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COMPOUNDS & ADVANCED SILICON

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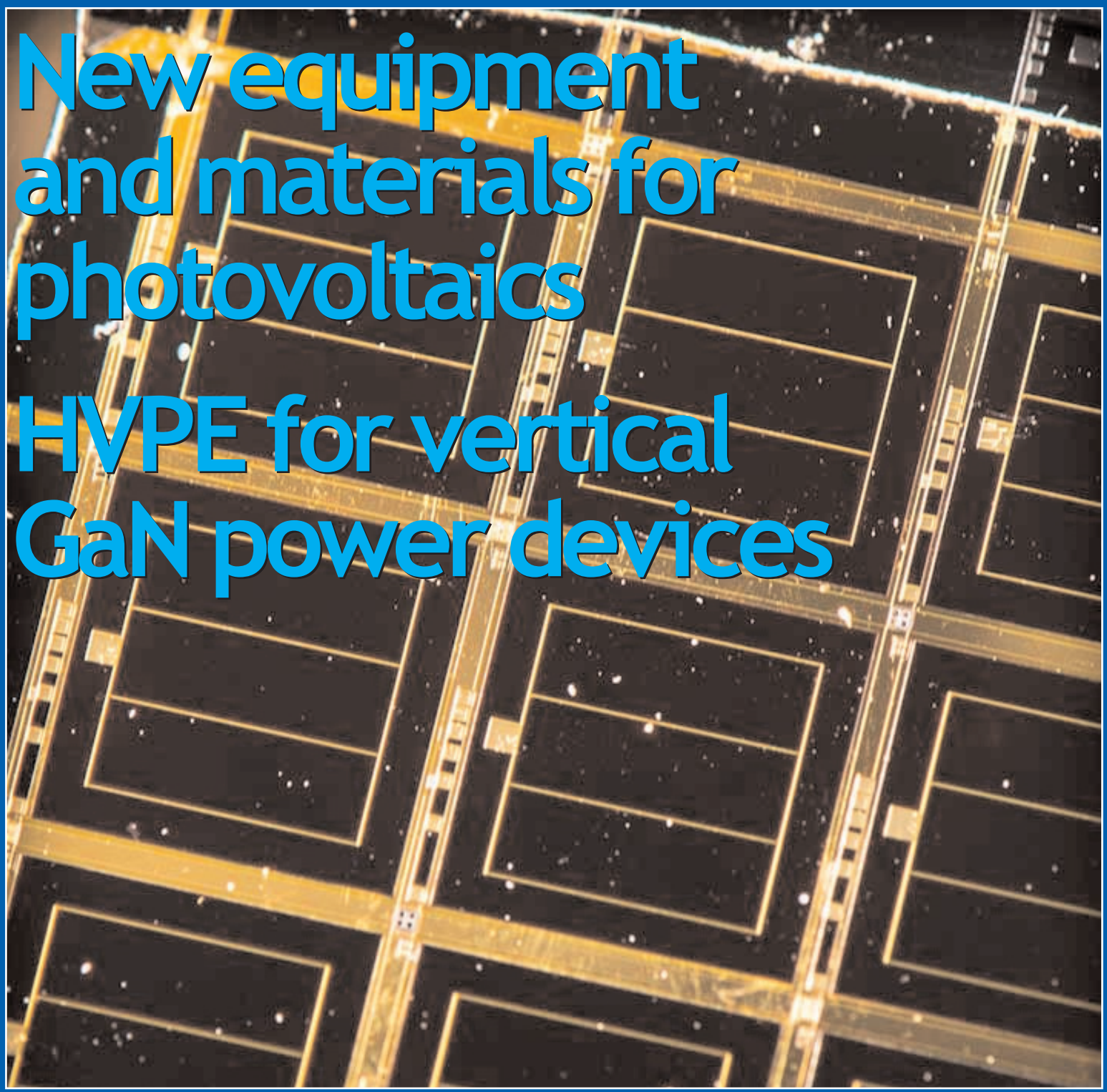
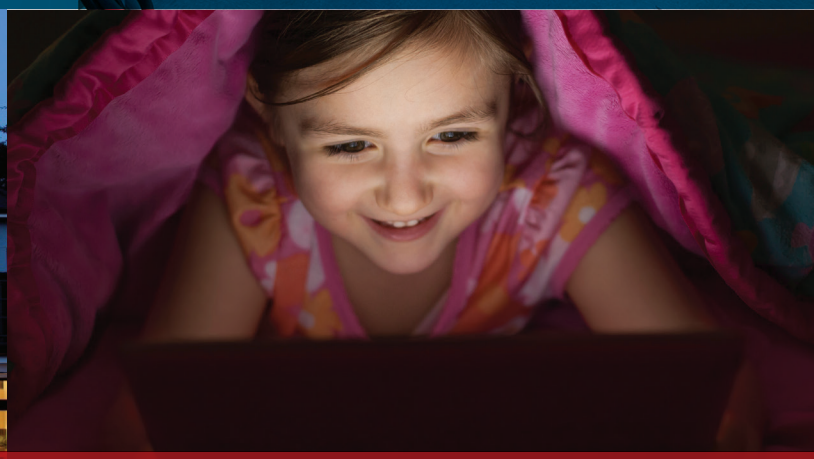


