, allowing Synopsys PhoeniX OptoDesigner customers to select the ones they need to build their circuits. Once the customers have a completed circuit design, Leti produces a proof of concept on a multi-project wafer run.

Used by more than 300 designers worldwide, OptoDesigner gives access to a complete set of passive components (such as grating couplers, silicon waveguides and transitions) and active components (such as high-speed Mach–Zehnder modulators and high-speed germanium photodiodes) based on Leti's fab. It also includes physical verification tools checking whether the contributions meet the design rules defined by the fabrication constraints in Leti's cleanroom.

"On the same mask, with this design kit, we are able to have photonic circuits performing various functions, according to the area of expertise of the different contributors," says Andre Myko, responsible for MPW runs at Leti. "Fabless companies and academics therefore can realize substantial cost savings by 'sharing' production costs on multi-project wafer runs."

Leti's photonic platform is France's largest R&D center for the development, characterization and simulation of optoelectronic systems and components. Its activities range from component design through component fabrication, integration into systems, and packaging.

"Leti's process design kit available for Synopsys' PhoeniX OptoDesigner is a licensed plug-in library of solutions that support multi-project wafers and custom runs provided by Leti," says Niek Nijenhuis, global business development manager of Synopsys' PhoeniX OptoDesigner products. "In addition to the photonic elements from the standard OptoDesigner library, Leti's PDK contains technology-specific information like mask-layer names, design rules, validated building blocks, die sizes and GDS file settings."

Leti's silicon photonics platform is also fully compatible with STMicroelectronics' platform in Crolles, France, which enables fabless customers to take their new circuits to high-volume production.

www.leti.fr
www.synopsys.com
www.phoenixbv.com

Luxtera demonstrates silicon photonics at OFC

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (13–15 March), fabless silicon photonics firm Luxtera of Carlsbad, CA, USA featured its latest advances in 100G/λ technology, PAM4 signaling, extended reach, increased operating temperature range, liquid immersion cooling, increased density, and photonic integration.

Demonstrations included:

- IEEE802.3bs-compliant 400G-DR4 technology platform demonstrating increased throughput and performance in Luxtera's next-generation products;
- 30km, 50G-PAM4 single-lambda QSFP link demonstrating Luxtera's extended-reach capabilities with PAM4 (4-level pulse amplitude modulation) signaling over duplex fiber;
- 4x25G-LR QSFP28 modules running error-free at industrial temperature extremes (–40°C and +85°C) over 10km of single-mode fiber (SMF) demonstrating increased operating temperature range and extended reach;
- 100G-PSM4 QSFP28 module running error-free while fully immersed in liquid immersion coolant demonstrating why Luxtera silicon photonics transceivers are suitable for liquid immersion applications;
- production 3.2Tb 0.5RU (rack unit) switch with 32 x 100G-PSM4 ports using Luxtera's 2x100G-PSM4 embedded optical module demonstrating Luxtera's higher-density products;
- the evolution of optics: an example high-density integrated photonics +ASIC switch demonstration; and
- photonics wafers from the latest TSMC 300mm CMOS wafer foundry process demonstrating Luxtera's new technology platform.

"These innovations will further expand our product portfolio to address the growing demands of our data-center and mobile infrastructure customers," says VP of marketing Ron Horan.

www.ofcconference.org
www.luxtera.com

NeoPhotonics makes available matched suite of 64GBaud coherent optical components for 1.2T applications

NeoPhotonics is now shipping (to multiple customers) its suite of 64GBaud optical components for coherent systems operating at 600G and 1.2T, consisting of three critical optical components available in compact form-factor packages suitable for CFP2 pluggable modules and compact daughter cards.:

- *64GBaud CDM*: NeoPhotonics' 64GBaud polarization-multiplexed quadrature coherent driver modulator (CDM) is shipping in limited availability and features a co-packaged indium phosphide modulator with a linear, high-bandwidth differential driver in a compact package designed to be compliant with the anticipated OIF Implementation Agreement. Co-packaging the InP IQ modulator with the driver enables an 85% reduction in line-card board space compared with equivalent lithium niobate solutions. Further, this facilitates transceiver applications up to 600GBps on a single wavelength for next-generation transport modules.
- *64GBaud Micro-ICR*: NeoPhotonics' Class 40 high-bandwidth micro-intradyne coherent receiver is in volume production and is designed for 64GBaud symbol rates, doubling the RF bandwidth of standard 100G ICRs. The 64GBaud Micro-ICR supports higher-order modulation such as 64 QAM. The compact package is designed to be compliant with the OIF Implementation Agreement OIF-DPC-MRX-02.0.
- *Low Profile Micro-TL*: NeoPhotonics' ultra-narrow-linewidth external cavity tunable laser has been proven in volume production and is now configured in a smaller, lower-profile package, which is designed to meet the stringent requirements for packaging density in pluggable modules. The firm claims that the external cavity laser design has a significantly narrower linewidth than competing designs, which is especially advantageous for higher-order modulation formats. The laser is available in a compact-package integrable tunable laser assembly (iTLA) form factor compliant with the OIF Implementation Agreements OIF-MicroITLA-01.1 and OIF-ITLA-MSA-01.3.

These components work together to enable users to implement single-channel 600G or dual-channel 1.2T data transmission over datacenter interconnect (DCI) reach of 80km. The components also support 400G over metro reach of 400–600km using 64GBaud and 16 QAM or 200G over long-haul reach of more than 1000km using 64GBaud and QPSK

64GBaud components double the symbol rate over standard 100G (32GBaud) coherent systems. Higher symbol rates increase data capacity while maintaining superior optical signal-to-noise ratio (OSNR), spectral density and reach. Higher-order modulation schemes such as 16 QAM and 64 QAM improve spectral efficiency, but require a higher OSNR and benefit from the ultra-narrow linewidth of NeoPhotonics' external cavity tunable laser.

"We ensure that each element is designed to work seamlessly with the others and offer our customers a complete optical solution, both increasing performance and reducing development time," says chairman & CEO Tim Jenks..

NeoPhotonics demonstrates 64Gbaud coherent optical sub-assembly for coherent 400G–1.2T applications

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (13–15 March), NeoPhotonics demonstrated its 64Gbaud coherent optical sub-assembly (COSA). Based on the same technology as its coherent intradyne receiver (ICR) product line and its recently introduced coherent driver modulator (CDM), the 64Gbaud COSA integrates these two functions into a single compact package.

The 64Gbaud COSA is designed to work with NeoPhotonics' ultra-narrow-linewidth external-cavity Nano-ITLA (integrated tunable laser assembly) to achieve high optical performance in a form factor compatible with coherent pluggable OSFP modules. A 400ZR OSFP module with the COSA and Nano-ITLA operating at 64Gbaud and 16 QAM were also demonstrated using off-module processing. The COSA and Nano-ITLA can also be used for single-lambda 600G and two-lambda 1.2T using 64Gbaud and 64QAM.

The 64Gbaud COSA contains a coherent I/Q modulator co-packaged with drivers, as well as a coherent receiver co-packaged with trans-impedance amplifiers (TIAs). The COSA is based on NeoPhotonics' photonic integration technology and uses design elements that have been proven in production. It is about the same size as either the discrete CDM or the discrete Micro-ICR, so cuts the component footprint in half while simplifying fiber management and board layout. When the COSA is combined with the external-cavity Nano-ITLA (which is also half the size of its Micro-ITLA predecessor), the size of the optics for next-generation modules is halved without impacting performance, meeting the requirements for OSFP pluggable modules and compact daughter cards.

The demonstration shows that "we have maintained all of the performance of the discrete components, but at half the size," says chairman & CEO Tim Jenks.

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NeoPhotonics launches 53GBaud linear optical component family for 400G data-center applications

NeoPhotonics Corp of San Jose, CA, USA has launched its 53GBaud linear optical component family, which includes PAM4 (4-level pulse amplitude modulation)-capable optical components for 100G and 400G cloud data-center and other client applications, including drivers and electro-absorption modulated lasers (EMLs) in transmitters plus PIN photodetectors and transimpedance amplifiers (TIAs) in receivers.

Cloud data centers are generating strong demand for transceiver solutions with higher port densities and lower cost per bit, which is driving the technology shift to single-lambda 100Gbps with PAM4 technology. The 53Gbaud family offers module designers a complete set of optical components together with analog electronic chips to achieve high performance with low power consumption in small-form-factor applications.

The 53GBaud linear optical component family includes:

- *an Open Drain Driver (ODD) for linear operation of EML lasers*. With a typical 90mW of power consumption per channel and small size, this high-speed driver is suitable for space and power efficiency in small-form-factor pluggable modules.
- *Mach–Zehnder modulator (MZM) drivers for silicon photonics modulators.* This quad driver has a high $3.5V_{ppd}$ output per channel and a typical 2.2W low power consumption for all four channels designed for small-form-factor pluggable modules.
- *a CWDM4 EML*, which includes the option for integration with NeoPhotonics' open drain driver. Over the operating temperature range 20–70°C, this EML is a preferred transmitter solution for PAM4 for intra-datacenter applications.
- *PIN photodetectors*. The side illumination structure of the PIN photodetector enables a simple coplanar assembly with mux/demux chip and TIA suited to compact modules.
- *Transimpedance Amplifier (TIA)*. With low noise and a typical power consumption of 60mA over a 3.3V rail, this TIA is suitable for receiver signal amplification for up to 10km transmission.

"Our complete 53GBaud linear optical component family, with a typical bandwidth of 35GHz for all these optical components, provides all needed optical components for single-lambda 100Gbps transmitters and receivers, scalable to 400Gbps transceivers with CWDM4 wavelengths," says chairman & CEO Tim Jenks. "NeoPhotonics is pleased to now also support the cloud data centers and the industry with a solid and growing portfolio of cost-effective optical components based on NeoPhotonics' high-speed platforms of gallium arsenide (GaAs) driver, indium phosphide (InP) EML/PIN PD, and silicon germanium (SiGe) TIA," he adds.

www.neophotonics.com

Demonstration of Nano-ITLA external-cavity tunable laser for coherent 400G-1.2T applications, halving size from Micro-ITLA

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (13–15 March), NeoPhotonics demonstrated its Nano-ITLA ultra-compact external-cavity tunable laser, along with its suite of coherent components for 600G and 1.2T as well as its broad family of products for high-speed applications.

The Nano-ITLA is based on the same proven and reliable external-cavity technology as the firm's Micro-ITLA product line. It also maintains the ultra-narrow linewidth, the low frequency phase noise performance, and the low power consumption of the existing product in a compact package about half the size.

The Nano-ITLA uses an ASIC control IC that reduces the size of the electronic control circuitry. The laser can also be used separately with the ASIC mounted on the customer's circuit board. Using both approaches, the Nano-ITLA is suitable for use in 400ZR small-form-factor pluggable coherent modules, including OSFP and DD-QSFP, and for compact daughter cards for 600G and 1.2T applications.

Coherent communications is moving simultaneously to higher data rates per wavelength and to smaller form factors, requiring higher performance from the optical components at the same time that the size and power must be significantly reduced. Increasing the symbol rate to 64Gbaud and using higher-order modulation, such as 16 QAM to 64 QAM, can increase the data rate per wavelength to 400G or 600G. However, such higher-order modulation schemes are more sensitive to both amplitude and phase noise since the separation between states is necessarily reduced. This situation therefore requires the most stable, ultra-narrow-linewidth laser sources. The new Nano-ITLA uses a miniaturized design while maintaining the performance of an external-cavity approach, which results in high output power, low electrical power consumption and what is claimed to be the narrowest linewidth in the industry, resulting in high fidelity in higher-order modulation formats.

"This Nano-ITLA delivers all of the performance advantages our customers currently enjoy with our external-cavity design, but with the laser size reduced by half," says chairman & CEO Tim Jenks.

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Oclaro highlights components & modules for up to 1Tb/s

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego, CA, USA (12–15 March), Oclaro Inc demonstrated a suite of components and modules for driving network speeds up to 1Tb/s and beyond, including 400G and 600G coherent optics, CFP2-digital coherent optical (DCO) modules, and the latest intra-data-center modules using electro-absorption modulator lasers (EMLs) and PAM-4 integrated circuits.

The firm also announced plans to expand its current portfolio of laser die to include its EMLs in response to high demand for high-speed interconnect applications.

Demonstrations included:

- 400Gbps components: Oclaro showcased its high-bandwidth components operating at 400G with 16QAM constellation at 64GBaud. This includes narrow-linewidth (NLW) lasers in conjunction with a single-channel lithium niobate modulator and a 64GBaud integrated coherent receiver (ICR). The demonstration showed the recovered constellation at the receiver as well as the optical spectrum at the transmitter spectrum validating the operation at 400G.
- 1.2Tb in-feed components: Features an integrated coherent transmitter (ICT) operating at 600G with a 64QAM constellation at 64GBaud.
- 400Gbps FR4 module: Features a 400Gbps QSFP56 DD module containing an Oclaro 53GBaud transmitter and receiver optical sub-assemblies (TOSA and ROSA) and a gearbox IC to convert between 8x50G PAM4 electrical host signals and 4x100G PAM4 optical line side signals. The demonstration highlighted progress towards realizing 400G single-mode client-side modules for the hyperscale data center.
- Live 100Gbps PAM-4 optical transmission: Demonstration of a 100G PAM-4 optical link using one lane of Oclaro's 4x 53Gbaud transmitter and optical sub-assemblies capable of 400G transmission.

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www.oclaro.com

Oclaro expands component and module portfolio into L-band to boost data-center interconnects to 600G

Oclaro is developing a suite of integrated optical components and modules in the L-band to allow data-center customers to expand capacity on interconnects between data centers on existing optical fiber.

Enabling transmission up to 600G per wavelength for long-haul, regional, metro and data-center interconnect applications, the portfolio includes a 64Gbaud micro-intradyne coherent receiver (μICR), 32 and 64Gbaud integrated coherent transmitter (ICT), 100kHz micro-integrated tunable laser assembly (micro-ITLA), a 64Gbaud high-bandwidth co-packaged driver modulator (HB-CDM), and a high-bandwidth $LiNbO_3$ polarization-multiplexed quad Mach–Zehnder (PM-QMZ) modulator.

"The requirement for L-band components has been largely driven by networks based on dispersion-shifted fiber," says Beck Mason, president of Oclaro's Integrated Photonic business. "Recently C+L band systems have been gaining popularity for data-center interconnect applications to maximize the use of existing fiber plant," he adds. "Oclaro is applying its world-class photonic integration and packaging expertise to develop a broad portfolio of L-band solutions."

The L-band micro-ITLA complies with the Optical Internetworking Forum (OIF) micro-ITLA Implementation Agreement and uses Oclaro's thermally tuned digital supermode-distributed Bragg reflector (DS-DBR) laser technology to reduce low-frequency phase noise and linewidth while also increasing optical output power, all contained in a reduced size footprint.

The L-band HB-CDM complies with the OIF HB-CDM Implementation Agreement and uses Oclaro's high-bandwidth L-band indium phosphide (InP) PM-QMZ modulator chip with a co-packaged matched RF driver. Flexible optical power and high linearity is achieved through the use of semiconductor optical amplifiers (SOAs) integrated within the InP modulator chip.

The high-bandwidth L-band $LiNbO_3$ PM-QMZ modulator is already released to production.

The L-band 64Gbaud+ ICT combines a narrow-linewidth L-band laser with a high-bandwidth L-band PM-QMZ Mach–Zehnder modulator to support flexible baud rates up to 64Gbaud and 64-QAM modulation. This enables transmission from 100G to 600G. Built-in SOAs, tunable filter and polarization multiplexer eliminate the need for external optical components and simplify assembly while enabling operation in colorless networks. The ICT provides a local oscillator output with +12dBm EOL power for a mated coherent receiver.

The L-band 64-Gbaud+ ICR is a fully integrated coherent receiver able to support flexible data rates from 100Gbp/s to 600G+. It supports rates up to 64Gbaud with modulation schemes such as 64-QAM. The 64Gbaud ICR has an integrated monitor photodiode (MPD) and variable optical attenuators (VOA) to support single- and multi-channel applications in colorless networks. It is compliant with the form factor specified in the OIF-DPC-MRX-01.0 Implementation Agreement

The compact form factors and integrated functionality of the L-band 64Gbaud ICT-ICR pair make them suitable for the stringent size requirements on next-generation high-density 600G platforms.

Oclaro's new 400G QSFP56-DD delivers 400% increase in bandwidth and faceplate density

Oclaro is integrating its 400G technology into the QSFP-DD high-density transceiver form factor. The new 400G (4x100G PAM4) QSFP56-DD module will enable 36 ports of 400G per 1RU (rack unit) — a 400% increase in bandwidth and faceplate density compared with similar-sized 100G QSFP28 transceivers.

The data-center market is in constant demand for greater bandwidth to support existing and emerging applications such as streaming video, cloud services, and the Internet of Things, says Oclaro. Data-center traffic is expected to rise at a compound annual growth rate (CAGR) of 27%, reaching 19.5ZB per year in 2021. The move to 400G optical interconnects is hence critical, but it must be done cost effectively and with power efficiency. The best way to accomplish this is by maximizing the data rate of each individual laser, which is the proven way to minimize cost and power consumption, adds the firm. Oclaro's QSFP56-DD optical transceiver contains four lasers operating at 100Gbps each and uses 4-level pulse amplitude modulation (PAM4) to realize an aggregate data rate of 400Gbps.

"We will deliver unprecedented bandwidth and performance in the 400Gbps QSFP56-DD by leveraging Oclaro's world-class integrated indium phosphide (InP) technology and our leading 100Gbps PAM4 EML [electro-absorption modulated laser] lasers," says Walter Jankovic, president of Oclaro's Optical Connectivity business unit. "This will be the highest-density 400Gbps transceiver that has ever been introduced for Ethernet switch architectures and is the missing link in the ecosystem to fully utilize a new generation of switching ASICs capable of 14Tbps or more," he reckons.

"The growth of traffic for data-center operators and service providers will demand the adoption of 400G optical interfaces in next-generation networking equipment," comments Bill Gartner, VP & general manager at Cisco. "The QSFP-DD pluggable optical module form factor provides the highest density while leveraging the industry's infrastructure that has made QSFP the de facto standard at 40G and 100G. In addition, QSFP-DD provides backward compatibility to lower-speed QSFP form factors providing customers maximum flexibility as they migrate their networks to higher speeds. Cisco considers Oclaro's support of the QSFP-DD as another step towards broad market adoption of this form factor," he adds.

"The increased bandwidth capability of the 400G QSFP56-DD module represents a much needed innovation," comments Vladimir Kozlov, founder & CEO of market analyst LightCounting. "With the availability of these modules, data centers will be able to achieve breakthrough switching capability that will drive their future growth," he adds. "Sales of 400GbE transceivers will reach $300m in 2019 and close to $2bn by 2022."

Oclaro claims that its 400Gbps QSFP56-DD FR4 module offers superior optical performance, quality and reliability through the use of its 100Gbps PAM4 (53GBaud) lasers that enable 4x100G PAM4 solutions. The module is compliant to the 53.125GBd PAM4 x 4-wavelength 400G-FR4 optical interface, the 26.5625GBd PAM4 x 8-lane 400GAUI-8 electrical interface, and the QSFP-DD MSA form-factor specs. Additional features include:

- transmission distance of up to 2km (which supports 95% of the links in data centers);
- compact size (that enables as many as 36 ports in 1RU);
- hot pluggability (to allow installation or removal without powering down entire switches or line cards);
- field pluggability (to enable a 'pay as you grow' approach to capacity increase).

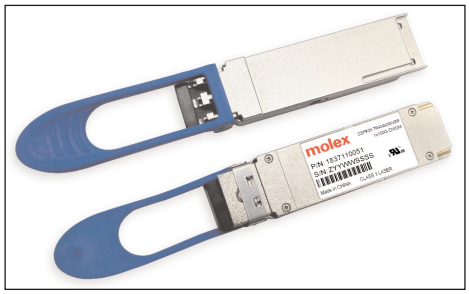
Oclaro expects to begin sampling modules in third-quarter 2018.

www.oclaro.com

Molex debuts 100G PAM-4 based 25G/50G/100G/400G products for next-generation data-center and 5G wireless applications

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (12–15 March), high-speed fiber-optic interconnect firm Molex Inc of Lisle, IL, USA announced a portfolio of 100G and 400G products based on its 100G PAM-4 (4-level pulse amplitude modulation) optical platform, including multi-rate 25G/50G/100G PAM-4 DWDM QSFP28, 100G FR QSFP28, 400G DR4 and 400G FR4 QSFP-DD and OSFP transceivers.

"Molex is a leader in the development of the foundational building blocks for 100G PAM-4 optoelectronics, and in collaborations for digital signal processing (DSP) integrated circuits," claims Rang-Chen Yu, VP of business development, general manager of optoelectronic solutions at Molex firm Oplink, and co-chair of the 100G Lambda MSA (multi-source agreement). "By leveraging these combined capabilities, we support high-bandwidth requirements for a wide range of applications across intra-data-center, data-center interconnect (DCI) and 5G wireless. In addition, 100G PAM-4 technology also lays the foundation for cost-effective and high-density 400G solutions."



QSFP28 transceiver for 100G DWDM.

Molex promoted industry-wide adoption of 100G PAM-4 technologies through standards such as the IEEE and multi-source agreement (MSA) forums such as the 100G Lambda MSA.

The firm's 100G PAM-4 platform-based products include:

- 25G/50G/100G multi-rate PAM-4 DWDM QSFP28 (which supports 40x100Gbps DWDM with a total of 4Tbps per fiber pair, and has flexible data-rate programmability to support 25Gbps and 50Gbps applications);
- 100G FR QSFP28 (which is compliant with the 100Gbps Lambda MSA, and supports 100G connectivity up to 2km);
- 400G DR4 (which is compliant with the 100G Lambda MSA, and supports 400Gbps connectivity up to 500m) and 4x100G FR QSFP-DD/OSFP (4x100G FR supporting four times 100G FR up to 2km);
- 400G FR4 QSFP-DD/OSFP (which is compliant with the 100G Lambda MSA, and supports 400Gbps connectivity up to 2km).

www.ofcconference.org
www.molex.com/opticalsolutions

Source Photonics launches suite of 400G client transceivers for data-center & telecom applications

Source Photonics Inc of West Hills, CA, USA (which provides optical connectivity products for access and datacom applications) launched a range of 400G client transceivers including the 400G QSFP-DD FR8/LR8 module for data-center applications and the 400G CFP8 FR8/LR8 module for telecom applications.

The 400G QSFP-DD is designed to be compliant with the IEEE 802.3bs 400GBASE-LR8/FR8 and QSFP-DD MSA specifications for links up to 10km. The 400G CFP8 FR8/LR8 is designed to be compliant with the IEEE 802.3bs 400GBASE-LR8/FR8 and CFP MSA specifications for links up to 10km.

"We are proving to the market that multiple 400G offerings will be available in the short term to support connectivity between transport, routing and switching equipment," says Ed Ulrichs, director of PLM. "Operators can now believe a strong foundation exists to plan network upgrades," he adds. "Both of these transceivers will be available for customer samples in early second-quarter 2018."

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (13–15 March), Source Photonics demonstrated an error-free link between its 400G QSFP-DD LR8 and 400G CFP8 LR8, proving that links up to 10km can soon upgrade from 100G to 400G, therefore significantly reducing total cost of ownership in the aggregation layer.

"We have successfully integrated our industry-leading signal integrity work with novel optical coupling concepts to demonstrate the highest-density optical transceiver ever," claims chief scientist Sheng Zhang. "Since we use a common manufacturing platform with our 100G products, we are confident we will be the first in the market to scale this platform," he adds.

In addition to the 400G product announcements at OFC 2018, Source Photonics showcased a range of optical connectivity products including active optical cables (AOCs) and 100G QSFP28 SR4, CWDM4, LR4, OTU4 and ER4 Lite modules, and 400G QSFP-DD SR8 modules.

www.sourcephotonics.com
www.ofcconference.org

Kaiam demos 8-lane single-mode 400G QSFP-DD

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (13–15 March), data-center optical transceiver maker Kaiam Corp of Newark, CA, USA demonstrated what it claims is the industry's highest-density 8-lane single-mode 400G transceiver in a QSFP-DD form factor, enabled by the same LightScale2 architecture used in its XQX5000 series of 100GBASE-CWDM4 QSFP28 pluggables.

The simplified, flattened, non-hermetic LightScale2 platform supports the dense requirements of 8 lanes of 50G PAM4 (4-level pulse amplitude modulation) in a QSFP-DD package with what is claimed to be excellent signal integrity and thermal performance. The LightScale2 platform is optimized for high-volume, low-cost manufacturing and flexibly supports both 4-lane and 8-lane 200G and 400G transceiver variants, including 400G-LR8/FR8, 400G-FR4, 2x100G-LR4, 2x100G-CWDM4, 2x100G-4WDM-10, 200G-FR4, and 2x200G-FR4. These can be supported in either QSFP-DD or OSFP packages. The platform can extend to future 800G solutions, and even beyond pluggables to Kaiam's Co-Packaged Photonics Interconnect (CoPPhI).

"As capacity and density requirements increase in the data center, our MEMS-based PLC [photonic lightwave circuit] approach further outperforms traditional approaches," says CEO Bardia Pezeshki. "We are demonstrating a transceiver that has 4x the bandwidth of the previous generation in roughly the same QSFP form factor, highlighting the bandwidth and density scalability of Kaiam's technology," he adds.

"We are seeing market need for 400G QSFP-DD transceivers in 2019, but uncertainty and skepticism about whether transceiver vendors can deliver cost-effective solutions at scale with the high speeds needed per lane and the desired reach," comments Jeremy Dietz, VP of global sales & marketing. "Our ability to offer a simple 8-channel 400G solution in advance of the more complex 4-channel electronics, with the full 10km reach, gives the customers faster and easier access to 400G in the desired compact form factor."

The LightScale2 platform leverages Kaiam's core technologies: Optical Wire Bond (OWB) hybrid optical integration, and SCOTS PLCs. OWB harnesses MEMS to enable hybrid optical integration of best-in-class technologies with high optical coupling efficiency, high parallelism, compactness, robustness and low cost. Kaiam's PLCs provide key transceiver optical functions such as wavelength mux/demux, power splitting, and mode size conversion. The firm says that the fundamental flexibility and extensibility of these core technologies expands the horizon of its product roadmap to 400G, 800G & beyond.

www.kaiam.com
www.ofcconference.org

100G single-lambda QSFP28 module for cloud data-centers

At OFC, MACOM Technology Solutions Inc of Lowell, MA, USA, along with optical transceiver firm ColorChip of Yokne'am, Israel, announced a full bi-directional 100G serial QSFP28 module leveraging the patented MACOM PRISM PAM-4 PHY.

Sampling now, PRISM is an integrated 4-level pulse amplitude modulation (PAM-4) PHY (physical layer) device that converts 100 Gigabit Ethernet traffic from four lanes running at 25Gb/s to a single 100Gb/s lane. Requiring only a single set of optical components in a 100GE module can achieve the requisite cost points for next-generation 100G links, MACOM says. By integrating features such as IEEE 100GBASE-DR-compliant forward error correction (FEC) and a linear modulator driver, the PRISM device is expected to ease the burden on module designers and allow for seamless integration with existing 100G switch ports.

As 100G technology reaches maturity in 2018, optical suppliers are intensifying their efforts to reduce module costs and increase system density, says MACOM. Single-lambda PAM-4 modulation is hence critical, enabling the delivery of 100G over a single fiber. This can reduce the number of lasers from four to one in a transceiver module, and the associated cost and density benefits can be significant. For data-center operators, single-lambda PAM-4 is expected to become the de-facto standard for 100G, with deployment starting later this year.

At OFC, ColorChip demonstrated its 100G single-lambda QSFP28 solution.

"Working with an industry pioneer like ColorChip, we have been able to show the performance and cost benefits of our PRISM Chip at 100G serial line rate," says MACOM's director of marketing Chris Collins. "This demonstration validates the R&D investment that MACOM has made in 53Gbaud PAM-4 and poises us to enable seamless integration with optical components for the next generation of cloud data-center deployment," he adds.

"ColorChip brings high-speed data transmission to the world's top mega-data centers," says its VP of R&D Eli Arad. "We are the pioneering global leader of hyperscale single-mode solutions, leveraging our patented SystemOnGlass platform to deliver robust yet compact optical transceivers that support immense rates of data-intensive traffic. MACOM was an early adopter of the single-lambda approach. By developing a cost-effective solution, while maintaining industry-leading performance, ColorChip believes we will enable the next generation of optics for 100G, 400G & beyond."

http://color-chip.com
www.macom.com

Finisar launches first 400G QSFP-DD AOC and transceivers for switching and routing

At the Optical Networking and Communication Conference & Exhibition (OFC) in San Diego (13–15 March), Finisar Corp of Sunnyvale, CA, USA introduced several new products including 400G QSFP-DD LR8 and FR8 transceivers, a 400G QSFP-DD active optical cable (AOC), a 100G serial QSFP28 transceiver, and two 50G SFP56 transceivers supporting a variety of next generation of Ethernet applications.

The new form factors and data rates represent the latest advances in networking technology, geared toward the next generation of optics that will operate at 50 and 100Gb/s per lane, says Finisar. The lanes use 4-level pulse amplitude modulation (PAM4) encoding instead of the traditional non-return-to-zero (NRZ) format, and are crucial to enable hyperscale data centers, service providers and enterprises to meet growing bandwidth demands.

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

400G QSFP-DD LR8 and FR8 transceivers

Finisar unveiled what is claimed to be the first demonstration of a 400G QSFP-DD LR8 transceiver, whose 10km reach is a critical requirement for service provider applications. Using 50G PAM4 technology, the demonstration shows an optical module transmitting data over 10km of duplex single-mode fiber (SMF). In addition to the 10km LR8 module being demonstrated, a 2km FR8 variant of this module will also be available from Finisar, primarily for intra-data-center applications. Both the LR8 and FR8 modules leverage directly modulated laser (DML) transmitter technology, providing a low-power, low-risk, cost-effective solution for 400G.

400G QSFP-DD AOC

Finisar is adding what it claims is the first 400G active optical cable in the QSFP-DD form factor. Leveraging vertical-cavity surface-emitting laser (VCSEL) technology to achieve the lowest power dissipation and lowest cost structure, it provides an alternative to copper cables, which cannot scale to the required cable lengths at these high data rates. In a joint collaboration, Finisar is demonstrating the 400G QSFP-DD AOC running traffic through a Cisco demonstration switch using Cisco's 36 Port QSFP-DD Demo Platform. "This demonstration effectively quadruples the aggregate switch bandwidth while maintaining port density, which is critical to support the continuing growth in network bandwidth demand and data-center traffic," says Cisco product line manager Ray Nering. "Cisco expects that QSFP-DD will become the de facto standard for 400G, just as other QSFP form factors have done so at 40G and 100G."

100G serial QSFP28 FR transceiver

Finisar is introducing a 100G serial FR transceiver in the popular QSFP28 form factor for inter-data-center, transport and router applications with 2km reaches. While leveraging a standard 4x25G electrical interface so that it plugs into standard QSFP28 slots, this module employs just one serial 100G PAM4 optical channel. Once deployed in sufficient volume, it is expected to replace existing 100G QSFP28 CWDM4 modules. Finisar also plans to introduce a 500m DR version of this module. Four of these FR or DR modules will be able to be used in a fan-out configuration with an IEEE standard 400G DR4 module, providing both 100G point-to-point and 100G-to-400G fan-out connectivity at 100G per lane. During OFC, the module is being shown transmitting data over 2km of SMF.

50G SFP56 SR & LR transceivers

Enabling the next generation of 50G single-lane optical connections, Finisar is also introducing what is claimed to be the first 50G SFP56 SR and LR transceivers, using serial PAM4 technology. The firm says that these modules represent the next step in the popular SFP+ family of optical modules that have become ubiquitous in worldwide enterprise, data-center and service provider networks. Primary applications for these products include server-to-switch and switch-to-switch 50G Ethernet connections, and future 5G wireless applications.

During OFC, Finisar demonstrated the SFP56 SR module transmitting over 100m of OM4 multi-mode fiber (MMF), and the SFP56 LR module transmitting over 10km of SMF. Leveraging in-house vertically integrated optics and ICs, the modules support interoperability with previous generations of 25G SFP28 and 10G SFP+ optical transceivers. Both modules comply with the corresponding 50GBASE-R specifications, as defined in the IEEE standards, and offer 50G PAM4 electrical and optical interfaces.

"Today, we have established a number of industry-first optical modules that will enable Finisar to maintain its leadership position for the next generation of products," believes Rafik Ward, senior VP, global marketing. "Building upon 30 years of success, we are gearing up for a new era of optical interfaces that will be built on 50G and 100G PAM4 technology. This will enable us to deliver unprecedented bandwidth to customers in form factors that are backwards compatible with industry established footprints," he adds.

www.finisar.com

Applied Optoelectronics showcases new technology at OFC

At March's Optical Networking and Communication Conference & Exhibition (OFC) in San Diego, Applied Optoelectronics Inc (AOI) of Sugar Land, TX, USA showcased its new 100G single-lambda PAM4 (4-level pulse amplitude modulation) electro-absorption modulated laser (EML) and directly modulated laser (DML) and 400G and 200G transceiver product portfolios, i.e.

- 400G (4x100G QSFP-DD DR4, 4x100G QSFP-DD FR4, 8x50G QSFP-DD FR8, 8x50G QSFP-DD LR8);
- 200G (2x100G QSFP-DD AOC, 2x100G QSFP-DD SR4, 2x100G QSFP-DD PSM4, 2x100G QSFP-DD CWDM4);
- 100G (100G QSFP28 DR1);
- laser technology (100G single-lambda PAM4 EML, 100G single-lambda PAM4 DML).

"By leveraging AOI's unique in-house laser capabilities and manufacturing expertise, we are committed to being a leading provider of optical components, modules and equipment worldwide," says founder & CEO Dr Thompson Lin. "At OFC, we are proud to not only showcase our next-generation transceiver product portfolio, but also to demonstrate the laser technology that will enable data rates up to 400G and beyond," he adds.

In addition, AOI's Mingshan Li presented a paper 'Demonstration of 53.125Gb/s, CWDM, PAM-4, Directly Modulated Laser Transmission over 20km SMF' in the 'Open Systems and Modules' session.

www.ofcconference.org

AOI launches 100G single-λ PAM-4 electro-absorption modulated laser

AOI has launched a 100Gbps electro-absorption modulated laser (EML) for next-generation 400Gbps optical transceivers.

High-speed EMLs are suitable for long-distance transmission due to their small chirp and low chromatic dispersion in fiber. The new EMLs operate at 1310nm, with a symbol rate of 53Gbaud, and are suitable for use with pulse amplitude modulation, enabling a data rate of 100Gbps over a single wavelength. Through careful optimization, AOI was able to achieve a very high bandwidth of 38GHz at 25°C and greater than 32GHz up to a transceiver case temperature of 70°C. The new lasers have demonstrated good 100Gbps PAM-4 eyes over transceiver case temperature of 70°C with a transmitter dispersion eye closure quaternary (TDECQ) value meeting the IEEE 802.3 and 100G Lambda MSA standards.

The new lasers are based on AOI's mature high-volume and high-yield laser production technology, and are suitable for the development of 100G DR1 and 400G DR4/FR4 transceivers for up to 10km fiber transmission. Transceivers operating at 400Gbps can be designed by combining four 100Gbps lasers, either in a coarse wavelength division multiplexed (CWDM) or parallel single-mode (PSM) arrangement. The resulting transceiver can share a common optical bench platform and similar production techniques as AOI currently utilizes in its production of 100G transceivers. By leveraging this common platform, AOI expects to offer substantial cost and time-to-market advantages over its competitors.

"The 100Gbps single-lambda laser is a key enabling technology for high-performance next-generation 400G transceivers," reckons Dr Jun Zheng, vice president of R&D. "With the addition of this new 100Gbps EML laser and the previously announced 100Gbps PAM-4 directly modulated laser (DML), AOI extends its technological leadership in laser development for cost-effective and high-performance 400G transceivers to longer-distance applications, potentially extending beyond the intra-datacenter realm," he adds.

www.ao-inc.com
www.ofcconference.org

Applied Optoelectronics launches 200G PAM4 PIN photodiode array

AOI has launched 200Gbps PIN photodiode (PD) array chips for high-speed optical receivers.

The new 4x50Gbps indium gallium arsenide (InGaAs) PAM4 PIN photodiode array is based on AOI's 4x25Gbps PIN photodiode array technology and is specifically designed for the PAM4 receivers used in 200G and 400G data-center transceiver modules.

The PIN photodiode array optimizes the aperture size and reduces the parasitic capacitance of the photodiode to achieve a high modulation bandwidth of 25GHz and high linearity suitable for PAM4 signal detection.

Typical receiver sensitivity tested with AOI's 50Gbps PAM4 directly modulated laser (DML) is −12dBm at a forward-error correction (FEC) KP4 bit-error rate (BER) threshold of 2E−4. Additionally, alongside the 1x4 array, the 50Gbps singlet photodiode can be used in 50Gbps transceivers for 5G wireless and fiber-to-the-home applications.

"With in-house manufacturing for both our 50Gbps PAM4 PIN photodiode array and 50Gbps PAM4 DML or electro-absorption modulated laser (EML), AOI now controls the two key optical components required to produce 200G and 400G transceivers based on 50Gbps per lambda technology," says vice president of R&D Dr Jun Zheng. "This vertical integration will improve the time to market for our 200Gbps DR4/FR4/LR4 and 400Gbps FR8/LR8 transceivers."

www.ao-inc.com

MACOM showcases next-gen cloud data center and 5G connectivity solutions at OFC

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (13–15 March), MACOM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications) debuted an expanded portfolio of optoelectronics and photonic solutions.

MACOM's complete portfolio includes high-performance modulator drivers, transimpedance amplifiers, clock/data recovery circuits, cross-points, avalanche photodiodes (APD), PIN photodiodes, Fabry–Perot (FP) and distributed feedback (DFB) lasers, silicon photonics, 53Gbaud PAM-4 physical layer devices (PHYs) and receiver optical sub-assemblies (ROSAs) and transmitter optical sub-assemblies (TOSAs) for enterprise and telecom optical systems operating up to 100G, 400G and beyond.

Highlights at OFC included:

- a 400G SR8 fully analog chipset solution for QSFP-DD applications (featuring MACOM's CDR, TIA and driver);
- MACOM's 100G CWDM4 L-PIC (laser photonic integrated circuit) solution;
- 400G-FR4, claimed to be the lowest-cost upgrade path for >100G throughput, featuring MACOM's PAM-4 PHY, L-PIC and TOSA/ROSA;
- 5G optical connectivity solutions for SFP28 SR/LR/ER and 100G wireless chipsets.

www.ofcconference.org

MACOM samples 400G chipset for short-reach optical connectivity

MACOM is sampling its MALD-38435 four-channel 56Gb/s PAM-4 vertical-cavity surface-emitting laser (VCSEL) driver and companion MATA-38434 four-channel transimpedance amplifier (TIA) devices for short-reach VCSEL-based optical module and active optical cables (AOC) applications.

The new devices complement previously announced transmit and receive clock data recovery (CDR) devices for a complete transmit and receive solution. The chipset operates at up to 56Gb/s PAM-4 (28GBbaud PAM-4) data rate per channel, enabling short-reach (up to 100m) optical modules for 200G QSFP and 400G QSFP-DD and OSFP applications. The new chipset follows the physical media device (PMD) chipset for 100G short-reach SR-4 QSFP modules launched in March 2016.

MACOM says that, as demand for 100G connectivity progresses to 200G and on to 400G, optical module suppliers are looking to enable Cloud data centers and high-performance computing (HPC) clusters with optical connectivity solutions delivered in a small form factor and consuming low power at low cost. Featuring the MALD-38435 driver and MATA-38434 TIA along with the existing MASC-38040 and MAOM-38051/38053 CDR devices, the fully analog chipset offers an optimal high-performance, low-power and low-cost combination, it is claimed. By utilizing fully analog circuitry as opposed to digital signal processing, MACOM's solution delivers what is claimed to be best-in-class low latency (especially critical for high-performance computing).

The MALD-38435 VCSEL driver and MATA-38434 TIA are offered as a die-level solution with 250μm channel spacing, optimal for direct wire-bonding to VCSEL lasers and photodetectors. The devices feature individual channel programmability control via an I2C interface for flexible management by the module's local microcontroller. The devices feature low power and a small die size, enabling implementations in QSFP and QSFP-DD modules. The devices' low jitter performance enables low bit error rate (BER) of 10^{-15} with a forward-error corrected (FEC) protected link. When combined with MACOM's CDRs, the solution delivers extensive per-channel equalization and eye-shaping programmable features as well as a pseudo-random bit sequence (PRBS) generator and checker and eye monitor features.

"By utilizing our analog circuit technology, we are delivering a complete chipset for high-performance, short-reach optical interconnect at low power, low cost and low latency critical for cloud computing and HPC applications," says Marek Tlalka, senior director of marketing, High-Performance Analog, at MACOM.

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (13–15 March), as well as showcasing a complete portfolio of PMDs for optical modules, MACOM demonstrated the new chipset with a QSFP-DD module from Dust Photonics.