New equipment and materials for photovoltaics

HVPE for vertical GaN power devices

Finisar opens Texas 3D sensing VCSEL fab • GTAT opens SiC plant
Alta raises its GaAs single-junction cell efficiency record to 28.9%

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.

It also features a reactor with more than twice the capacity of previous generation reactors. This increased volume coupled with productivity advancements within the EPIK700 reactor, results in an unmatched 2.5x throughput advantage over previous reactors.

Learn how Veeco's TurboDisc EPIK700 GaN MOCVD system can improve your LED manufacturing process today.

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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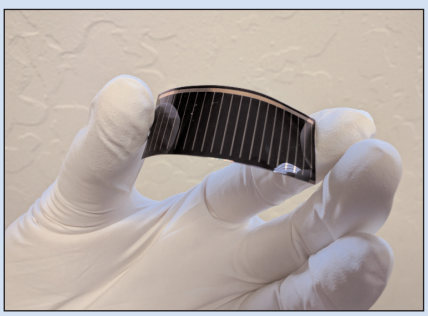
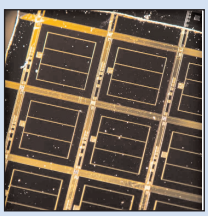
p47 Finisar has formally opened its new 3D sensing VCSEL manufacturing plant in Sherman, Texas.



p52 Alta Devices has raised its own world record for GaAs single-junction solar cell energy conversion efficiency from 28.8% to 28.9%.



Cover: The US Department of Energy's National Renewable Energy Laboratory (NREL) is working to refine the hydride vapor phase epitaxy (HVPE) technique, which holds the potential to produce cheaper, more efficient solar cells capable of producing more electricity. **p58**

editorial

US-China trade impacting industry

After receiving eight of the nine approvals required around the world under anti-monopoly laws, San Diego-based telecom chip and mobile processor provider Qualcomm has just terminated its $44bn acquisition (agreed in October 2016) of Netherlands-based NXP Semiconductors, which makes LDMOS, GaN and GaAs RF power transistors for automotive and Internet of Things (IoT) applications. This was after China's State Administration for Market Regulation (SAMR) failed to give clearance by the deal's agreed 'end date' of 25 July. Qualcomm has now had to pay NXP a termination fee of $2bn. Also as promised to shareholders, Qualcomm has announced a stock buyback program of up to $30bn. Likewise, NXP has announced a $5bn stock buyback program.

Despite China's Ministry of Commerce asserting that non-approval was due entirely to anti-trust laws, the suspicion is that it was influenced by the growing trade war between the USA and China, as exemplified by March's US Department of Commerce ban (on grounds of national security/foreign policy) on exports of chips to China-based telecom equipment maker ZTE. This halted ZTE's operations and impacted first-half 2018 financial results of US-based chip suppliers.

Earlier, in March, the proposed $117bn acquisition of Qualcomm by Singapore-based Broadcom was blocked — despite planning to move its legal headquarters to the USA — by the Committee on Foreign Investment into the United States (CFIUS) on the grounds of national security, arguing that any cutback in R&D would weaken Qualcomm's lead in developing critical 5G technology standards versus Chinese rivals like Huawei.

Previously, at the end of 2016, CFIUS thwarted China-based Grand Chip Investment's attempted acquisition of German epitaxial deposition equipment maker Aixtron, on the grounds that 20% of Aixtron's business is US-based and that its technology for manufacturing gallium nitride devices was security related (through application to defense electronics).

CFIUS is currently subject to reform by the Foreign Investment Risk Review Modernization Act of 2018 (FIRRMA), which has achieved approval by the US House of Representatives (and, most likely, soon by the Senate too). The focus remains national security, but "investments in unaffiliated critical technology or critical infrastructure companies should expect CFIUS review", without specifying the scope of "critical technology".

Regarding trade tariffs, Jonathan Davis, global VP of industry advocacy at semiconductor industry association SEMI, testified to an inter-agency US government panel, opposing tariffs imposed on 6 July on $34bn of Chinese goods that, it says, impact products such as test and inspection equipment as well as spare parts entering the USA from China. A second round of tariffs on 29 product lines worth $16bn spanning "items critical to semiconductor manufacturing, including machines and spare parts used to make wafers, flat-panel displays and masks" will cost its 400 US-based SEMI members over $500m annually in duties, it is reckoned. Applied Materials' corporate VP Joe Pon adds that the tariffs will effectively be a tax on exports of high-value US goods, giving non-US firms a competitive advantage.

In the meantime, the ZTE ban has been removed in exchange for a $1bn fine and compliance monitoring by a US-selected team. SEMI is therefore urging its members to request exclusions from tariffs, on grounds that they could harm US economic interests.

Mark Telford, Editor

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

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

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HVM: High Volume Manufacturing

LED market rising at CAGR of 16% to $23.98bn in 2022

Acceleration expected from 10.44% year-on-year growth rate in 2018

The LED market is rising at a compound annual growth rate (CAGR) of more than 16% during 2018–2022, reaching $23.98bn in 2022, according to a report by Technavio. This represents an acceleration from the 10.44% year-on-year growth rate expected for 2018.

A major trend is the growing number of households and urbanization. The increase in urbanization is driving the installation of new lamps and LED luminaires which, in turn, will lead to an increase in unit shipments and hence revenue for LED products, the report notes. In addition, rapid urbanization is driving governments of various countries to invest in large-scale urban infrastructure projects.

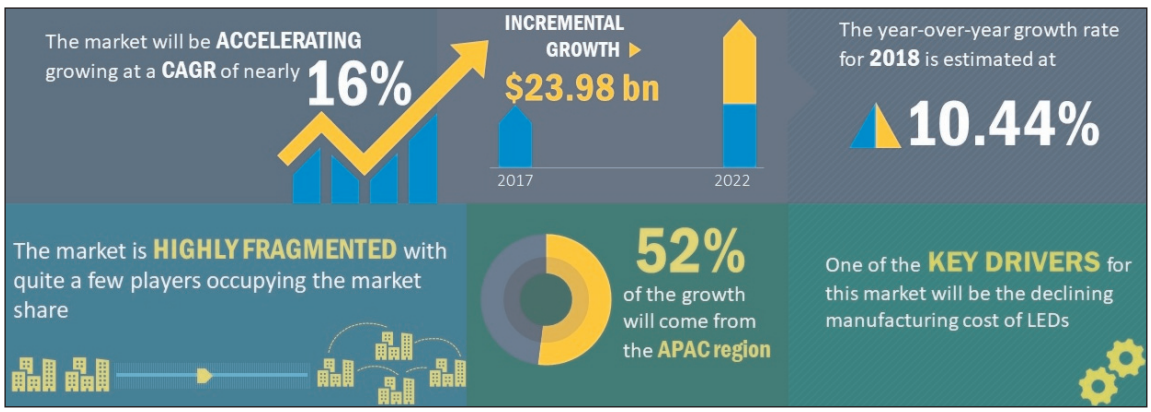
Another factor is that LED manufacturing cost has fallen since 2012 and will continue to do so during the forecast period, mainly because of the declining average selling price (ASP) of chips and components used in the manufacturing process. This is leading to a decrease in the installation costs of LED lamps and fixtures, driving the installation of new LED lamps and fixtures across all application segments.