"We are pleased to demonstrate the industry's leading 400G QSFP-DD-SR8 short-reach module utilizing MACOM's chipset," says Dust Photonics' CEO Ben Rubovitch. "MACOM's fully inter-operable solution and great technical support reduced our time to market," he comments. "We look forward to expanding our portfolio to additional optical modules and AOC applications," Rubovitch concludes.

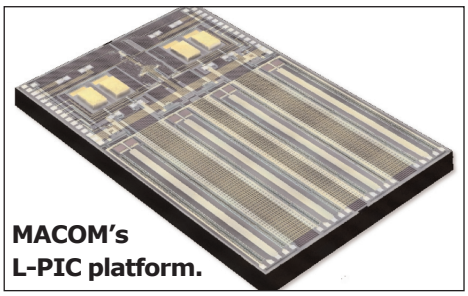
www.macom.com/products/product-detail/MALD-38435
www.macom.com/products/product-detail/MATA-38434

MACOM launches L-PIC-enabled CWDM4 TOSA to drive cloud data centers and 5G optical connectivity

At the Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego (13–15 March), MACOM Technology Solutions Inc of Lowell, MA, USA launched the MAOT-025402 CWDM4 transmitter optical sub-assembly as part of its L-PIC (laser-integrated silicon photonic integrated circuit) solution for 100Gbps CWDM4. Leveraging the firm's patented L-PIC, the MAOT-025402 is designed to mate with the MASC-37053A CDR (clock & data recovery chip) to form the complete high-speed transmit path for QSFP28 CWDM4 solutions.

As the growth of data traffic and demand forces Cloud data centers to rapidly scale their capabilities, MACOM is targeting the transition from 100Gbps to 400Gbps and from 4G to 5G with a cost-effective, high-performance and highly integrated interconnect chipset for CWDM4, scalable to FR4 and FR1/DR1 applications.

Core to the MAOT-025402 is the MAOP-L284CN L-PIC, which integrates four 25Gbps CWDM wavelengths in a single silicon photonic integrated circuit to communicate 100Gbps over duplex single-mode fiber. MACOM's L-PIC platform provides a highly integrated silicon photonic solution targeting specific data-center applications that includes four CW lasers, monitor photodiodes, high-bandwidth waveguides, modulators and multiplexers. Utilizing the firm's patented self-aligning etched facet technology (SAEFT) for precision attachment of the lasers to the silicon chip, the L-PIC platform removes the need for active laser alignment and offers what is claimed to be a significant cost reduction, enabling mainstream deployment.



MACOM's L-PIC platform.

"MACOM is leveraging our L-PIC platforms to enable leading scalability that meets the rapidly increasing CWDM4 module demand," says Vivek Rajgarhia, senior VP & general manager, Lightwave, at MACOM. "The platform's automated self-aligning calibration and firmware control is anticipated to deliver the requisite combination of scale and cost for mainstream cloud data-center deployment."

MACOM says that its L-PIC platform delivers the bandwidth that is critical to enabling CWDM4, and is now available in a transmitter optical sub-assembly (TOSA) and at die level. Each L-PIC product includes a companion matched driver and PIC controller. Leveraging this three-device chipset, users can significantly reduce engineering risk and achieve faster time-to-market, it is claimed. The accompanying software provides automatic calibration and self-test capabilities, and greatly reduces capital investment required for production lines, the firm adds. Fully integrated and pre-assembled, MACOM's sub-assembly platform is expected to provide the performance required for achieving 100Gbps and 400Gbps data-center links while reducing a transceiver manufacturer's engineering and capital equipment costs, enabling an overall faster time-to-market with lower investment.

www.macom.com/products/product-detail/MASC-37053A
www.ofcconference.org

Emcore reduces its quarterly revenue forecast from $21–23m to $18–19m

Excess inventory at major CATV customer having greater-than-expected impact

In preliminary financial results for fiscal second-quarter 2018 (to end-March), Emcore Corp of Alhambra, CA, USA — which provides InP-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets — has lowered its revenue guidance from $21–23m to $18–19m.

This would be down 22.9% on $24m last quarter and 43% on $32.6m a year ago.

The main contributory factors include:

- A greater-than-expected impact of a major cable TV (CATV) customer working through a large inventory accumulation, resulting in lower-than-expected revenue from the customer.
- Although other CATV customers showed strong demand, some of the orders were received too late to ship before the end of fiscal Q2.

"CATV experienced significant demand shortfall from one major customer but saw bright spots in terms of LEML [linear externally modulated laser] adoption and strength from our other customers," says president & CEO Jeffrey Rittichier. "During the quarter, our Chip and Navigation businesses performed well and demonstrated the expected strength in demand."

www.emcore.com

Fraunhofer ISE demonstrates two-terminal GaInP/GaAs/Si solar cell with efficiency of 33.3%

Performance similar to standard III–V/Ge triple-junction solar cells

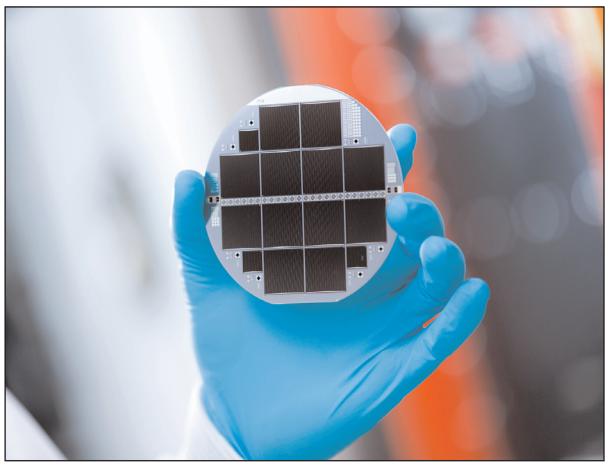
Fraunhofer Institute for Solar Energy Systems ISE of Freiburg, Germany — together with wafer-bonding equipment maker EV Group of St Florian, Austria — has developed a new silicon-based multi-junction solar cell with 1-sun AM1.5G solar energy conversion efficiency of 33.3% (Romain Cariou et al, Nature Energy, vol3 (2018), p326).

Silicon solar cells currently have a 90% share of the photovoltaic market, but they are nearing their theoretical efficiency limit. The efficiency of silicon single-junction solar cells is intrinsically constrained to 29.4%, and practically limited to around 27%. It is possible to overcome this limit by combining silicon with higher-bandgap materials, such as III–V compound semiconductors, in a multi-junction device. However, challenges associated with combining these materials have hindered the development of highly efficient III–V/Si solar cells.

Fraunhofer ISE achieved the silicon-based multi-junction solar cell's high conversion efficiency by using the microelectronics manufacturing process of direct wafer bonding to transfer III–V layers just 1.9μm thick — which had been epitaxially deposited on a gallium arsenide (GaAs) substrate — onto a silicon solar cell.

The surfaces were first deoxidized in an EVG580 ComBond chamber under high vacuum with an ion beam and then bonded together under pressure. The atoms on the surface of the III–V subcell form bonds with the silicon atoms, creating a monolithic device. The GaAs substrate is subsequently removed.

The III–V/Si multi-junction solar cell specifically consists of a sequence of subcells stacked on top of each other. Specifically, a gallium indium phosphide (GaInP) top cell absorbs visible sunlight with wavelengths of 300–670nm, a middle gallium arsenide (GaAs) subcell absorbs 500–890nm near-infrared radiation, and a bottom silicon subcell absorbs longer 650–1180nm wavelengths. Spanning the absorption range of the sun's spectrum boosts the efficiency significantly.



III-V/Si multi-junction solar cell with record conversion efficiency of 33.3% (© Fraunhofer ISE/Photo: Dirk Mahler).

The three subcells are internally connected by tunnel diodes, including a tunnel oxide passivated contact (TOPCon) applied to the front and back surfaces of the silicon. Also, the cell has a simple front and rear contact (as for a conventional silicon solar cell) and can therefore be integrated into photovoltaic modules in the same manner.

Fraunhofer ISE and industry partner EVG had already demonstrated 30.2% efficiency in November 2016, raising it to 31.3% in March 2017. They have now again improved the light absorption and the charge separation in silicon, achieving a record of 33.3% efficiency. Specifically, a nanostructured diffraction-grating back-side contact is implemented on the silicon bottom cell to prolong the path length of light, and a front-side contact grid and anti-reflection coating are also applied. Performance is said to be similar to standard III–V/Ge triple-junction solar cells.

"Costs have decreased to such an extent that photovoltaics has become an economically viable competitor to conventional energy sources," says Fraunhofer ISE director Dr Andreas Bett. However, for industrial manufacturing of III–V/Si multi-junction solar cells in particular, the costs of the III–V epitaxy and the connecting technology with silicon must be reduced. There are still great challenges to overcome in this area, which Fraunhofer ISE intends to solve through future investigation.

"The new result shows how material consumption can be reduced through higher efficiencies, so that not only the costs of photovoltaics can be further optimized but also its manufacture can be carried out in a resource-friendly manner," says Bett.

Fraunhofer ISE's new Center for High Efficiency Solar Cells (being constructed in Freiburg) will provide a setting for developing next-generation III–V and silicon solar cell technologies. The ultimate objective is to make high-efficiency solar PV modules with efficiencies of over 30% possible in the future.

Dr Roman Cariou, the young scientist and first author of the paper, was supported through the European Union with a Marie Curie Stipendium (HISTORIC, 655272). The work was also supported by the EU within the NanoTandem project (641023) as well as by the German government's Federal Ministry for Economic Affairs and Energy BMWi in the PoTaSi project (FKZ 0324247).

www.nature.com/articles/s41560-018-0125-0
www.ise.fraunhofer.de/en/research-projects/nano-tandem.html
www.EVGroup.com

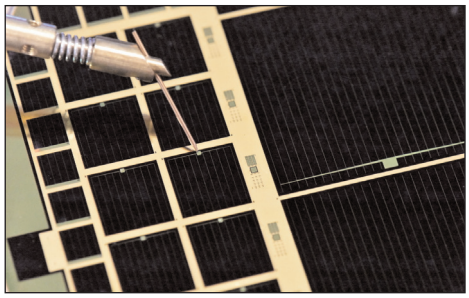
MicroLink achieves NREL-certified record 37.75% efficiency for triple-junction ELO solar cell on 6-inch GaAs production platform

Power density exceeds 3000W/kg under 1-sun AM0 spectrum

MicroLink Devices of Niles, IL, USA has achieved a record 37.75% power conversion efficiency for a triple-junction epitaxial lift-off (ELO) thin-film solar cell produced on a 6-inch gallium arsenide (GaAs) substrate production platform, as officially certified by the US National Renewable Energy Laboratory (NREL) and tested under the industry-standard air-mass 1.5 global (AM1.5G) simulated 1-Sun solar spectrum.

The specific power of the ELO solar cell design exceeds 3000W/kg under the 1-sun AM0 spectrum, which is also claimed to be a record compared with any other solar cell technology.

The solar cells are currently used to provide energy to the Zephyr HALE (High Altitude Long Endurance) platform produced by Airbus Defence and Space in Farnborough, UK. MicroLink has an exclusive licensing agreement with NREL for the inverted metamorphic multi-junction (IMM) technology used to manufacture the high-efficiency solar device.



MicroLink's triple-junction IMM ELO solar cells being tested.

MicroLink says that its proprietary ELO process makes it possible to peel off thin layers of active solar cell material that were deposited on a GaAs substrate. The expensive GaAs substrate can then be re-used multiple times to lower manufacturing costs. The firm's ELO technology development has been supported over the past decade by numerous US agencies including NASA, DARPA, the Air Force Research Laboratory (AFRL), the Office of Naval Research (ONR), NAVAIR, Army Research Office, Army REF, CERDEC, ARPA-E, and the Department of Energy (DOE).

"We are continuing to push the limits of what can be achieved with the ELO technology," says founder & president Dr Noren Pan. "Our triple-junction IMM ELO solar cells combine the highest efficiency with the lowest mass density of any solar cell technology available," he claims. "This represents a compelling solution for demanding unmanned aerial vehicle (UAV) and satellite applications."

More details about the record ELO cell performance are being presented at the 36th annual Space Power Workshop in Los Angeles (23–26 April) and at the 45th IEEE Photovoltaics Specialists Conference (PVSC 2018) in Waikoloa, HI, USA (10–15 June).

www.mldevices.com
www.wcpec7.org/WCPEC-7

NREL releases database of inorganic thin-film materials

An extensive experimental database of inorganic thin-film materials that organizes a decade of research at the US Department of Energy's National Renewable Energy Laboratory (NREL) is now publicly available (Andriy Zakutayev et al, Scientific Data vol.5, no.180053 (2018)).

The High Throughput Experimental Materials (HTEM) Database contains over 140,000 sample entries collected by NREL scientists investigating inorganic materials for use in energy applications such as thin-film solar. Entries provide details about structural, chemical and optoelectronic properties, and synthesis conditions.

"All existing experimental databases either contain many entries or have all this property information, but not both," says Andriy Zakutayev, a scientist at NREL's Materials Science Center, which is dedicated to developing new materials and devices for solar cells and other renewable energy technologies.

The HTEM database draws from nearly a decade of thin-film experiments at NREL. Even data that was published, but not in a form that could be searched, was digitized and added to the database. "Once it's all been amassed, it's a non-trivial job to curate it and get it in a form where it can be analyzed and understood," Phillips says, adding that this is where the future opportunities lie.

Now, NREL is collaborating with the US National Institute of Standards and Technology (NIST) to deploy a network of high-throughput experimental tools that would allow researchers to collaborate virtually on the synthesis and analysis of new materials, with results being added to databases like this. The pilot project has been dubbed the High-Throughput Experimental Materials Collaboratory.

Development, curation and filling out of the HTEM database was supported by NREL's Laboratory Directed Research and Development program, the Department of Energy's Office of Science, and the Office of Energy Efficiency and Renewable Energy.

www.nature.com/articles/sdata201853
https://htem.nrel.gov

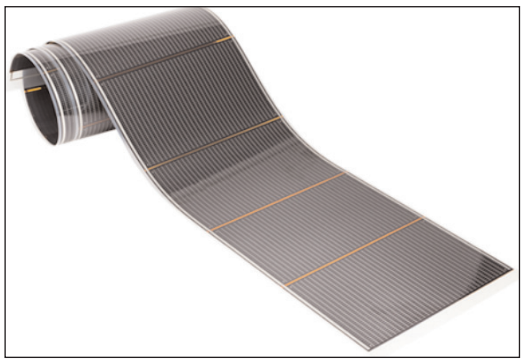
Ascent Solar ships first ultralight thin-film modules for high-altitude airships

Ascent Solar Technologies Inc of Thornton, CO, USA — which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules that can be integrated into consumer products, off-grid applications and aerospace applications — has developed and shipped its next-generation laminated aerospace product, using Ultralight technology.

Representing an advance over the firm's prior Superlight technology in terms of weight and performance for ready-to-integrate PV modules for aerospace applications (such as high-altitude airships), Ultralight has been validated in terms of a major contract from a European-based customer.

Valued at more than $300,000, the shipment was delivered ahead of schedule before the end of first-quarter 2018. The Ultralight PV module is the first of its kind for Ascent Solar to introduce two major advances over previous products: next-generation PV developed originally for Ascent's space customers and manufactured on a substantially thinner substrate than Ascent's standard bare PV module; and asymmetric laminate packaging to reduce thickness and weight substantially from the Superlight product.

These changes have resulted in vastly reduced areal density to nominally 330g/m^2, or about 50% less than 'thin' crystalline PV airship options. Nominal specific-power



under terrestrial (AM1.5) lighting is 280W/kg, and is projected to exceed 330W/kg in near-space conditions (AM0).

Modules provided to the customer in this shipment are designed for easy integration to reduce assembly time of the power system and increase overall array reliability.

"Our company was created, in part, to address the emerging unmanned high-altitude airship market through the use of our unique, extremely light and flexible photovoltaic product, and we have customizable solar blankets that address multiple aspects of this unique market segment," says chief technology officer & founding member Dr Joseph Armstrong. "The customer has ordered a custom version of one of our existing 25W Superlight airship PV blankets with dimensions and electrical connections specific to their vehicle. By combining our space PV technology with our new asymmetric laminate packaging, we were able to achieve the breakthrough in terms of substantially higher power-to-weight ratio with Ultralight. Furthermore, our proficiency at rapid prototyping and concurrent design for manufacturability allowed us to accept this custom order with a swift turnaround time to delivery. By proving out the Ultralight construction, we have opened the door for other customers who wanted an even lighter version of our aerospace product that cover drones, tethered aerostats, and both fixed-wing and lighter-than-air high-altitude long-endurance (HALE) applications," he adds.

"This contract, which accounted for approximately 50% of our 2017 full-year revenue, will be booked as revenue in the first quarter and give the company a strong head start into 2018," comments president & CEO Victor Lee. "This is not only significant in value but also underscores the power of Ascent's proprietary technology to address these rapidly emerging and growing premium PV markets," he adds. "We hope that this contract is only the 'tip of the iceberg' as the airship project, when successfully launched, is expected to be rolled out on a much larger scale in the near future. Our technical team has been working with our aerospace customer to identify the best solution for their needs while providing a product that takes full advantage of the key attributes of our monolithically integrated flexible CIGS PV."

www.AscentSolar.com

Riber receives repeat evaporator order from Singulus for CIGS solar cell production

Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has received a new order worth over €1m from Singulus Technologies AG of Kahl am Main, Germany (which makes production equipment for the optical disc and solar sectors).

Riber will supply Singulus with its Jet 40K Selenium linear evaporators, which are used for the production of copper indium gallium diselenide (CIGS) thin-film solar cells. The new order (which is for delivery in second-half 2018) follows a previous order received from the customer in October 2016.

www.riber.com

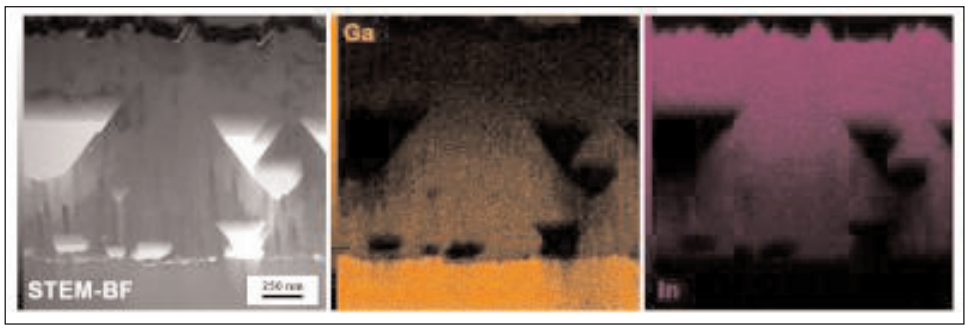
Luxembourg researchers show that sodium enhances indium-gallium interdiffusion in CIGS cell production

Research led by the University of Luxembourg has investigated solar cell manufacturing processes and proved that assumptions about chemical processes that have been commonplace for the past 20 years are, in fact, inaccurate (Colombara et al, Nature Communications vol9 (2018) article no. 826; DOI: 10.1038/s41467-018-03115-0).

In the past, scientists discovered by accident that the efficiency of copper indium gallium diselenide (CIGS) solar cell technology improves vastly if sodium is added to the light-absorbing layer. At the same time, they observed that the sodium impacts growth of this layer and the interaction of the other chemical elements, namely it inhibits the mixing of gallium and indium. This leads to less homogenous layers and thus impairs the results. Therefore, in the past, scientists and manufacturers believed that the ideal way to produce a solar cell was to only add the sodium after the growth process was concluded.

By using a different approach, researchers at the University of Luxembourg's Physics and Materials Science Research Unit, along with four internationals partners, have shown that the truth is more nuanced. While conventionally the light-absorbing layer is made up of thousands of individual grains, the research group chose a more demanding fabrication strategy and grew the layer as a single grain. "If the absorber is made of only one grain, adding a small amount of sodium helps to homogenize the distribution of the elements," says principal investigator Diego Colombara, now Marie Curie Research Fellow at the International Iberian Nanotechnology Laboratory. "More than 20 years of previous research have consistently shown the opposite effect on absorbers made of many grains," he adds.

The conclusion is that sodium has a dual effect: it homogenizes the elements inside each grain but it slows down homogenization in the interplay between grains. "This gives us the opportunity to rethink how we produce solar cells," concludes Dr Phillip Dale, head of the research group at the University of Luxembourg's Laboratory for Energy Materials (LEM) and an Attract fellow of the Luxembourg National Research Fund (FNR). "In the future, these insights might lead to improvements in the manufacturing process."



Microscope image of solar cell absorber made of one grain (black and white) and corresponding chemical analysis showing the concentration of gallium (orange) and indium (purple).

www.nature.com/articles/s41467-018-03115-0
https://wwwen.uni.lu/research/fstc/physics_and_materials_science_research_unit/research_areas/energy_materials

Midsummer doubles annual revenue and profit

Midsummer AB of Järfälla, near Stockholm, Sweden — a provider of turnkey production lines for manufacturing flexible, lightweight copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) solar panels — says that, for full-year 2017 compared with 2016, its revenue nearly doubled, up 94% from SEK59m to SEK115m ($14m; €11.3m). This follows a previous doubling of revenue and profit in 2016 compared with 2015.