"Megacities concentrate on investing in infrastructure development to meet the needs of the growing population," notes a senior analyst at Technavio for research on semiconductor equipment. "These megacities consume a large amount energy, due to which governments of these countries are planning to install energy-efficient lighting sources such as LED lamps and luminaires to reduce electricity consumption. This will lead to the growth of the LED market."

Demand for LED products is also expected to be fuelled by the high demand for energy-efficient lighting solutions in the general lighting market. This segment is expected to increase its market share by nearly 29% over the forecast period, while the backlighting segment is expected to see a significant drop in market share.

The Asia-Pacific (APAC) held the largest share of the market in 2017 (at nearly 47%), followed by the Americas and Europe, Middle-East and Africa (EMEA) respectively. Indeed, 52% of market growth expected over 2018–2022 should come from the APAC region. APAC and the Americas are expected to see a significant increase in their market shares while EMEA will see a corresponding decrease over the forecast period, the report concludes.

www.technavio.com/report/global-led-market-analysis-share-2018



Consumption of LED lamps in general lighting to grow to $30.81bn in 2022 then $36.34bn in 2027

The global consumption value of LED lamps used in general lighting (i.e. providing the main illumination of an area, including directional and supplementary lighting, in both functional & decorative light fixtures) will rise from $23.15bn in 2017 to $30.81bn in 2022 then $36.34bn in 2027, forecasts a market study by ElectroniCast Consultants.

The LED lamps covered in the report are used in luminaires in stationary/fixed locations (non-vehicle/non-portable) general lighting applications, and in new fixtures as well as retrofitting/replacement of existing (installed-based) lamps.

Compared to incandescent lighting, LED-based solid-state lighting (SSL) delivers visible light with reduced heat. In addition, its solid-state nature provides greater resistance to shock, vibration and wear, significantly increasing lifespan.

The market study breaks the forecast into eight major lamp types: parabolic aluminized reflector (PAR); general service (A-Type); decorative; multi-faceted reflector (MR) compatible; tube and strips/tape; street-lights; high-bay; and other/miscellaneous LED lighting. Some lamp categories, in turn, have multiple sub-categories, determined by physical size and Watt equivalents.

www.electronicast.com

Micro-LED market to grow from $2.7bn in 2019 to $10.7bn in 2022, mainly in advanced displays

...but LCD and OLED technologies to continue to do well in smartphones, tablets and regular TVs

The global micro-LED market will grow from $2.7bn in 2019 to $10.7bn in 2022, forecasts analyst firm n-tech Research in its report 'Micro-LED Market Opportunities: 2018–2027'.

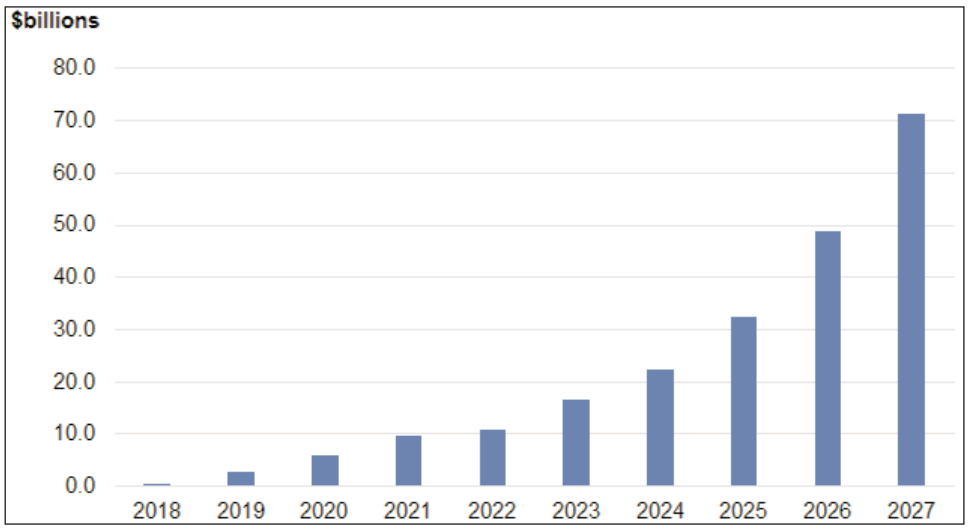
Micro-LEDs have superior performance qualities to other advanced display technologies. They have already proven superior to LCDs and OLEDs through numerous working prototype evaluations. Such superiority will be an immediate enabling factor in near-eye AR/VR (augmented reality/virtual reality) projectors and automotive HUDs (heads-up displays). Such applications require a combination of small form factor, low weight, super-high resolution and super-high brightness.

Another lucrative opportunity for micro-LEDs is the smart watch market, where the combination of extremely low power consumption and very strong brightness make micro-LEDs an obvious choice for wearable displays. n-tech sees this segment generating $1.6bn in 2022.

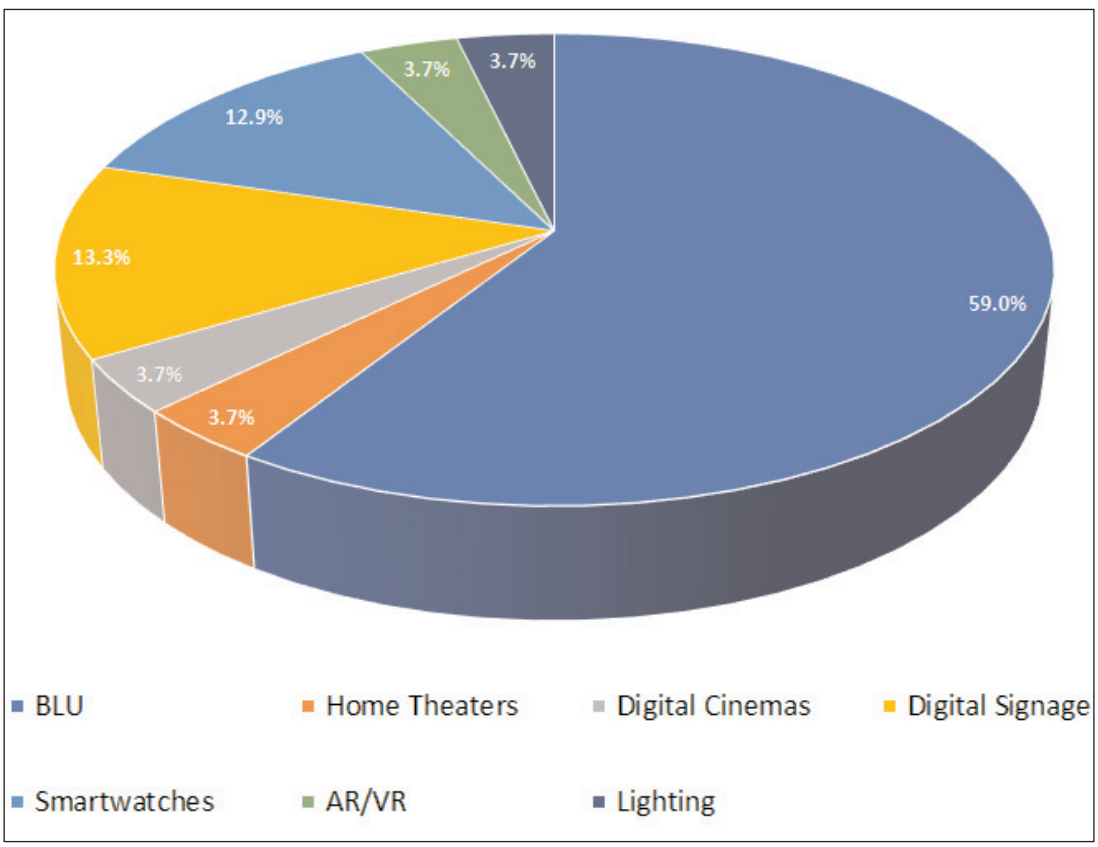
Extra-large displays (as used in video walls, digital cinemas, digital signage and home theaters) are expected to greatly benefit from the scalability of micro-LED technology to large areas (as already demonstrated by Sony and Samsung). Micro-LEDs also offer the 'giant screen' sector the possibility of hybridization with other functionalities, and compatibility with flexible and transparent display designs, says n-tech.