Annual profit before taxes more than doubled, up by 135% from SEK10.4m to SEK24.5m ($3m; €2.5m). Operating margin was 21.7%.

Growth was due to several new orders for the firm's compact DUO thin-film solar cell manufacturing system and a "positive market response" to the launch of its new building-integrated photovoltaic (BIPV) business concept.

Midsummer claims that the DUO system has established itself as the most widespread manufacturing tool for flexible CIGS solar cells, and that it is now the only firm to offer light, flexible, robust solar panels with high energy efficiency.

Last year, Midsummer established a strategic production partnership with Swedish roof manufacturer Clix for the launch of Clixsun, a roofing system with integrated solar panels that has added a second business area to Midsummer.

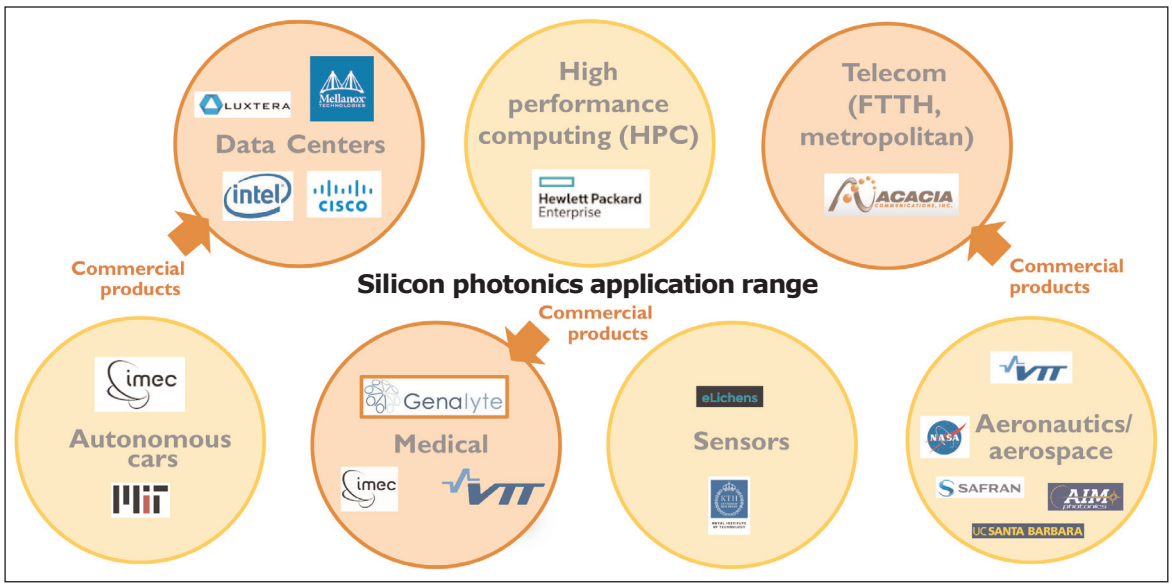
"We see a continued high demand for our products and the order outlook for 2018 is very promising, both for DUO manufacturing systems and for deliveries of solar panels," says CEO Sven Lindström. "We expect to double the number of employees in 2018."

www.midsummer.se

Silicon photonics reaches tipping point, with transceivers shipping in volume

Market to boom for 100G then 400G, with 200G a parallel intermediate step.

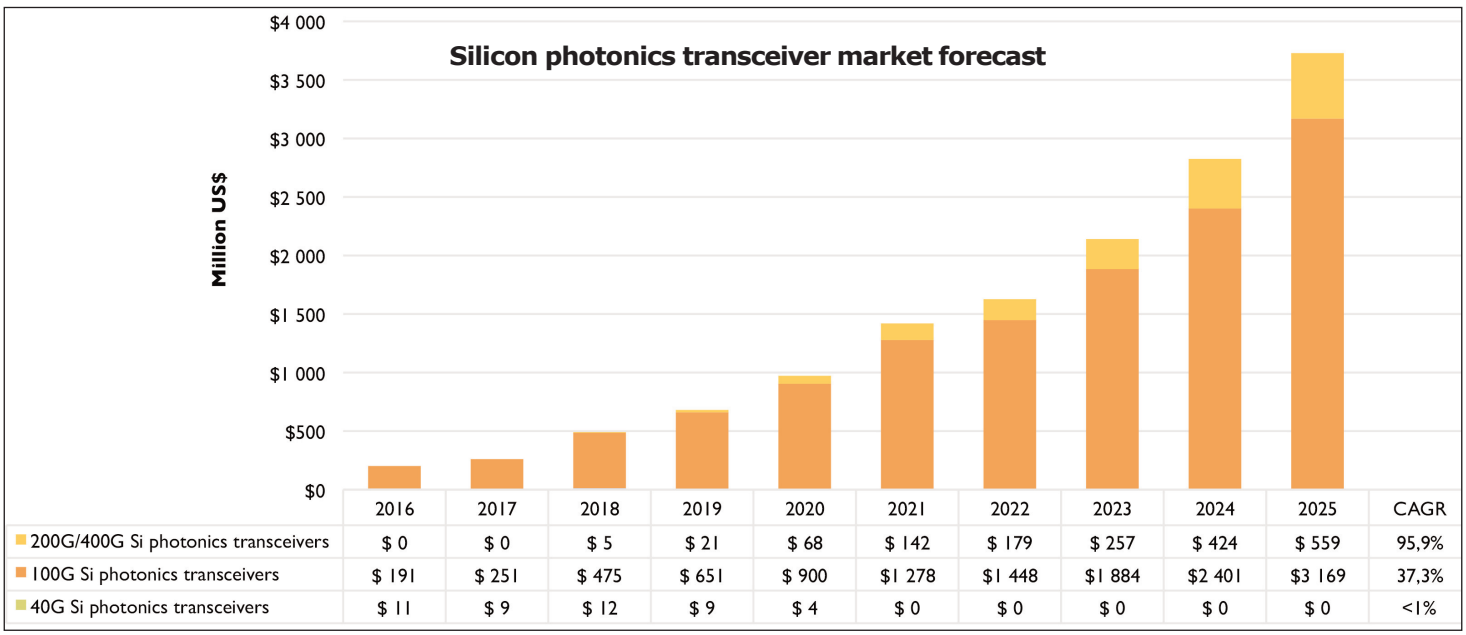
Silicon photonics is still a small market today, with sales at the die level estimated to be $30m in 2016, but the market has reached its tipping point (as transceivers are now shipping in volume), and will rise to $560m at the chip level and almost $4bn at the transceiver level in 2025, forecasts market research & strategy consulting company Yole Développement in its technology & market report 'Silicon Photonics'.



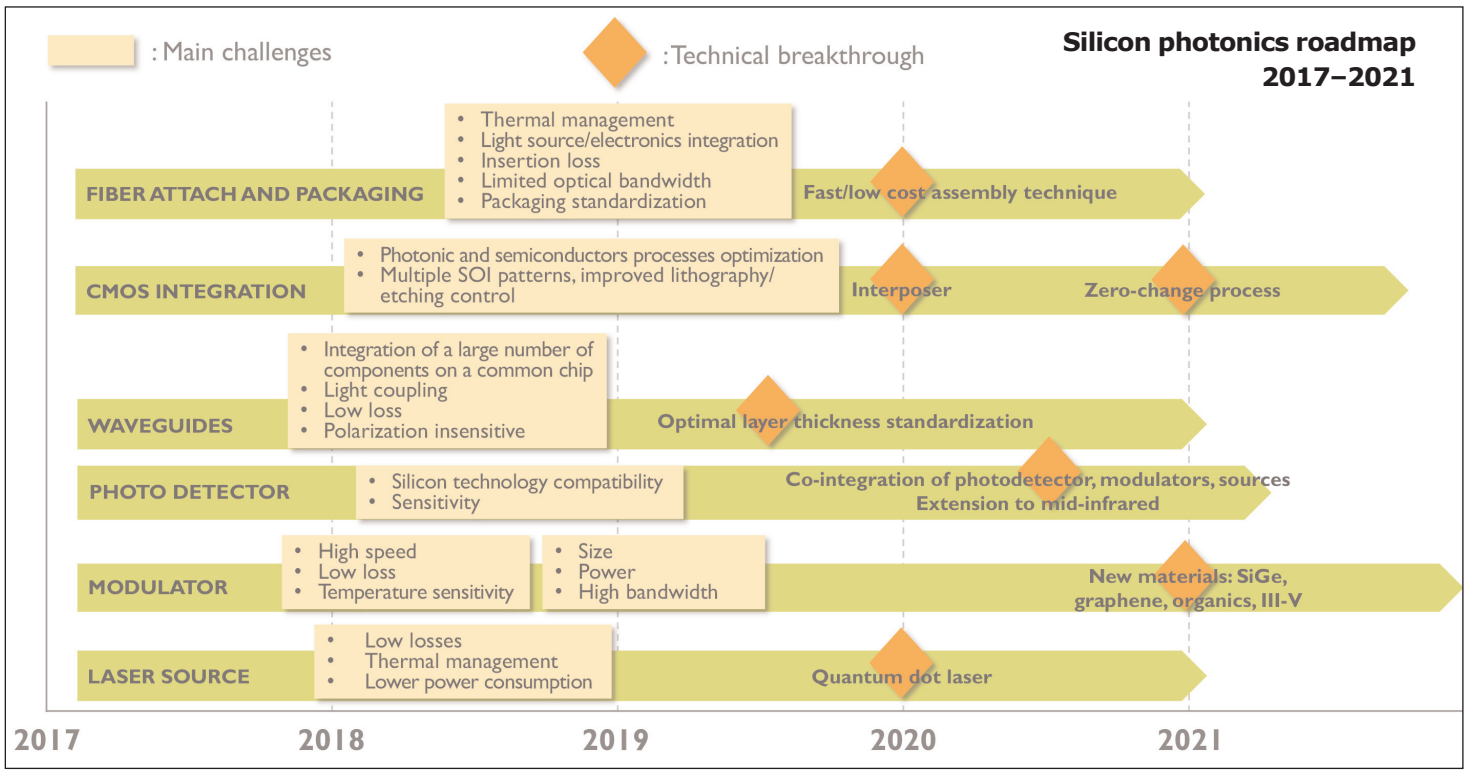
Silicon photonics technology will grow from a few percent of total optical transceiver market value in 2016 to 35% in 2025, mostly for intra-data-center communication, the firm adds.

The strongest demand is for 400G. In parallel, 200G could be just an intermediate step between 100G and 400G. "The next evolution is to develop a 400G optical port over a single fiber across 500m at less than $1 per gigabit and with power <5mW/Gb," says senior technology & market analyst Dr Eric Mounier. One terabit per second rates should follow. Although the wafer area this accounts for will be a minute part of the worldwide silicon-on-insulator (SOI) market, it will represent significant value because of the SOI wafer's high price, the report notes.

"We are only at the very beginning, as there is massive ongoing development worldwide for further integration," believes Mounier. "The recent involvement of large



	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	CAGR
200G/400G Si photonics transceivers	$ 0	$ 0	$ 5	$ 21	$ 68	$ 142	$ 179	$ 257	$ 424	$ 559	95,9%
100G Si photonics transceivers	$ 191	$ 251	$ 475	$ 651	$ 900	$1 278	$1 448	$1 884	$2 401	$3 169	37,3%
40G Si photonics transceivers	$ 11	$ 9	$ 12	$ 9	$ 4	$ 0	$ 0	$ 0	$ 0	$ 0	<1%

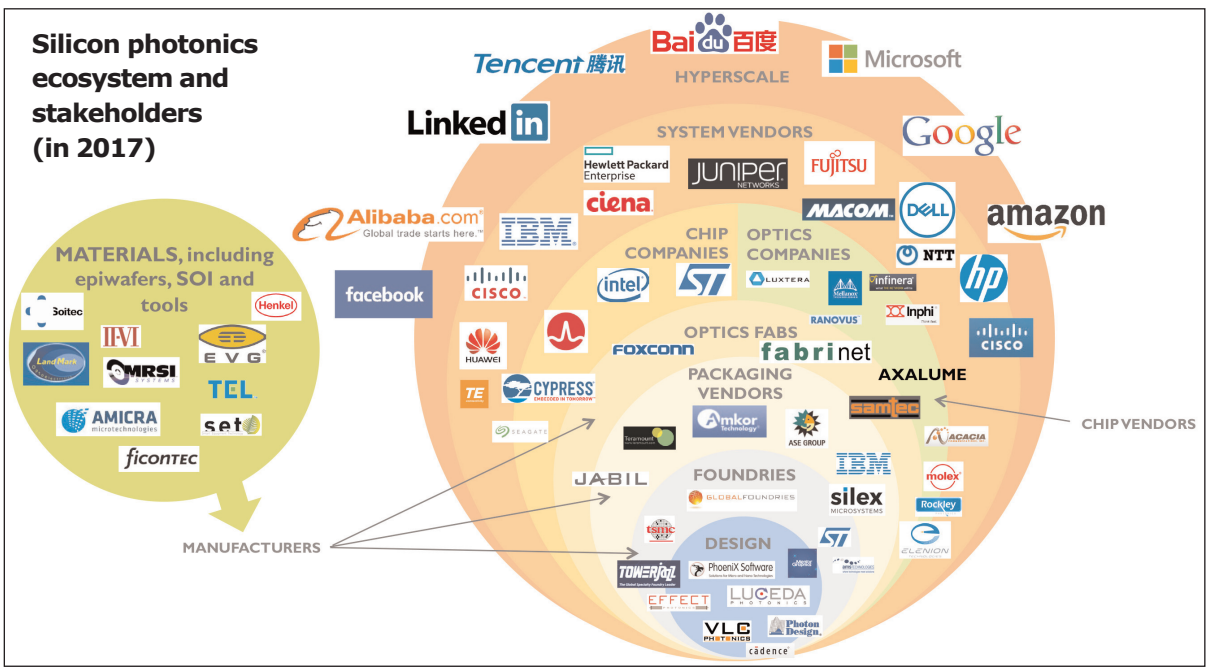


integrated circuit foundries, such as TSMC's relationship with Luxtera and GlobalFoundries with Ayar Labs, are very encouraging signs showing the big promise for silicon photonics."

The 'Zero-Change' processes currently in development — i.e. manufacturing optical components without making any changes to a complementary metal oxide semiconductor (CMOS) process — are targeting future inter-chip optical interconnects that could represent huge market volumes, notes the report. Silicon photonics is at the maturity level of the electronics industry in the 1980s, and there are still challenges to overcome. For all these challenges, technical breakthroughs will be necessary, and are detailed in Yole's silicon photonics roadmap:

- Laser source integration: lasers are still in competition with vertical-cavity surface-emitting lasers (VCSELs) for low distance, and developments of silicon-based lasers are no longer progressing. However, quantum dot lasers could be a solution in the long term, as they are less temperature sensitive.
- Modulators: smaller-size modulators are required, and silicon photonics offers the advantage of modulator integration.
- Assembly and testing: more advances in lower-cost packaging and wafer-level testing are needed.
- Design and software: specific software is required for photonics with pre-defined models.
- Supply-chain maturation similar to the semiconductor supply chain.
- New manufacturing solutions: for example, a new trend is to have a zero-change approach on CMOS lines.
- Higher-distance transmission. ■

www.i-micronews.com/category-listing/product/silicon-photonics-2018.html



Near-ultraviolet AlGaN laser diode on silicon

Researchers in China have claimed the first observation of room-temperature electrically injected lasing in an aluminium gallium nitride near-UV laser on silicon.

Researchers in China claim the first observation of room-temperature electrically injected lasing in aluminium gallium nitride (AlGaN) near-ultraviolet (NUV) laser diodes (LDs) grown on silicon (Si) [Meixin Feng et al, ACS Photonics, vol5, p699, 2018].

The team from Suzhou Institute of Nano-Tech and Nano-Bionics, University of Science and Technology Beijing, University of Science and Technology of China, and Changchun Institute of Optics Fine Mechanics and Physics see prospects for laser microscopy, fluorescence spectroscopy, mass spectrometry, surface analysis, material processing, and laser lithography. Laser diodes offer compact, efficient, tunable alternatives to conventional gas and solid-state lasers at longer wavelength, and the researchers hope this can be extended into the NUV range. The use of silicon substrates should reduce costs through low material prices and the deployment of larger-diameter wafers.

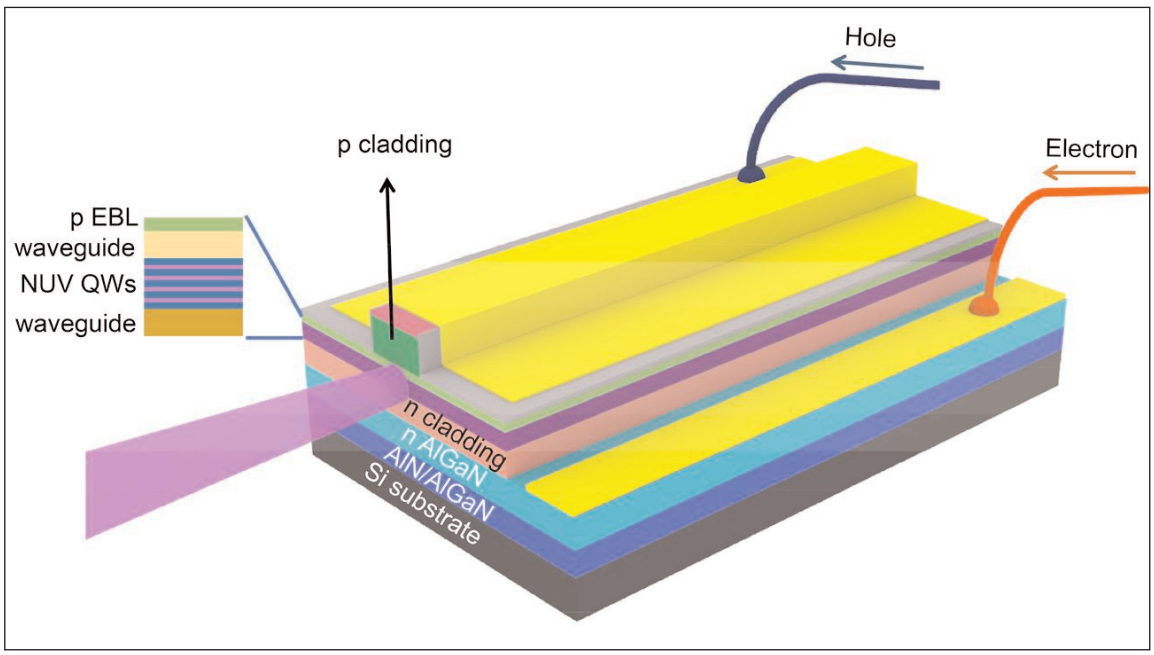


Figure 1. Schematic architecture of AlGaN-based NUV-LD directly grown on silicon.

The team reports that, while it has recently achieved visible electrically pumped lasing of III-nitrides on silicon, other groups have only managed optically pumped lasing.

Silicon substrates with (111) lattice orientation were processed with metal-organic chemical vapor deposition (MOCVD) to give a structure of an AlN/AlGaN multi-layer buffer, a 3.5μm n-$Al_{0.03}Ga_{0.97}$ contact, 150x 2.5nm/2.5nm n-$Al_{0.2}Ga_{0.8}$/n-GaN superlattice cladding, an 80nm n-GaN waveguide, 4x 2.5nm/10nm $In_{0.05}Ga_{0.95}N/Al_{0.1}Ga_{0.9}N$ quantum well (QW)/barrier pairs, a 60nm GaN waveguide, a 20nm n-$Al_{0.25}Ga_{0.75}$ electron-blocking layer (EBL), 100x 2.5nm/2.5nm p-$Al_{0.2}Ga_{0.8}$/p-GaN superlattice cladding, and a 30nm p-GaN contact.

Coplanar 4μmx800μm ridge-waveguide laser diodes were fabricated (Figure 1). The cleaved facets were coated with quarter-wave pairs of tantalum oxide/silicon dioxide dielectric. The front facet coating consisted of four pairs of layers, while the back facet had eight pairs. Facet coating reduced the laser threshold current from 550mA (17.2kA/cm^2) to 350mA (10.9kA/cm^2). The lasing was signalled by narrowing of the electroluminescence (EL) spectral linewidth, an elongated far-field pattern, and a discontinuity in the slope of light output power with current (Figure 2).