However, there are still applications that micro-LEDs will have a hard time penetrating, such as smartphones, tablets and regular TV market, where LCD and OLED technologies will continue to do well, believes n-tech. In these markets benefits from micro-LEDs are not very obvious, although low power consumption could be a selling feature for tablets and smart phones, concludes the market research firm.

www.ntechresearch.com/market-reports/microled-market



Micro-LED market, 2018–2027.



Micro-LED market segmentation, 2019.

Skyworks reports above-expected quarterly revenue of $894.3m, despite $25–30m hit from ZTE ban

September quarter to show return to sequential revenue growth, up 11–13%

For fiscal third-quarter 2018 (ended 29 June), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of $894.3m, down 20.9% on $913.4m last quarter and less than the $900.8m a year ago, but towards the upper end of the $875–900m guidance range. China comprised 25–30% of total revenue.

However, this follows the loss of $25–30m of revenue (mostly in mobile, but including some infrastructure) after the temporary ban imposed by the US government on US exports to China-based ZTE Corp. Without this loss, revenue would have grown sequentially.

By market sector, Mobile (Integrated Mobile Systems and Power Amplifiers) comprised under 70% of revenue (down from 73% last quarter) and Broad Markets just over 30% (up from 27%).

"Our confidence is underpinned by our product expansion and reach, expanding premier mobile and broad market accounts," says president & CEO Liam Griffin. For example, during the quarter, Skyworks commenced production of access solution for Cisco's enterprise systems, captured content in Linksys new dual-band mesh networks, ramped connectivity engines for Amazon's 4K Fire TV voice-enabled streaming media platform, partnered with Sierra Wireless on LTE CAT-12 data cards for M2M (machine-to-machine) applications, deployed networking solutions supporting AT&T DirecTV gateway routers, extended Skyworks' footprint across Nest home automation platforms (thermostats, fire detectors and video doorbells leveraging Bluetooth Low Energy, Zigbee, Thread and Wi-Fi protocols), enabled LTE telematics at General Motors and BMW, and introduced high-precision GPS functionality improving ride sharing, mobile payment and fleet management services. The firm also secured strategic flagship wins at Huawei, Samsung, Oppo, Vivo, LG and Nokia. In infrastructure markets, Skyworks deployed massive MIMO base-station architectures with a leading European infrastructure provider.

"In addition, last quarter we successfully demonstrated our proprietary fully integrated Sky5 sub-6GHz engines supporting new 5G and our radios across frequency bands 77, 78 and 79. Sky5 is enabling new 5G networks and facilitating ubiquitous wireless connectivity," says Griffin. "We are gaining first-mover advantage across Internet of Things (IoT) and rapidly emerging 5G applications with our Sky5 platform."

On a non-GAAP basis, gross margin was 50.9%, up from 50.7% both last quarter and a year ago (and towards the top end of the 50.7–51% guidance range).

Operating expenses were cut from $132m last quarter to $130m (remaining 14.5% of revenue).