The researchers comment: "As compared with the reported value (~3kA/cm^2) of NUV-LD grown on high-quality GaN substrates (TDD ~ 10^6cm^{-2}) by epitaxial lateral overgrowth (ELOG), the threshold current density of the as-fabricated AlGaN-based NUV-LD grown on silicon was relatively high, which caused a limited lifetime (~1.5h) under a pulsed injection current of 450mA (pulse width of 400ns and a repetition rate of 10kHz) at room temperature."

The multi-layer buffer between the silicon substrate and device layers was designed both to compensate for tensile strain from the thermal expansion mismatch

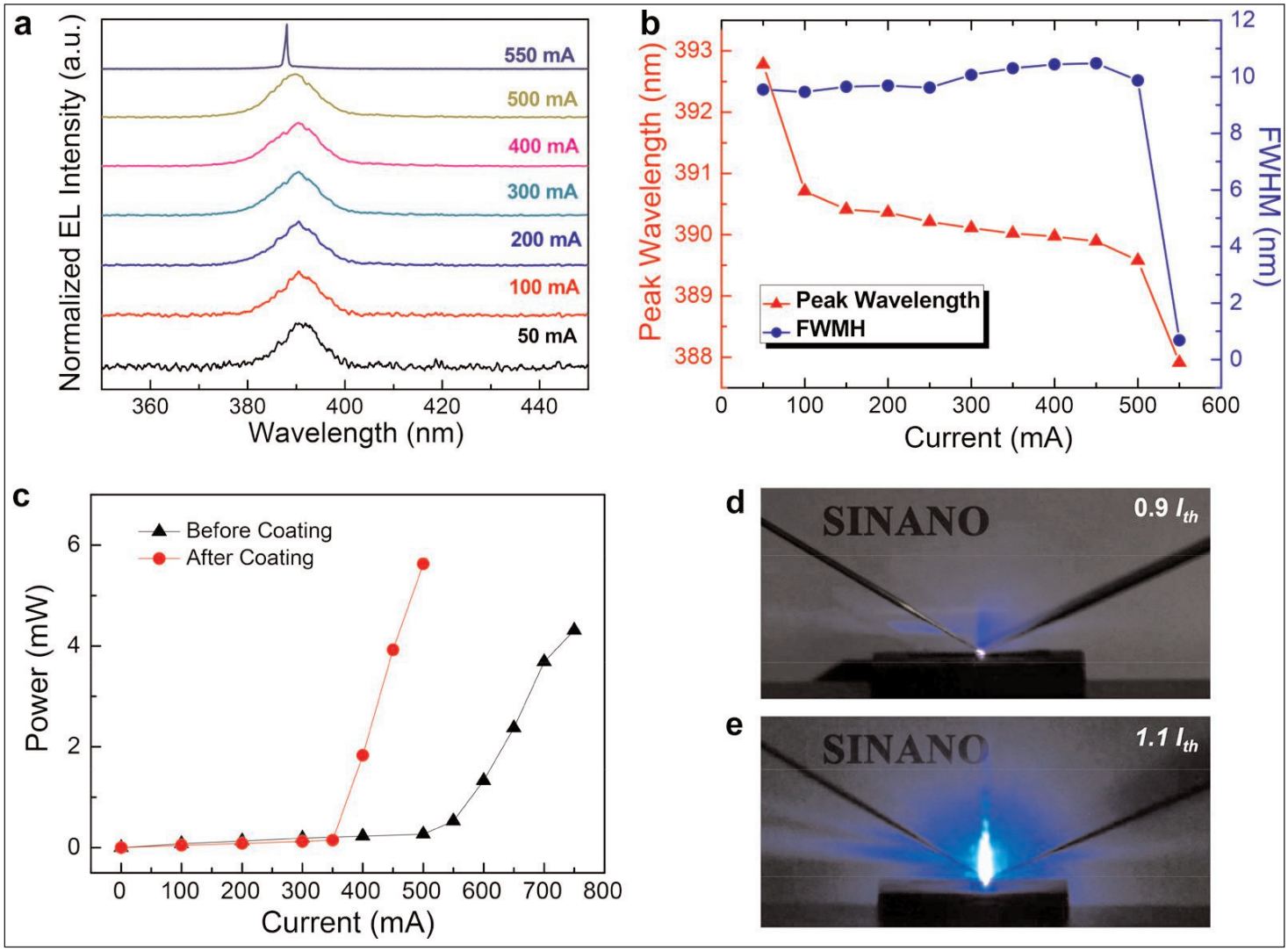


Figure 2. EL characteristics of as-fabricated AlGaN-based NUV-LD grown on silicon at room temperature. (a) EL spectra before cavity facet coating under various pulsed currents (400ns width, 10kHz repetition rate) — spectral resolution 0.1nm. (b) Peak wavelength and full-width at half maximum (FWHM) linewidth of laser diode before coating. (c) EL light output powers of laser diode before and after facet coating. Far-field patterns observed below (0.9x) (d) and above threshold current (1.1x) (e) as shown by blue fluorescence under NUV of white copying paper.

and cooling after growth, and to help prevent dislocations threading into the upper layers. The buffer structure consisted of steps from 300nm AlN nucleation, through 320nm $Al_{0.35}Ga_{0.65}N$ and 450nm $Al_{0.17}Ga_{0.83}N$. ■

https://pubs.acs.org/doi/abs/10.1021/acsphotonics.7b01215

Author:
Mike Cooke

Silicon hole injector for deep ultraviolet AlGaN diodes

Devices fabricated with 229nm emission wavelength and 160μW output power.

Researchers based in the USA have used p-type silicon (p-Si) nanomembranes as hole injector layers for deep ultraviolet (DUV) light-emitting diodes (LEDs) emitting at 229nm [Dong Liu et al, Appl. Phys. Lett., vol112, p081101, 2018].

The team from University of Wisconsin-Madison, HexaTech Inc, University of Texas at Arlington, and Michigan State University, hope to overcome the low hole injection efficiency of p-type III–nitride materials such as aluminium gallium nitride (AlGaN) alloys, particular those with high aluminium fractions. Apart from boosting the efficiency of LEDs, the researchers also believe that p-Si nanomembrane hole injection layers may lead to DUV laser diodes in the future.

DUV devices are desired for applications such as biological and chemical detection, decontamination, medical treatment, high-density optical recording, and lithography. AlGaN alloys allow access to bandgaps of 3.3eV–6.2eV (GaN–AlN), giving wavelengths from 376nm down to 200nm. However, high-Al-content AlGaN devices with emission wavelengths shorter than 300nm have sharply decreasing efficiency. Poor hole injection and high defect densities are leading causes of inefficiency.

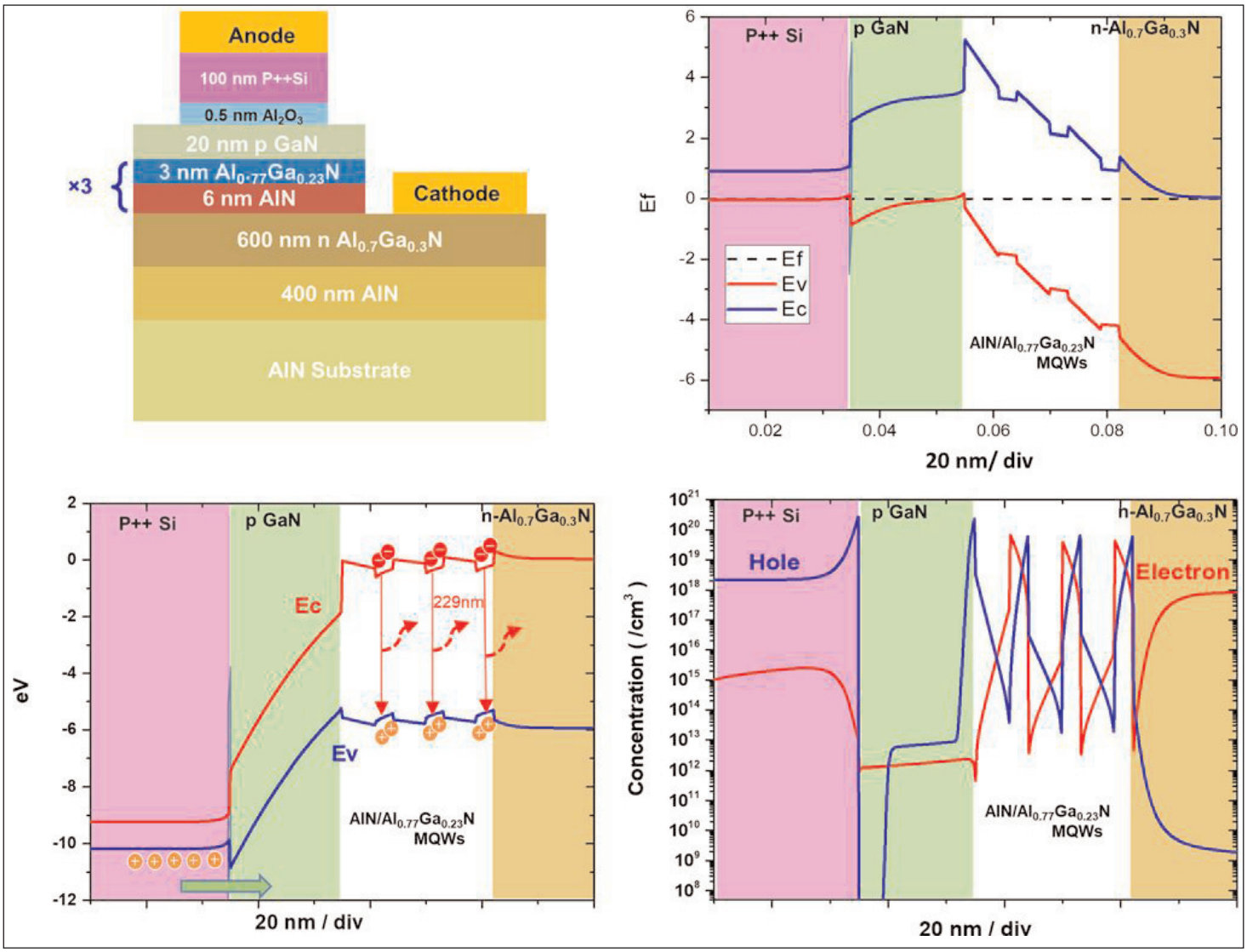


Figure 1. (a) Schematic of LED device. (b) Band diagram simulations at equilibrium and under 10V forward bias giving 300A/cm² current density (c). (d) Calculated barrier concentration distribution across structure under forward bias.

Bulk AlN with low dislocation density of 10^4/cm^3 was used as a substrate for low-pressure organometallic vapor phase epitaxy of the DUV structure (Figure 1). The 20nm p-GaN cap protects against rapid oxidation of the underlying Al-containing material.

The p-GaN was covered with 0.5nm aluminium oxide (Al_2O_3) from five cycles of atomic layer deposition (ALD). The 100nm p-Si nanomembrane hole injector had a heavy doping concentration of $5x10^{19}$/cm^2. The Al_2O_3 acted and passivation and quantum tunnel barrier for hole injection.

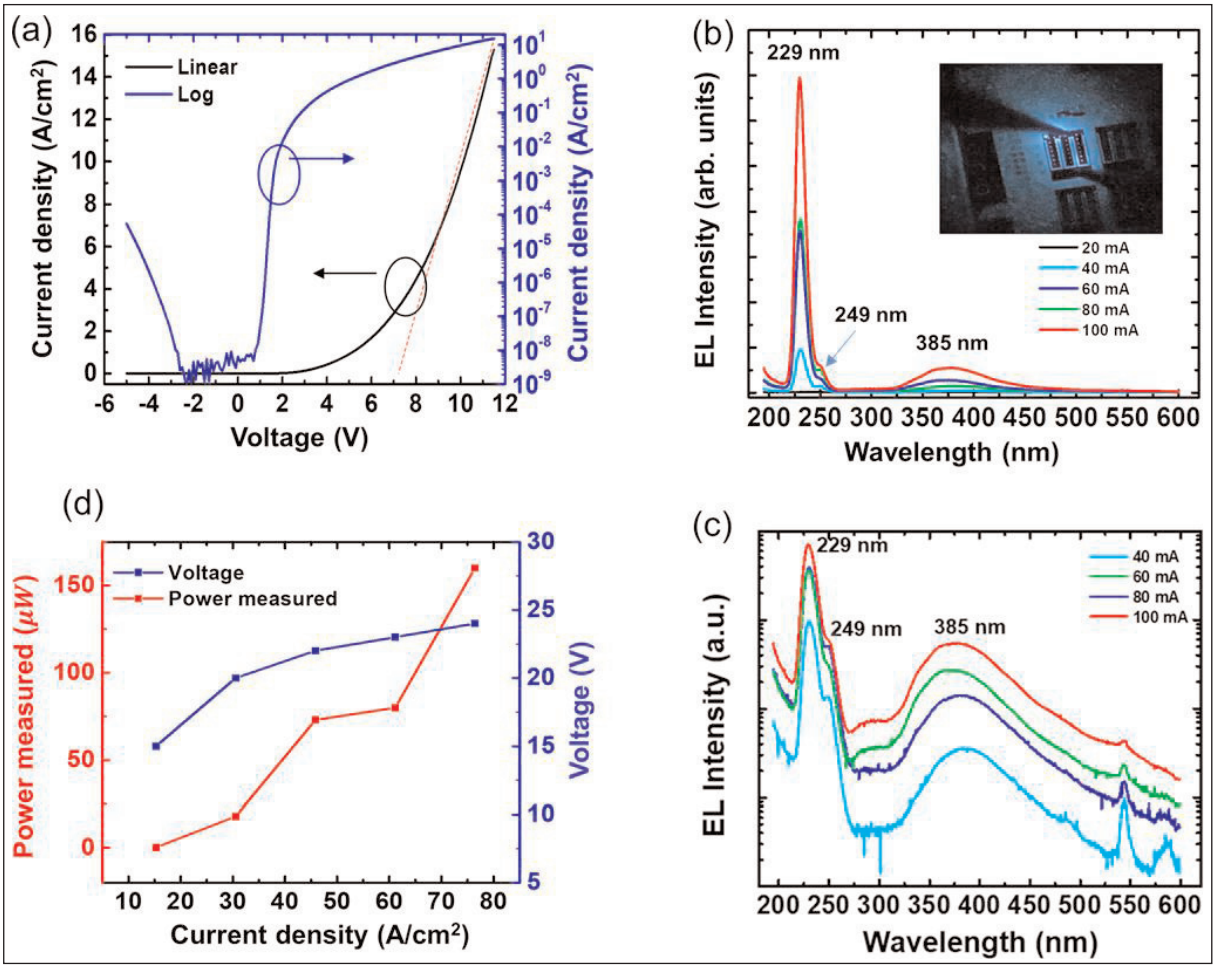


Figure 2. (a) Current density-voltage characteristics of typical LED on linear and log scales. (b) Electroluminescence (EL) spectra under different driving current densities with CW operation. Inset: optical microscopic image of forward-bias LED diode showing visible blue illumination. (c) Log-scale plot of EL spectra under currents of 40mA, 60mA, 80mA and 100mA. (d) Plot of measured light output power as a function of driving current density and associated voltages.

The nanomembrane was released from a silicon-on-insulator (SOI) substrate and transferred to the III–nitride structure. Rapid thermal annealing at 500°C for five minutes was used to increase the strength of the Al_2O_3–p-Si bonding. Also, a very smooth epitaxial surface with root-mean-square roughness of 0.547nm aided the bonding process with the transferred p-Si, which resulted in 0.677nm roughness of the total structure.

The LED fabrication consisted of mesa isolation, exposure of the n-AlGaN contact for deposition of the titanium/aluminium/nickel/gold cathode, and deposition of the titanium/gold anode. The cathode and anode geometries were interdigitated to minimize losses from lateral current spreading resistance. The effective device area was estimated at $1.31x10^{-3}$cm^2.

The LED turn-on voltage was about 7V. The reverse leakage was relatively high due to wafer growth dislocation defects, it is thought. The devices were operated in continuous wave (CW) mode without thermal management or cooling. No special light extraction enhancements were applied.

The peak wavelength was around 229nm. Parasitic peaks were also seen at 249nm DUV and ~380nm blue. These parasites were more than one order of magnitude less intense than the main peak. The 249nm peak is attributed to the 4.98eV bandgap of the n-AlGaN electron-injection layer. The researchers add: "The broad peak at 385nm in the visible range has multiple contributions, likely from the top p-GaN combined and with deep-levels in AlGaN, excited by 229nm photons."

The output power reached 160μW at 24V bias and 100mA injection (76A/cm^2). "The light emission at 229nm showed no significant efficiency droop up to 76A/cm^2 in CW operation and without thermal management," the researchers claim. The external quantum efficiency was 0.03%. The team believes this could be improved by thinning the AlN substrate to reduce point-defect absorption in the 229nm wavelength range. ■

https://doi.org/10.1063/1.5011180

Author: Mike Cooke

Tunneling to green light emission with improved efficiency performance

Researchers combine MOCVD and MBE to create LEDs with gallium nitride tunnel-junction contacts.

Researchers based in USA and Saudi Arabia have used tunnel junctions (TJs) to improve the efficiency performance of indium gallium nitride (InGaN) green light-emitting diodes [Abdullah I. Alhassan et al, Appl. Phys. Express, vol11, p042101, 2018]. The team from University of California Santa Barbara (UCSB) and King Abdulaziz City for Science and Technology (KACST) used a combination of metal-organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE) to allow high-quality n-type material to be grown on top of p-GaN and the thermally unstable InGaN quantum wells (QWs).

The TJ layers are seen as being an alternative to transparent conductive oxides (TCOs) for current spreading, allowing for more uniform current conduction and reducing peak current density. High current density reduces the efficiency of conversion of electrons and holes into photons. GaN TJs also absorb less green light compared with the most popular transparent conductor, indium tin oxide (ITO).

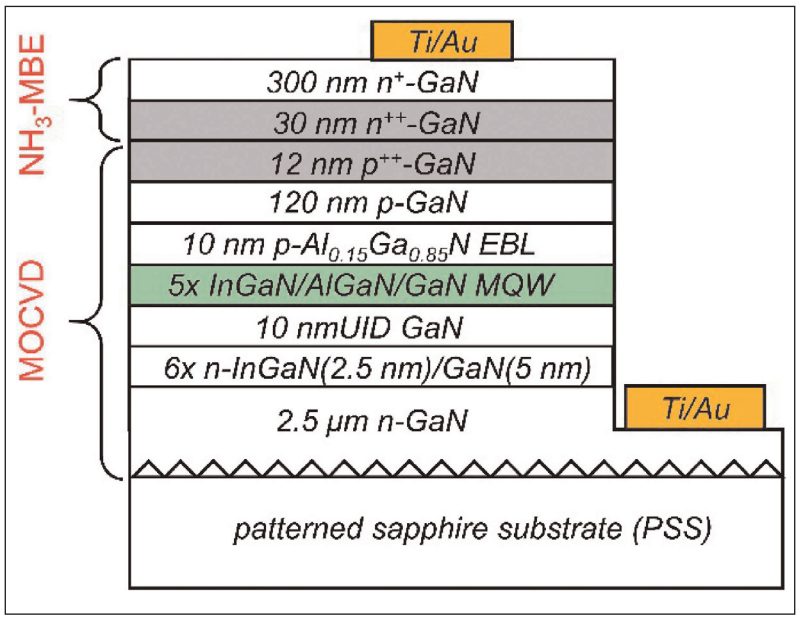


Figure 1. Cross-sectional schematic of LED structure processed with TJ contact.

The LED structure (Figure 1) was grown by atmospheric-pressure MOCVD up to the p-GaN layer. The substrate was patterned sapphire with a 1μm unintentionally doped (UID) GaN template layer.

The undoped active region consisted of five periods of 2.7nm InGaN quantum wells, a 2nm aluminium gallium nitride ($Al_{0.3}Ga_{0.7}N$) cap, and a 9nm GaN barrier. Various indium contents were used to create material for LEDs emitting in the range 490–526nm.

The structure included an electron-blocking layer (EBL). The samples were annealed to activate the magnesium doping of the p-type layers. Excess magnesium was cleaned from the surface of the materials before MBE of the TJ layers. Before the MBE process, the materials were activated again by annealing at 600°C for 10 minutes in vacuum in the reaction chamber. The growth of the n-type GaN tunnel layers was carried out at 700°C.

Mesa-type LEDs were fabricated with titanium/gold (Ti/Au) contacts. Comparison devices were produced with the TJ replaced by ITO transparent conductor from electron-beam deposition. The ITO electrode was chromium/nickel/gold (Cr/Ni/Au). The TJ simplified the fabrication by not needing the Cr/Ni/Au deposition.

The devices were packaged in a vertical stand geometry so that light could be extracted from the top and bottom surfaces of the LED.