Operating income was $324.8m, down from $331.1m last quarter (with operating margin falling from 37% of revenue a year ago to 36.3%).

Net income was $299.9m ($1.64 per diluted share, exceeding the $1.59 guidance), roughly on a par with the record $302.3m ($1.64 per diluted share) last quarter and up from $292.7m ($1.57 per diluted share) a year ago.

Cash flow from operations was $258m (down from $434.2m last quarter). Capital expenditure (CapEx) has more than doubled from $90.3m to $191.5m, supporting expected revenue growth in the second half of the calendar year as well as the necessary technology investments for emerging 5G opportunities in IoT markets. "Most of the CapEx is related to capacity expansion in preparation of the steep ramp that we have in front of us here in the September and December quarter, as well as some technology-related investment," says senior VP & chief financial officer Kris Sennesael.

"We continue to deploy our cash to create shareholder value, returning nearly $300m during the quarter through share repurchases and dividends," notes Griffin. Dividends paid were $57.7m. Skyworks repurchased 2.5 million shares of common stock for $240.3m, bringing total share repurchases so far during fiscal 2018 to about 5.2 million shares. "In fiscal 2018, Skyworks returned essentially all of our free cash flow back to the shareholders."

During the quarter, cash and investment balance hence fell from $1.881bn to $1.649bn. Skyworks has no debt.

"Skyworks exceeded June-quarter expectations driven by our broadening market reach, solid execution and resilient business model," says Griffin. "Leveraging our scale and decades of system-level expertise, we are positioned to capitalize on increasing demand for powerful and complex connectivity engines as the global data economy accelerates," he reckons. "We are entering the seasonally strong second half while on track for another year of record financial performance," says Griffin.

For fiscal fourth-quarter 2018, Skyworks expects revenue to grow 11–13% sequentially to $1bn as design-win momentum transitions to volume production. This is despite expecting just a few million dollars from ZTE, after the US export ban was lifted. "It will take

time for ZTE to rebuild their supply chain, which could take multiple months, if not multiple quarters," warns Griffin.

Gross margin should rise to 51–51.5%. "We continue to make really good progress towards our target model of 53%," says Sennesael. Despite operating expenses rising to $135m, diluted earnings per share should increase to $1.91.

"Based on our Q4 outlook, we will end the fiscal year with mid-single-digit revenue growth, greater than a 10% EPS increase and record cash returns. This despite a choppy market backdrop and a government-imposed trade ban on a sizable Chinese customer," says Griffin.

"We are growing in the low to mid-teens year-over-year, and so we are now at a $1.1bn annualized revenue run rate. So we see really good strength across the board, especially the IoT segment that's including the connected home, the connected car, machine-to-machine industrial applications, some consumable applications," notes Sennesael. "We also see some really good traction there on the infrastructure segment, so broad market is doing really well," he adds.

Reflecting confidence in its business model and sustainable cash generation capabilities, Skyworks' board of directors has declared a cash dividend of $0.38 per share (up 19% on fiscal Q3's dividend of $0.32 per share), payable on 28 August to stockholders of record at the close of business on 7 August.

www.skyworksinc.com

Skyworks appoints Kimberly Stevenson to board

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has appointed Kimberly S. Stevenson to its board of directors.

Stevenson is currently senior VP & general manager of Data Center Products and Solutions for multinational technology company Lenovo. Prior to joining Lenovo, she held various senior management positions in operations and information technology at Intel Corp, serving as VP & chief information officer. Stevenson also spent seven years at Electronic Data Systems (responsible for information technology operations and global service delivery) and more than 17 years at IBM in finance and operational roles.

"She brings extensive experience spanning technology, finance and operations," comments chairman of the board David J. Aldrich. "Her background will be invaluable to supporting our ambitious vision of Connecting Everyone and Everything, All the Time."

"With the proliferation of the Internet of the Things and advent of 5G, Skyworks is well positioned to capitalize on ubiquitous wireless connectivity," says Stevenson. "I look forward to leveraging my network infrastructure and cloud expertise to enhance Skyworks' scalability."