At 20A/cm^2 current injection density, a green-emitting tunnel-junction device achieved an output power of 17mW, which compares with 15.6mW for the ITO LED. However, the TJ increased the forward voltage by 0.9V, increasing the power consumption. The researchers suggest that the penalty is due to a relatively low silicon concentration in the n^{++}-GaN part of the TJ. A high silicon doping concentration should reduce the width of the depletion layer at the interface with the p^{++}-GaN, which should increase the tunnel current.

The peak emission wavelength of the TJ-LED was 527nm at 20A/cm^2 (20mA) injection. The peak wavelength shortened by about 10nm between 5mA and 40mA injection. The blue-shift was attributed to charge

polarization-related effects in the MQW. Over the same current range, the full-width at half maximum increased from 32nm to 38nm. The ITO-LED showed similar spectral behavior. The FWHM at 20A/cm^2 was 34nm.

While the two devices had similar peak ~41% external quantum efficiency (EQE) at 3A/cm^2, at a current injection of 35A/cm^2 the EQE of the TJ-LED was 31.2%, compared with 27% for the ITO device. The researchers comment: "The lower droop of the TJ LEDs may be attributed to the improved current-spreading uniformity in n-GaN compared with that of ITO, resulting in less current crowding. This reduction in current crowding leads to a reduction in local carrier density that mitigates efficiency droop."

The researchers also studied the output powers of a series of devices emitting different wavelengths (490–526nm, Figure 2). The TJ-LEDs exhibited a higher power for a given wavelength. The power reduced as the wavelength extended further into the green region. ■

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Author: Mike Cooke

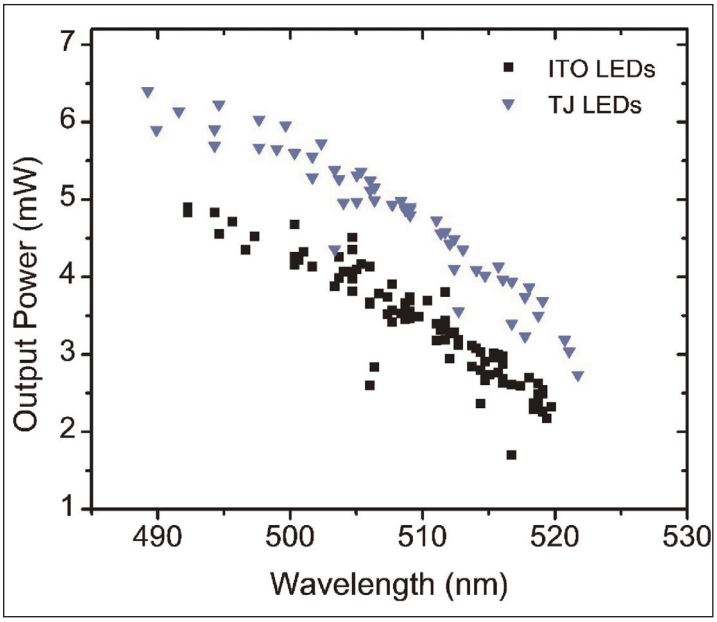

Figure 2. Dependence of electroluminescent output power on emission peak wavelength for ITO and TJ green LEDs at 35mA (35A/cm^2). Output power was measured from the back side of wafers.

InAs-channel transistors for millimeter-wave and high-speed applications

Researchers achieve record 420GHz maximum oscillation and 410GHz/357GHz maximum oscillation/cut-off frequency balance.

University of California Santa Barbara (UCSB) in the USA claims a record 420GHz maximum oscillation frequency (f_{max}) for a III–V metal-oxide-semiconductor field-effect transistor (MOSFET) based on indium gallium arsenide (InGaAs) layers on semi-insulating iron-doped (100) indium phosphide (InP:Fe) substrate [Jun Wu et al, IEEE Electron Device Letters, vol39 (2018) no4, p472]. The conduction channel was indium arsenide (InAs).

The design reduced parasitic gate–source and gate–drain capacitances through increasing the lateral modulation-doped access region, giving a wider separation of the gate and source–drain regions. The researchers see the devices as promising candidates for high-speed applications, particularly millimeter (mm)-wave.

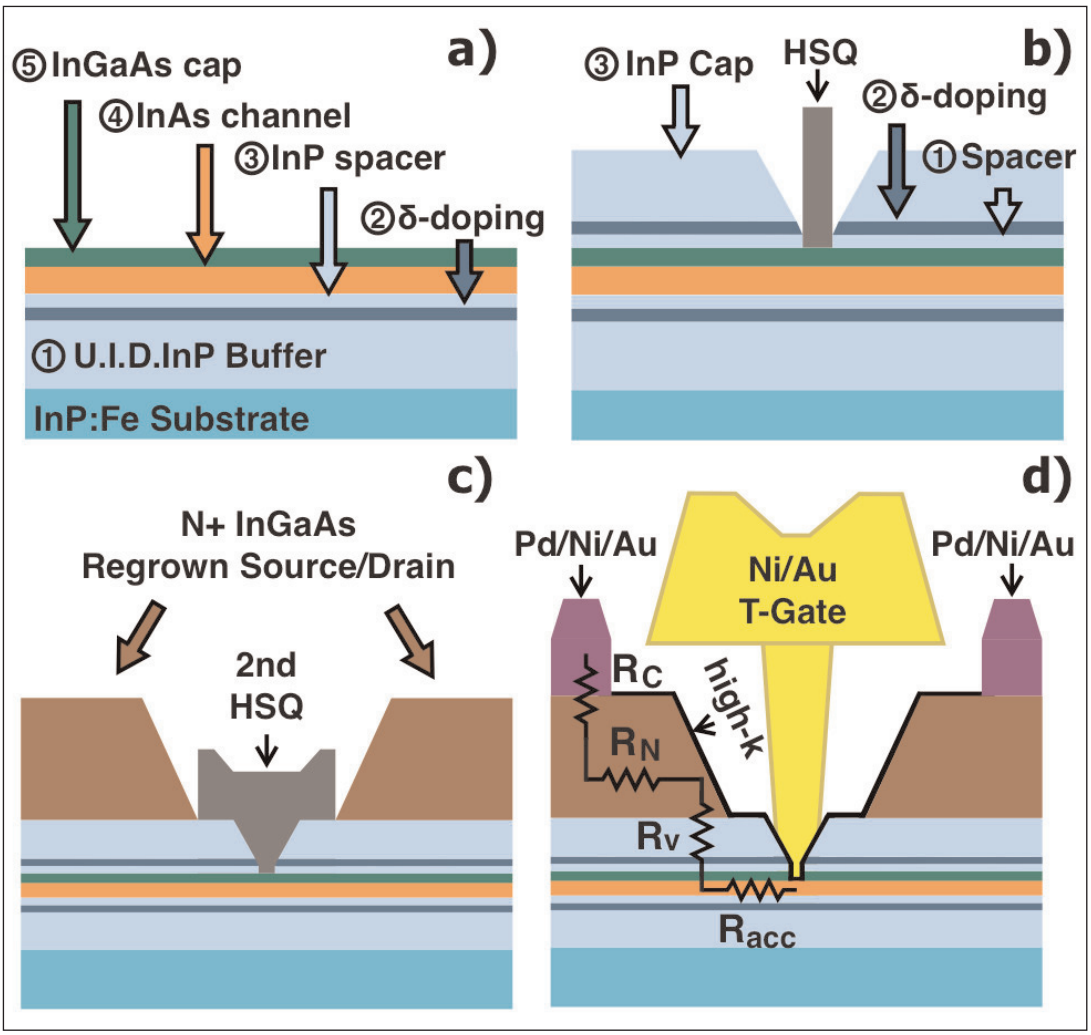

Figure 1. (a-c) Schematic of MOSFET processing. (d) Final device with definitions of contact resistance (R_C), regrown N^+ contact film resistance (R_N), vertical resistance through InP layer (R_V), and access resistance (R_{acc}).

Metal-organic vapor phase epitaxy deposited a 10nm unintentionally doped (U.I.D.) InP buffer, 2nm silicon-doped InP (δ-doping), 2nm U.I.D InP spacer, 5nm strained InAs channel, and a 3nm U.I.D. In0.53Ga0.47As cap (Figure 1). A low growth temperature of 500°C was used for the channel layer, along with a low 7.8 V/III ratio.

A dummy gate of hydrogen silsesquioxane (HSQ) was fabricated before further MOVPE growth of a 2nm U.I.D. InP spacer, 2nm silicon-doped InP, and 10nm U.I.D. InP cap. The dummy gate was removed and replaced by a wider dummy gate, creating 50nm access regions for regrown source-drain layers of 80nm-thick highly doped (N+) InGaAs.

The transistor fabrication consisted of mesa isolation, dummy gate removal, digital etch of the InGaAs cap from the channel, nitrogen-plasma and tri-methyl-aluminium passivation and atomic layer deposition of

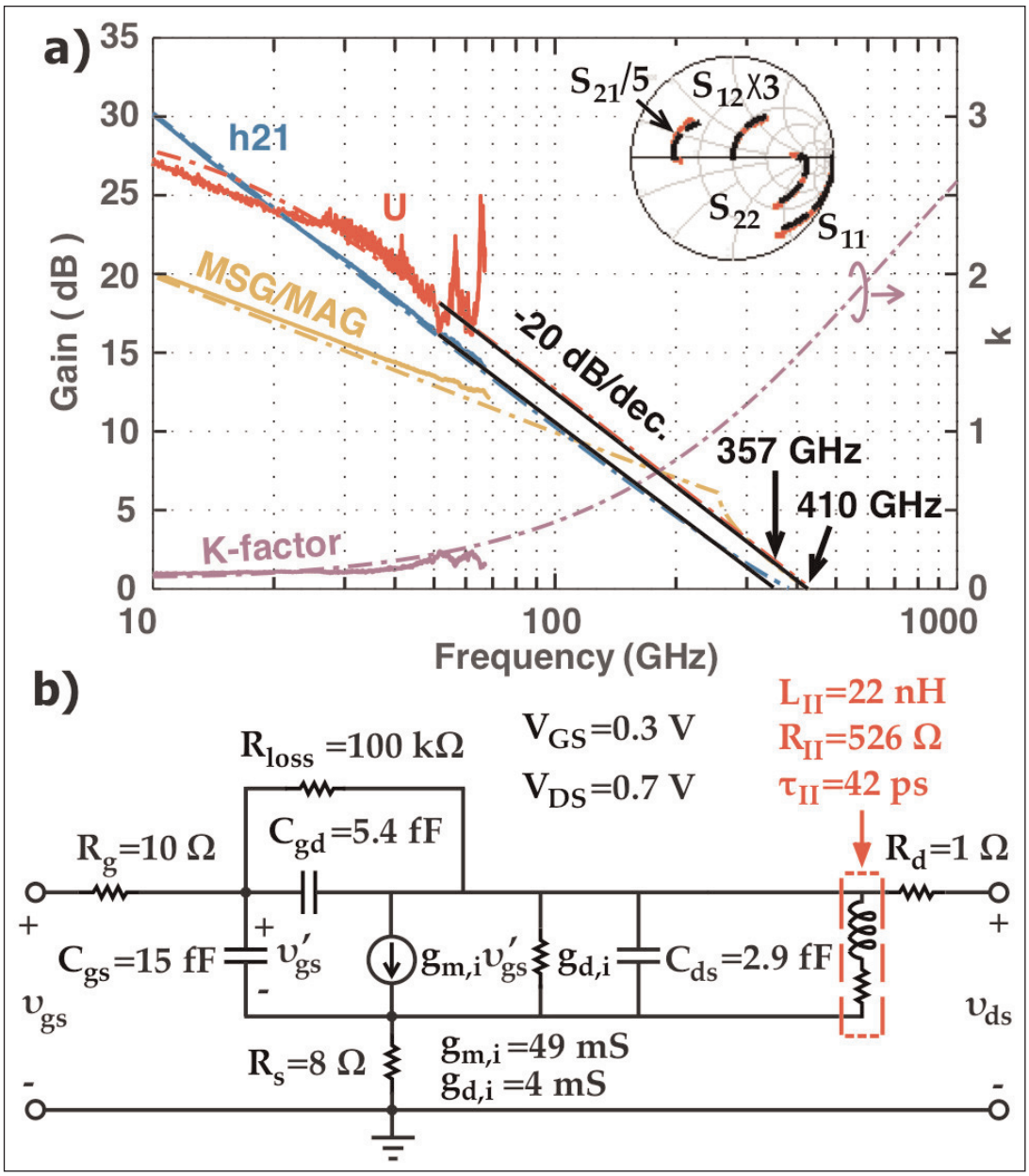

Figure 2. (a) Measured (solid curves) and modeled (dashed curves) current gain, unilateral power gain, maximum stable/available gain and stability factors at 0.3V gate and 0.7V drain. Solid black lines indicate −20dB/decade extrapolations from 30–50GHz region to determine f_T and f_{max}. Inset: measured (red) and modeled (black) S-parameters. (b) Small-signal equivalent circuit model.

3nm zirconium dioxide high-k dielectric, deposition of palladium/nickel/gold (Pd/Ni/Au) source–drain contacts, and Ni/Au T-gate formation.

A device with 30nm gate length had 1.5mS/μm peak extrinsic transconductance with 0.5V drain bias. The peak came at 0.3V gate potential. The minimum sub-threshold swing was 90mV/decade. The off-state (−0.1V gate) current was 0.9μA/μm.

Frequency performance was measured between 10MHz and 67GHz on a device with two 10μm gate fingers (Figure 2). De-embedding gave an extrapolated cut-off frequency (f_T) of 357GHz and $f_{max)}$ of 410GHz with 0.7V drain and 0.3V gate bias. Reducing the gate voltage to 0.2V increased $f_{max)}$ to 420GHz, but at the cost of reducing f_T.

A shorter 16nm gate length resulted in reduced $f_{max)}$, but similar f_T. The degraded $f_{max)}$ was blamed on short-channel effects giving an increased output conductance ($g_{d,i}$). ■

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Widening the prospects for gallium oxide power electronics

Mike Cooke reports on research on gallium oxide as a wider-bandgap semiconductor than gallium nitride and silicon carbide.

Scientists and engineers are on the constant look-out for materials that may help create effective new technologies. There is increasing demand for 'smart' compact power electronics systems, which need to be able to handle high electric fields. Materials with wider bandgaps should in principle support larger electric fields. The drawback is that wide bandgaps mean that the materials are more insulating and less semiconducting. In wide-bandgap materials that allow conduction with suitable doping there is usually a trade-off between high breakdown voltages and low on-resistance.

A recent power electronics

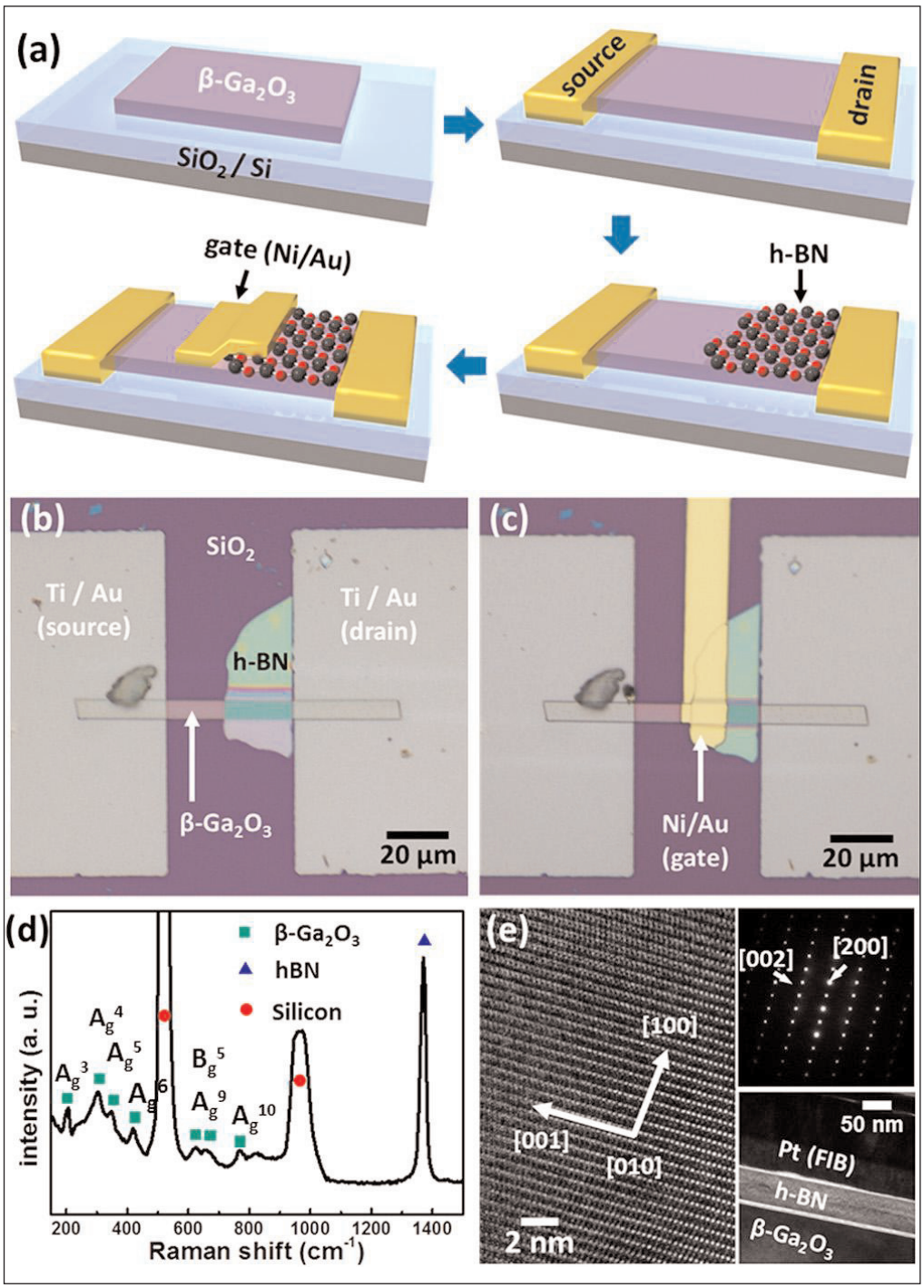

Figure 1. (a) Schematic fabrication process for nano-layer β-Ga_2O_3 MESFET with h-BN field plate. Optical microscopy images (b) before and (c) after the deposition of top-gate electrode (Ni/Au). (d) Raman spectra of fabricated h-BN/β-Ga_2O_3 structure. (e) Cross-sectional high-resolution transmission electron microscope TEM image of β-Ga_2O_3. Insets show selected-area diffraction patterns of β-Ga_2O_3 flakes (top), and a cross section of stacked layers of platinum (Pt) from focused ion beam (FIB) sample preparation and h-BN/β-Ga_2O_3 heterostructure (bottom).

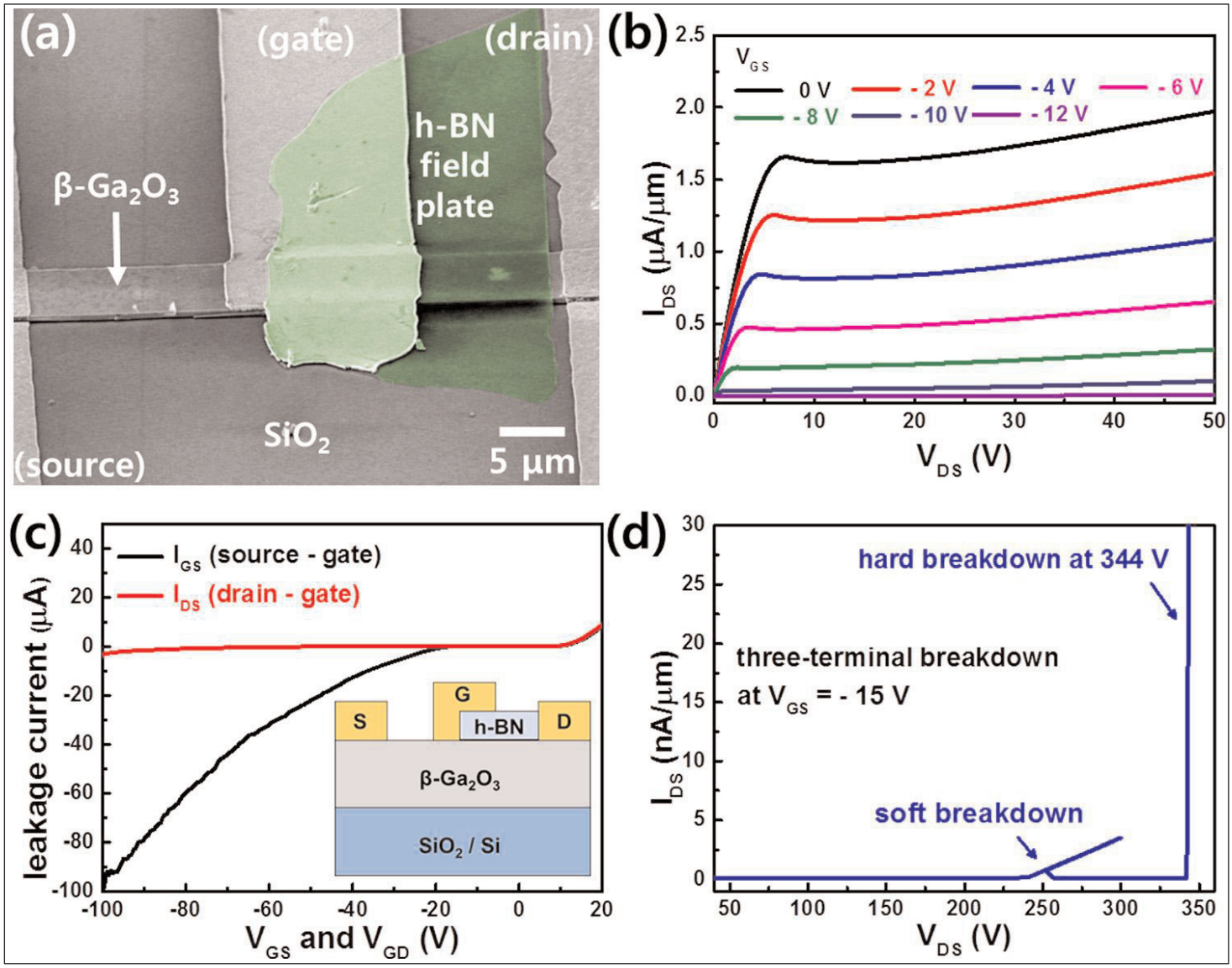

Figure 2. (a) False-color scanning electron microscope image of exfoliated quasi-two-dimensional β-Ga_2O_3 field-plate MESFET. (b) DC output characteristics of MESFET drain current (I_{DS}) versus bias (V_{DS}) for various gate potentials (V_{GS}). (c) Two-terminal gate leakage current in source–gate and drain–gate regions (inset: schematic of fabricated MESFET). (d) Off-state three-terminal breakdown curve showing soft and hard breakdown voltages.

contender is gallium oxide, generally with the more stable beta crystal structure (β-Ga_2O_3). Devices based on β-Ga_2O_3 are being developed in the hope of power electronics applications, based on an ultra-wide 4.5–4.9eV direct bandgap and good thermal stability. These bandgap energies are larger than for competitors such as gallium nitride (3.4eV), silicon carbide (~3eV) or silicon (1.12eV). Theory also suggests that β-Ga_2O_3 has potential for high saturation velocity (~2x10^7cm/s) and breakdown field (8MV/cm).

The Baliga and Johnson figures of merit for β-Ga_2O_3 are 3214.1 and 2844.4, respectively, which correspondingly compare with gallium nitride's 846.0 and 1089.0, and with silicon carbide's 317.1 and 277.8. These figures focus on the suitability of the material for high-frequency power electronics and low on-resistance.

Another development is larger-diameter commercial β-Ga_2O_3 substrates beyond the 2" of gallium nitride.

These features could be brought to bear on power amplifier applications in the RF and millimeter-wave regimes, especially at high frequencies and high power densities that are enabled by high thermal conductivity.

Devices based on β-Ga_2O_3 are n-type 'unipolar', depending on negative charge carriers, due to the lack of a suitable p-type dopant. The donor dopants for n-type conductivity include group IV elements such as silicon, germanium and tin. Also, background unintentional n-type 'doping' can occur according to different growth conditions, which can lead to oxygen vacancies or hydrogen inclusion. The restriction to unipolar conductivity limits device architectures.

Developments are at an early stage, and generally devices don't reach the performance of more established technologies. Here, we report on recent research.

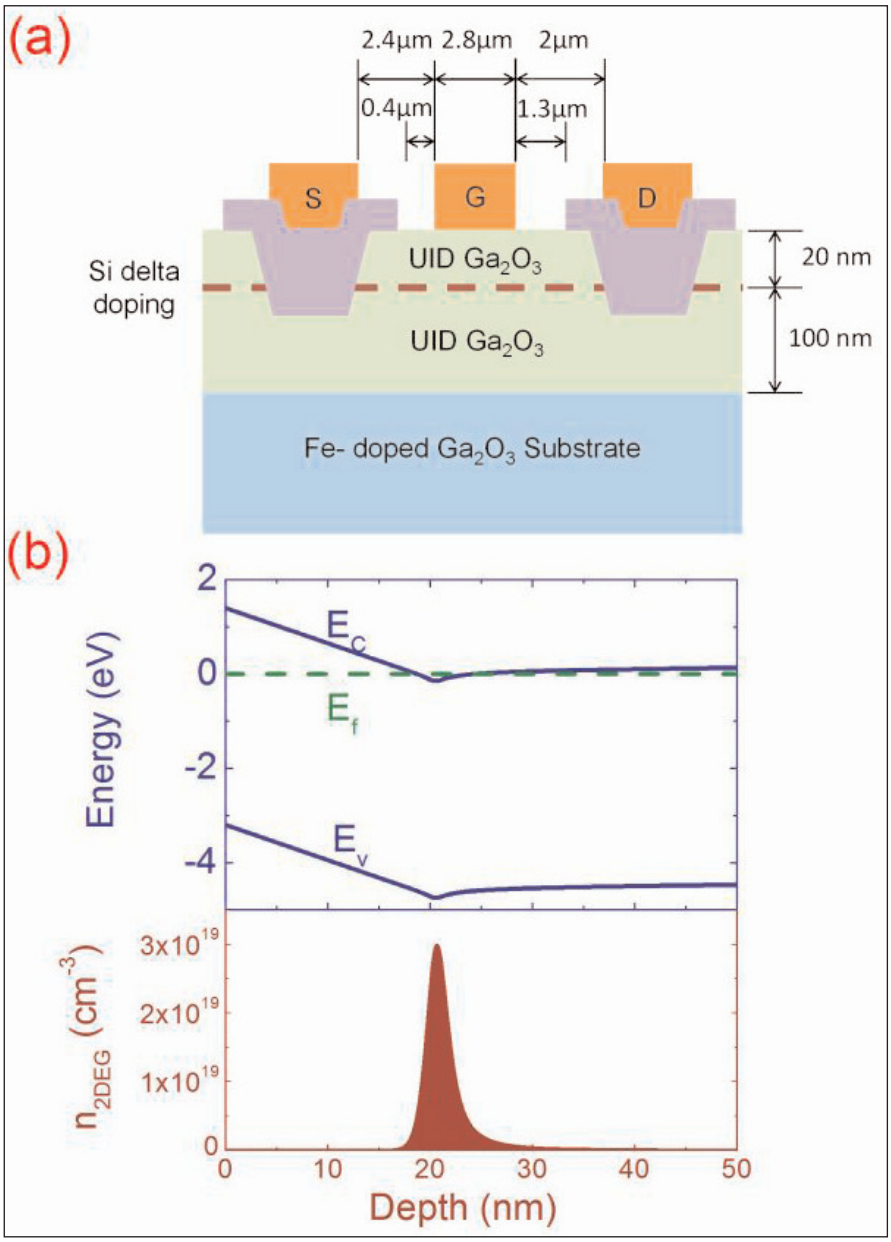

Figure 3. (a) Device schematic and (b) equilibrium energy-band diagram and 2DEG charge profile of delta doped MESFET.

Field-effect transistors

Korea University and Korea Electrotechnology Research Institute (KERI) have used hexagonal boron nitride (h-BN) as part of a field-plate structure for β-Ga_2O_3 metal-semiconductor field-effect transistors (MESFETs) [Jinho Bae et al, Appl. Phys. Lett., vol112, p122102, 2018]. The off-state breakdown reached 344V.

The researchers used single-crystal β-Ga_2O_3 substrate from Tamura Corp for the transistor (Figure 1). The material was mechanically exfoliated into quasi-two-dimensional flakes 200–400nm thick using adhesive tape. The flakes were transferred onto a 300nm silicon dioxide layer on a 500μm-thick silicon substrate.

Ohmic source–drain electrodes consisted of annealed titanium/gold. The ~70nm-thick h-BN field-plate insulation material was mechanically exfoliated from bulk powder supplied by Momentive Corp. The transfer to the transistor was assisted using transparent gel-film from Gel-pak to allow for precise positioning. The top gate electrode was nickel/gold.

In addition to having a high dielectric breakdown field of 8–12MV/cm, the h-BN has a high thermal conductivity of 1700–2000W/m-K. The h-BN crystal structure has van der Waals forces linking 'two-dimensional' hexagonal layers, allowing thin flakes to be produced by mechanical exfoliation. While β-Ga_2O_3 is not structured in this way, it does have bond anisotropy that favors cleavage along the (100) face of the crystal lattice. The researchers suggest that thinner β-Ga_2O_3 could be obtained with reactive-ion and/or inductively coupled plasma etch.

A gate potential of –12V gave complete pinch-off of the n-channel device (Figure 2). The threshold voltage was at –7.3V. Unlike many common 2D materials such as graphene and transition-metal dichalcogenides, these devices had a knee in the current performance with respect to drain voltage, giving a saturation region. The sub-threshold swing was relatively low, at 84.6mV/decade, indicating sharp switching behavior. Previously reported β-Ga_2O_3 transistors have had swings of more than 100mV/decade.

The soft breakdown in pinch-off (gate at –15V) occurred at 250V drain. Complete failure came at 344V. Devices without the field-plate structure broke down at 113V. The researchers suggest that more complex field-plate arrangements could improve the breakdown performance.

Without field plates, the researchers simulated a peak electric field for 200V drain bias of 7.3MV/cm, close to the ~8MV/cm critical field for β-Ga_2O_3. The simulations used to give the estimate suggest the breakdown occurs near the gate edge. With a field plate, the peak field at 200V was reduced to 4.5MV/cm.

The long-term chemical stability of the device was also investigated, since 2D structures are often vulnerable to degradation from the atmosphere. The researchers stored the device in ambient air for a month. "Device properties including on/off current ratio, saturation current, transconductance, subthreshold swing, and threshold voltage were maintained," they report.

Meanwhile, the USA's Ohio State University, University of Utah and the Indian Institute of Technology in Bombay have used oxygen-plasma-assisted

molecular beam epitaxy (MBE) at 700ºC on a semi-insulating iron-doped (010) β-Ga_2O_3 substrate to produce MESFETs [Zhanbo Xia et al, IEEE Electron Device Letters, vol39, p568, 2018] (Figure 3). The substrates were mounted on silicon with indium bonding during the MBE.

A 0.2nm silicon delta-doped region was used to create a two-dimensional electron gas (2DEG) for the transistor channel. The source and drain regions were re-grown heavily n-type doped β-Ga_2O_3 in 40nm-deep trenches. The ohmic contacts for the source and drain were annealed titanium/gold/nickel. After mesa isolation, the nickel/gold/nickel Schottky gate metal was applied.

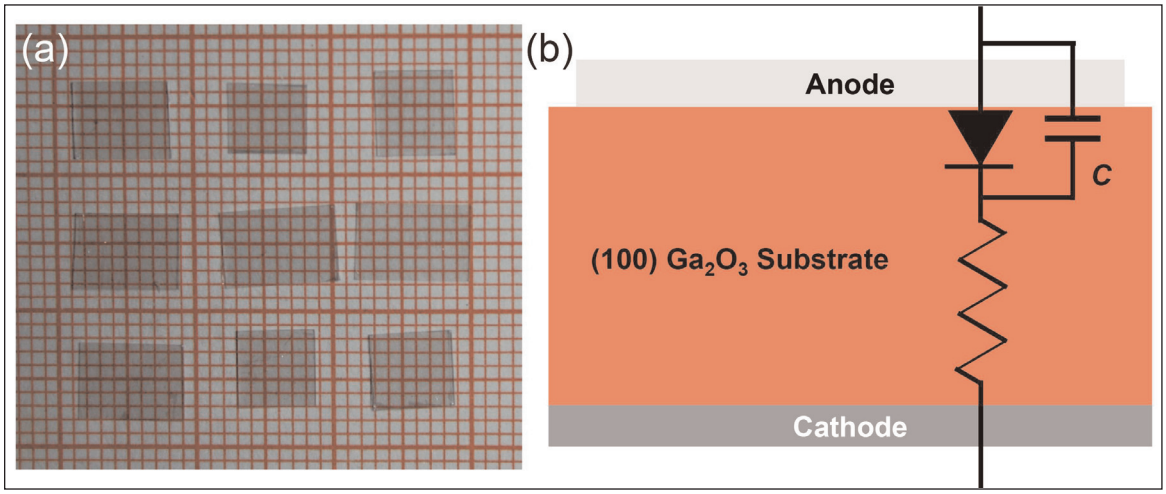

Figure 4. (a) (100) β-Ga_2O_3 substrates used for Schottky barrier diode fabrication. (b) Schematic structure and equivalent circuit of Pt/(100)β-Ga_2O_3 Schottky barrier diode.

Devices based on β-Ga_2O_3 are n-type 'unipolar', depending on negative charge carriers, due to the lack of a suitable p-type dopant. The donor dopants for n-type conductivity include group IV elements such as silicon, germanium and tin. The restriction to unipolar conductivity limits device architectures

A device with 2.8μm gate length achieved a normalized maximum drain current of 140mA/mm at +2V gate potential and 10V drain bias, across a 100μm width. The gate–source and gate–drain separations were 0.4μm and 1.3μm, respectively. A peak transconductance of 34mS/mm was found with +0.5V on the gate. The threshold voltage was estimated at −3.4V — i.e. the device is normally-on.

The on/off current ratio was of the order 10^5. With the gate at −5V, the three-terminal breakdown occurred at 170V drain bias for a 0.1mA/mm leakage current. The peak electron mobility was estimated to be 95cm^2/V-s. The researchers comment: "Further theoretical analysis is required to understand the detailed scattering mechanisms that limit 2DEG mobility."

Schottky barrier diodes

Researchers based in China have reported on β-Ga_2O_3 Schottky barrier diodes with AC rectification assessed up to 1MHz [Qiming He et al, IEEE Electron Device Letters, vol39, p556, 2018]. The team from Xiangtan University, Jiangsu National Synergetic Innovation Center for Advanced Materials (SICAM), Shandong University and Sun Yat-sen University found that the devices demonstrated a short reverse recovery time of 20ns.

Edge-defined film-fed growth (EFG) gave blocks of (100)-oriented β-Ga_2O_3 smaller than 10mm x 10mm and 480nm thick. EFG creates ribbons of crystalline material pulled from a melt through a 'die'. Optimization of the growth process in terms of temperature control and seeding improved the crystal structure. Tin dioxide (SnO_2) powder was used for n-type doping, giving a carrier density of 2x10^{17}/cm^3 determined from Hall-effect and capacitance–voltage measurements. Mechanical exfoliation reduced surface roughness to 0.1nm root-mean-square.

The Schottky barrier diodes used platinum for the 150μm-diameter Schottky circular anode contact (Figure 4). The ohmic cathode metal was titanium, which was optimized with a 400ºC oxygen plasma pre-treatment. The contact stacks (Pt/Ti/Au and Ti/Au) were deposited by magnetron sputtering.

The forward current density was 421A/cm^2 at 2V bias, a seven-fold improvement on the group's previous work. The on-resistance was reduced from the previous 12.5mΩ-cm^2 to 2.9mΩ-cm^2. Under reverse bias of −200V, the current was 2.3x10^{-4}A/cm^2. The leakage was somewhat higher than the previous work. The team suggests that this can be reduced with epitaxial device layers, field plates and rings, and/or trench structures. The test equipment was unable to take the device to breakdown.

Frequency-dependent capacitance-voltage studies gave a built-in potential of 0.63V. This was lower than the 1.07V normally given — the team suggests that this is due to a higher-than-usual carrier density in the β-Ga_2O_3. The recovery time from 4V forward to −10V reverse bias was 20ns. With a 20V peak-to-peak AC signal, the device rectified the sine input into half-sine output at frequencies up to 1MHz. At 1MHz, there was a slight negative current attributed to junction capaci-

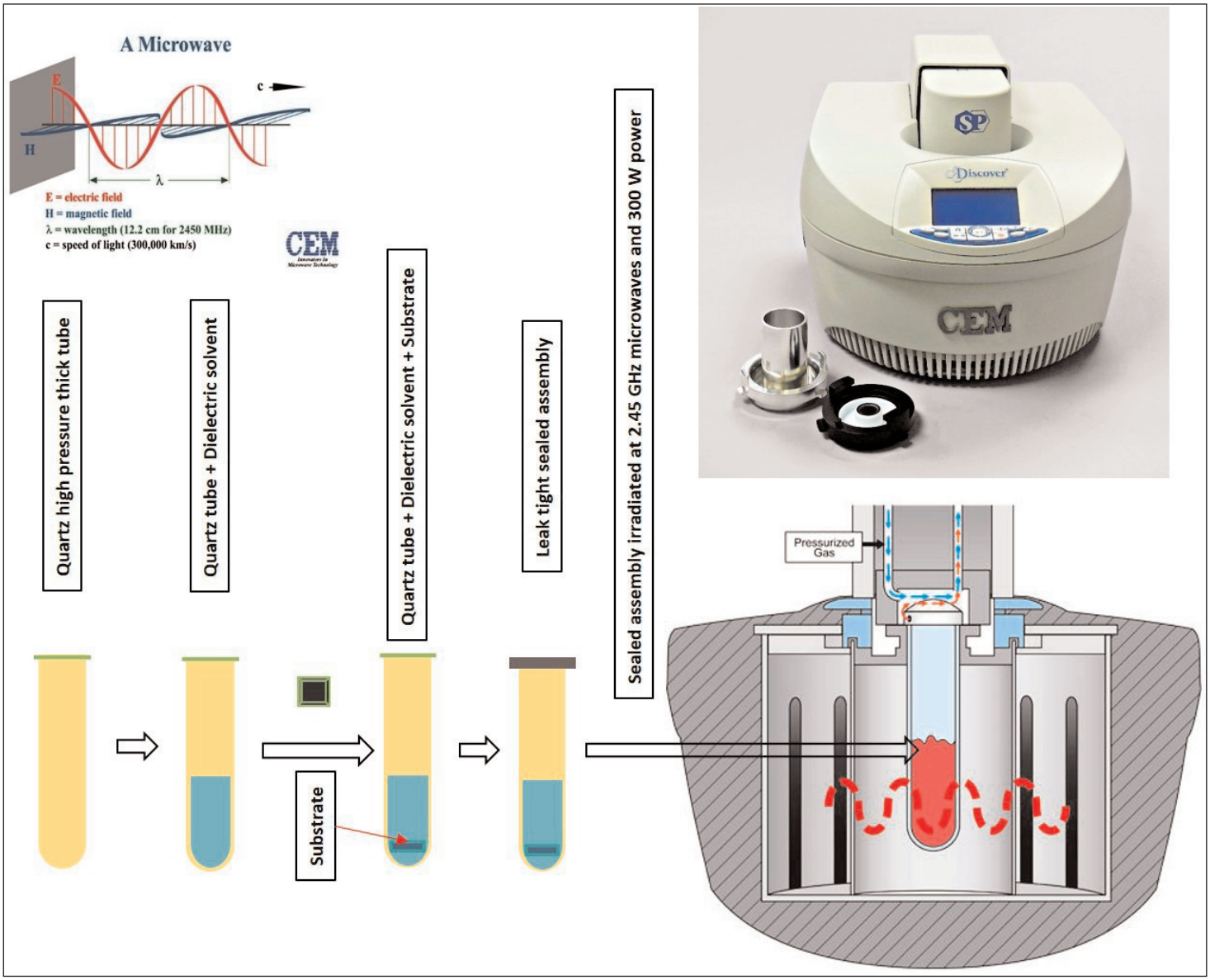

Figure 5. Schematic representation of microwave-irradiation-assisted film deposition process.

tance. The researchers say this capacitance could be reduced by reducing the doping in an epitaxial layer or by using ultra-thin wafers.

Researchers based in USA and India have produced bevel-field-plated Schottky barrier diodes [Chandan Joishi et al, Appl. Phys. Express, vol11, p031101, p2018]. Breakdown occurred at −190V and the device was able to withstand 1A/cm^2 before catastrophic damage. Repeatable breakdown for 0.2A/cm^2 compliance was −129V. The estimated peak breakdown field (F_{BR}) was 4.2MV/cm, which compares with the 8MV/cm theoretical critical field for β-Ga_2O_3.

The team from Ohio State University, the Indian Institute of Technology Bombay, and the USA's Case Western Reserve University and University of Utah adds: "The extracted F_{BR} is higher than the theoretical F_{BR} values for 4H-SiC (2.2MV/cm) and GaN (3.3MV/cm)." This research grouping partly overlaps that for the MESFET of Zhanbo Xia et al above.

The edge field was estimated at 5.9MV/cm. The extrinsic on-resistance was 3.9mΩ-cm^2 — the intrinsic value was 0.023mΩ-cm^2. The difference between the two values is attributed to the resistance of the substrate.

The researchers grew 2mm of β-Ga_2O_3 on a commercial tin-doped (Sn) (010) β-Ga_2O_3 substrate by low-pressure chemical vapor deposition (LPCVD) using gallium from high-purity pellets and oxygen in argon carrier gas. Silicon n-type doping was achieved with silicon tetrachloride. Atomic force microscopy on the epitaxial surface gave a roughness value of 4.86nm root-mean-square.

Platinum/nickel/gold (Pt/Ni/Au) was used as a 50mm x 1mm beveled stripe anode. The electrode had rounded corners to avoid the formation of spherical junctions under high bias. The titanium/gold/nickel (Ti/Au/Ni) cathode was deposited on the substrate side of the device. The bevel anode was covered with plasma-enhanced CVD silicon dioxide surface passivation and a field plate formed from titanium that extended out 4μm (L_{FP}). The distance from the start of the bevel and the anode electrode (L_{AB}) was 0.25μm.

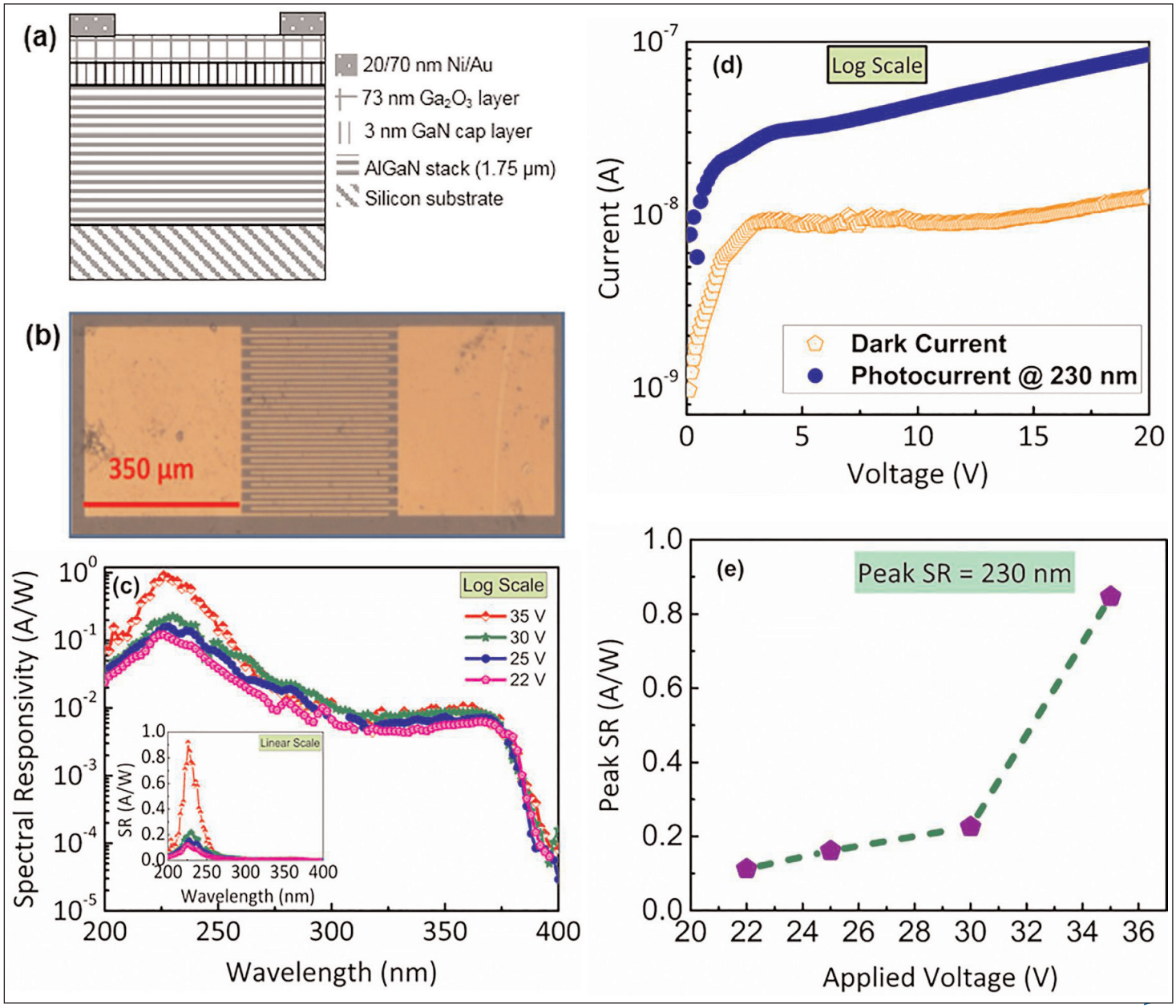

Figure 6. (a) Schematic of AlGaN/GaN HEMT stack (side-view). (b) Optical micrograph of fabricated MSM device (top-view). (c) Variation of spectral response (SR) with wavelength on log scale as function of bias. Inset: variation of SR with wavelength as function of bias on linear scale. (d) Variation of dark and photocurrent with applied bias. Photocurrent measured under 230nm illumination. (e) Variation of peak responsivity (SR at 230nm) with applied bias (measured at optical chopping frequency of 30Hz).

III–nitride on silicon substrate

The Indian Institute of Science has also been developing microwave polycrystal deposition of β-Ga_2O_3 on gallium nitride (GaN) on silicon with a view to deep ultraviolet (UV) optoelectronics [Piyush Jaiswal et al, Appl. Phys. Lett., vol112, p021105, 2018]. The team also demonstrated a visible-blind 230nm-wavelength deep UV photodetector based on the wide bandgap of β-Ga_2O_3 material.

The absorption edge for β-Ga_2O_3 is in the wavelength range 240–250nm. Meanwhile, GaN has been developed for visible and near-UV light emission, along with, more recently, high-voltage and high-current-density electronics and for operation at high switching speeds. Bringing these technologies together, the researchers target heterostructures and devices that would exploit bandgap engineering opportunities.

The Ga_2O_3 was deposited on III–nitrides by microwave irradiation of a reactant solution containing Ga(III)acetyl-acetonate, a β-ketonate complex (see Figure 5). The solvent was a mix of ethanol and 1-decanol. The substrate was a GaN stack with aluminium gallium nitride (AlGaN) layers typically designed for high-electron-mobility transistors (HEMTs).

"Epitaxially grown GaN layers were used as substrates, because of the close lattice match between h-GaN and β-Ga_2O_3 along the (100) direction," the team comments. Temperatures during the deposition did not exceed

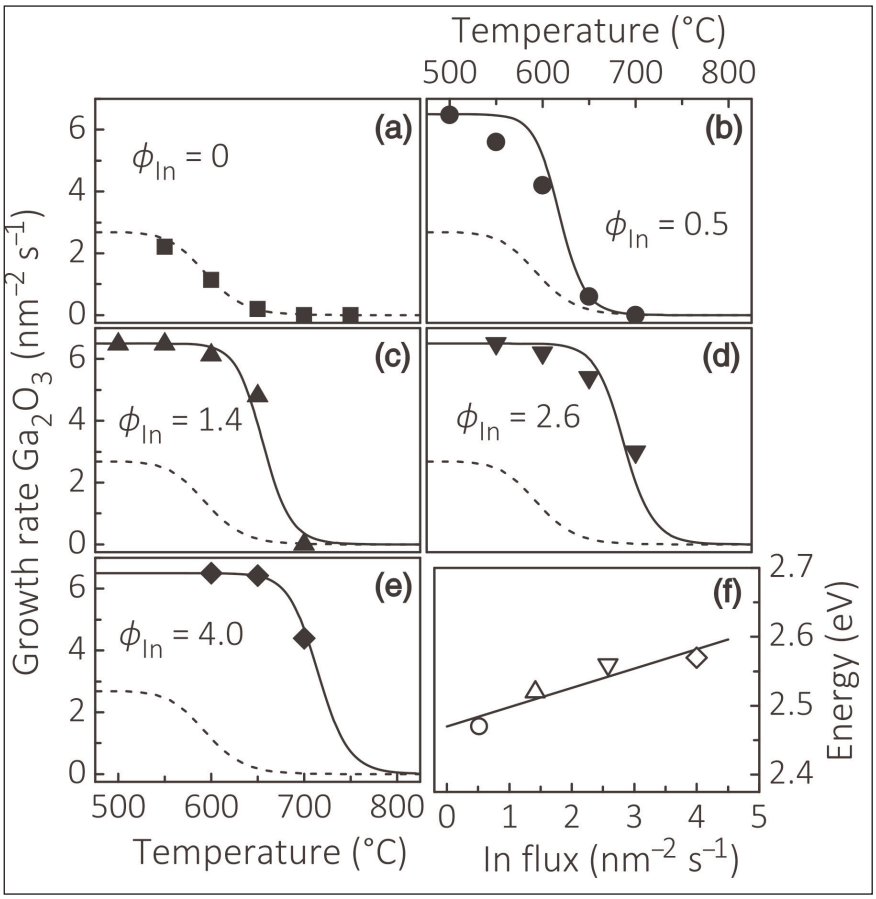

Figure 7. (a)–(e) Temperature dependence of Ga_2O_3 growth rate with varying indium flux (ϕ_{In} in units of $nm^{-2}s^{-1}$). The gallium flux was 6.5/nm^2-s. (f) Activation energy of In desorption as function of ϕ_{In}.

200ºC. The duration was less than an hour, including thermal ramp up and down.

X-ray photoelectron spectroscopy (XPS) of the β-Ga_2O_3 did not find any nitrogen, suggesting uniform coverage of the III–nitride layers. Further findings were some carbon from the organic solvents and an oxygen deficiency leading to vacancies and an expectation of n-type conductivity.

X-ray diffraction studies suggested a nano-crystalline Ga_2O_3 structure with an estimated thickness of 70–80nm. The average crystallite size was 3.3nm and the material was in the gamma(γ)-phase. Rapid thermal annealing at 950ºC for 10 minutes converted the phase to β with 22.4nm crystallites.

The researchers comment: "The counter-intuitive formation of γ-Ga_2O_3 at sub-200ºC is attributable to locally elevated temperatures in the irradiated solution and to the nucleation kinetics of γ-Ga_2O_3 formation because γ-Ga_2O_3 has a spinel structure associated with many vacancies, and crystals containing vacant sites are stabilized at low crystallization temperatures."

The x-ray results were backed up with scanning electron microscopy and atomic force microscopy.

Nickel/gold Schottky contacts were deposited on the β-Ga_2O_3 layer to create a metal-semiconductor–metal photodetector (PD — see Figure 6). The electrodes consisted of 16 interdigitated fingers. The width of the fingers was 5μm and the spacing 6μm. The active area is given as 250μm x 300μm.

Peak spectral responsivity occurred at 236nm deep UV — 0.1A/W at 22V bias and 0.8A/W at 35V. Compared with the response at 400nm visible wavelengths, the rejection ratio was more than 10^3 at 22V bias. The kink downward in the response at 365nm near-UV is attributed to absorption and conduction in the narrower ~3.4eV-bandgap GaN layer beneath the β-Ga_2O_3. The dark current at 20V was ~12nA, compared with ~82nA under 230nm illumination.

The researchers suggest that the increase in peak response at 35V was due to internal gain. The team explains: "This gain comes from either an oxygen-deficient film, leading to trapping of holes in bulk, or interface states at the metal-semiconductor (M–S) Schottky junction enabling hole trapping at the M–S junction itself. As the M–S junction has to maintain charge neutrality, more electrons have to flow from the metal side, subsequently lowering the Schottky barrier, thereby leading to gain in the photodetector."

Plasma molecular beam epitaxy

Germany's Paul-Drude-Institut für Festkörperelektronik has developed epitaxy techniques for gallium oxide growth that could lead to sesquioxide heterostructures where the metal involved is aluminium (Al_2O_3), gallium (Ga_2O_3) or indium (In_2O_3) [Patrick Vogt et al, Phys. Rev. Lett., vol119, p196001, 2017]. In particular, the team found that the presence of indium during plasma-assisted molecular beam epitaxy (PAMBE) increased the growth rate of Ga_2O_3, even when there is no growth without indium.

The researchers hope that their work will be a path for bandgap engineering and heterostructural growth of transparent semiconducting oxides. They see analogies with the III–V world, where heterostructures of semiconductor alloys have created a vast range of optoelectronic and telecom devices. For the sesquioxides, the team suggests applications in deep-ultraviolet detection, transparent transistors, and high-power electronics.

One problem is that the sesquioxides tend to crystallize in incompatible structures: corundum (rhombohedral, $R\bar{3}c$) for α-Al_2O_3, gallia (monoclinic, C2/m) for β-Ga_2O_3, and bixbyite (body centered cubic, $Ia\bar{3}$) for In_2O_3. Also, the complexity of the oxide reactions leading to sesquioxides restricts growth to lower temperatures, reducing crystal quality.

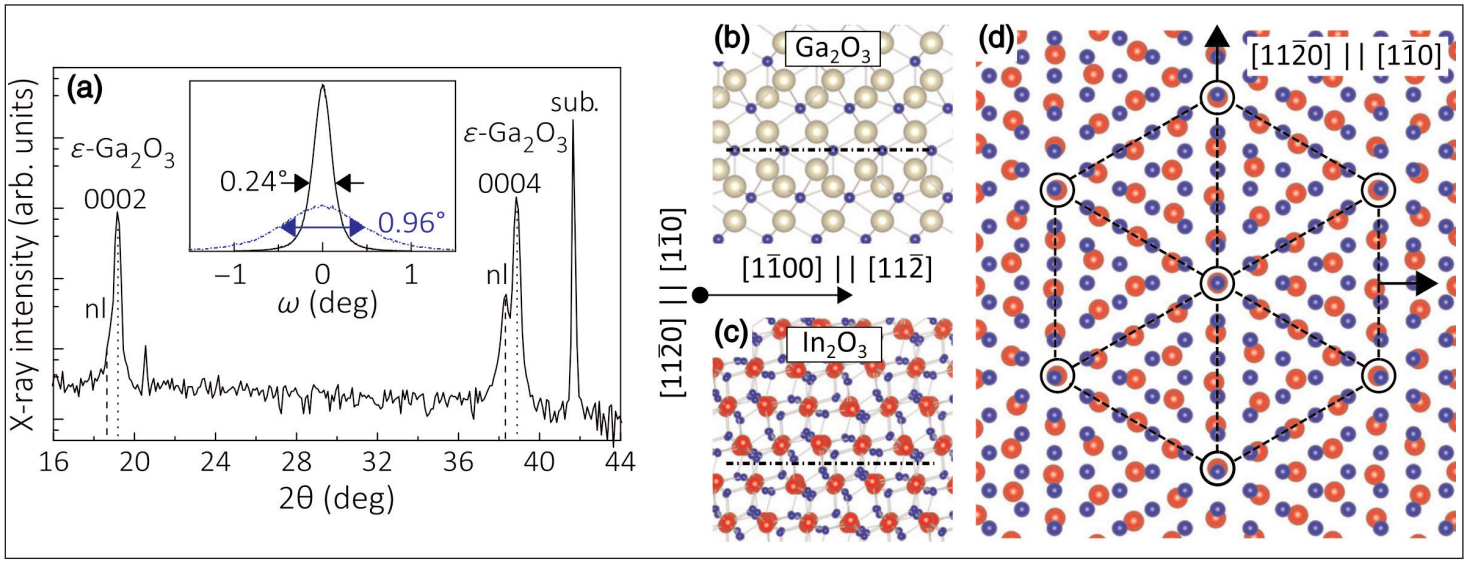

Figure 8. (a) Longitudinal x-ray diffraction scan of In_2O_3-catalyzed Ga_2O_3 700ºC film with 5.4/nm²-s indium flux. Reflections labeled 'sub.' and 'nl' stem from substrate and nucleation layer, respectively. Inset: transverse scans across ε-Ga_2O_3 (0004) (solid black line) and (10$\bar{1}$4) (dashed-dotted blue line) reflections with full-width at half maxima (FWHM). (b) (c) Side-view schematics of ε-Ga_2O_3 (0001) and In_2O_3 (111) planes, respectively. Dashed-dotted lines indicate bulk-terminated surfaces. Ga, In and O atoms are depicted in gold, red and blue, respectively. (d) Top view of ε-Ga_2O_3 (0001) and In_2O_3 (111). Dashed lines illustrate 5:4 coincidence lattice of O-terminated ε-Ga_2O_3 (0001) relative to indium-terminated In_2O_3 (111).

The researchers used PAMBE on the (0001) surface of α-aluminium oxide (sapphire) substrates. The growth started with 20nm β-Ga_2O_3 nucleation. In further growth, the team found that the presence of indium catalyzes the growth of Ga_2O_3 in 700ºC conditions where no growth occurs in the absence of indium (Figure 7). At the same time, the indium is not incorporated into the growing Ga_2O_3 crystal structure. "This effect should not be confused with that of a surfactant, which either inhibits or induces a morphological phase transition but does not affect the growth rate of the material," the researchers warn.

The team explains the effect in terms of two steps: first, the formation of In_2O_3 is kinetically favored over Ga_2O_3 by a factor of 2.8; second, however, In_2O_3 is unstable in the presence of Ga, and energy factors favor indium replacement by gallium.

X-ray analysis suggested that the Ga_2O_3 grown with indium catalysis does not correspond to the underlying nucleation layer with the reflections shifted to larger angles. The team reports; "The angular position of these reflections perfectly agrees with those of the 0002 and 0004 reflections of the metastable ε-Ga_2O_3 phase, which crystallizes in a hexagonal structure ($P6_3mc$)."

Further x-ray and electron diffraction analysis confirmed the ε-Ga_2O_3 attribution, according to the researchers. "Clearly, the profiles reveal a well-oriented epitaxial film, which is particularly remarkable since films in the ε phase could not yet be obtained by PAMBE," they add.

The researchers see the ε-Ga_2O_3 (0001) structure as being better suited to heterostructures involving In_2O_3 (111) since the planes match in terms of symmetry, atomic spacing and surface chemistry (Figure 8). The researchers comment: "the two lattices are in almost perfect registry when forming a 5:4 coincidence lattice with a residual mismatch of 1.3%."

The researchers suggest that the metal-catalysis could apply to systems with similar kinetic and thermodynamic properties: "For example, we recently showed that the oxidation efficiency of Sn (η_{Sn}) is even larger than that of indium, which, in turn, is larger than that of gallium, i.e. $\eta_{Sn} > \eta_{In} > \eta_{Ga}$. Thus, we expect catalytic effects for a wide range of ternary oxide alloys, but also for various other multi-component oxides fabricated by MBE." ■

The researchers hope that their work will be a path for bandgap engineering and heterostructural growth of transparent semiconducting oxides. They see analogies with the III–V world, where heterostructures of semiconductor alloys have created a vast range of optoelectronic and telecom devices. For the sesquioxides, the team suggests applications in deep-ultraviolet detection, transparent transistors, and high-power electronics

Author: Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.

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13–17 May 2018
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Chicago, IL USA
E-mail: info@ispsd.org
www.ispsd2018.org

16–18 May 2018
IEEE Workshop on Wide Bandgap Power Devices and Applications in Asia (WiPDA Asia 2018)
Xi'an, Shaanxi, China
E-mail: xiaotian@xjtu.edu.cn
www.wipda-asia.org

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http://spie.org/Optics_Photonics

17–21 September 2018
EPE'18 ECCE Europe (20th European Conference on Power Electronics and Applications)
Riga, Latvia
E-mail: info@epe2018.com
www.epe2018.com

23–28 September 2018
13th European Microwave Integrated Circuits Conference (EuMIC 2018), part of 21st European Microwave Week (EuMW 2018)
IFEMA, Madrid, Spain
E-mail: eumwreg@itnint.com
www.eumweek.com/conferences/eumic.html

24–28 September 2018
35th European Photovoltaic Solar Energy Conference (EU PVSEC 2018)
SQUARE - Brussels Meeting Centre, Belgium
E-mail: pv.conference@wip-munich.de
www.photovoltaic-conference.com

24–26 October 2018
BIT's 8th Annual Congress of Nano Science and Technology-(Nano S&T-2018)
Kongresshotel Potsdam am Templiner See, Germany
E-mail:stella@bitconferences.com
www.bitcongress.com/nano2018

3–5 December 2018
IEEE International Electron Devices Meeting (IEDM 2018)
Hilton San Francisco and Towers, San Francisco, CA, USA
E-mail: iedm@his.com
www.ieee.org/conference/iedm

5–8 December 2018
49th IEEE Semiconductor Interface Specialists Conference (SISC 2018)
San Diego, CA, USA
E-mail: meetings@ucsd.edu
www.ieeesisc.org

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