Stevenson currently serves on the board of directors for Boston Private Financial Holdings, a financial services firm focused on private banking and wealth management. She previously has held board positions with private enterprise software company Cloudera; publicly traded hardware and software developer Riverbed Technology; and the non-profit organization National Center for Women and Information Technology. Stevenson graduated from Northeastern University in Boston, Massachusetts, with a bachelor's degree in business. She also earned a master's in business administration from Cornell University in Ithaca, New York.

Lattice to discontinue millimetre-wave business to focus on core business

Lattice Semiconductor Corp of Portland, OR, USA, which provides programmable logic devices (PLDs) and video connectivity application-specific standard product (ASSP), is to discontinue its silicon-based 60GHz millimeter-wave business. This is expected to result in about $25m of primarily non-cash restructuring and impairment charges in second-quarter 2018, and an annualized reduction in operating expenses of about $13m.

The firm does not expect a significant impact to its potential full-year 2018 revenue due to strength in other areas of its business. Lattice says that it is committed to supporting customers' product and support requirements during the transition period.

"After careful evaluation, millimeter wave was determined to be a non-core business, unable to achieve the required near-term scale to be profitable or to warrant any further investment," says interim CEO Glen Hawk. "We considered various strategic alternatives for this business but none proved to be viable," he adds. "We continue working to further improve operational efficiencies and to accelerate revenue growth of our existing semiconductor solutions into attractive control, connect and compute applications," Hawk concludes.

www.latticesemi.com

Analog Devices breaks ground on new global HQ

Facility to accommodate 450+ additional staff

Analog Devices Inc of Norwood, MA, USA (which provides mixed-signal ICs for cable access) has officially broken ground on its new global headquarters in Wilmington, MA, in a ceremony attended by Jay Ash (Secretary of Housing and Economic Development for the Commonwealth of Massachusetts), Senator Bruce Tarr, Jeff Hull (manager of the Town of Wilmington) and other dignitaries from the Commonwealth, Associated Industries of Massachusetts, the Town of Wilmington Board of Selectmen and Finance Committee.

The expanded facility will feature laboratories, as well as design and manufacturing and cross-functional group collaboration space. In addition to 147,000ft^2 extra for R&D, the headquarters will include a 50,000ft^2 Hub comprising a café, fitness facility and auditorium designed to enable and encourage employees from all departments and functions to gather, connect and engage. Analog Devices partnered with architect Steven Baker on design, and Lee Kennedy for construction. The firm anticipates moving into the new buildings by 2020.

"We have invested and upgraded our facilities globally to provide more modern, latest technological and work design advances, to support and foster the highest level of innovation," says John Hassett, senior VP of global operations and technology. "This new campus will be our global showcase — enabling us to highlight our best work, attract top talent and build new partnerships."

With a presence in Wilmington dating back to 1981, Analog Devices is the longest-standing and largest manufacturer in the town, supporting the local community from underwriting local STEM scholarships to sponsoring athletics and contributing to environmental causes.

"The strength of Massachusetts is exemplified by Analog Devices and its position at the forefront of technology," said Ash at the ceremony, following brief remarks from guests including Analog Devices' co-founder & chairman Ray Stata.

www.analog.com

Qorvo's 5GHz FEM integrated in Qualcomm's 802.11ax chipset for new commercial carrier gateway

Qorvo Inc of Greensboro, NC, USA says its QPF4528 high-efficiency 5GHz front end module (FEM) is part of a new commercially available draft 802.11ax carrier gateway. The new gateway, which integrates Qualcomm Technologies Inc's IPQ807x family of 802.11ax chipsets, provides up to four times higher wireless networking throughput and better performance in bandwidth-intensive applications than previously deployed carrier gateways.

As part of Qorvo's 802.11ax portfolio of high-performance 2.4GHz and 5GHz FEMs, the QPF4528 transmits increased linear power without increasing power dissipation versus previous generations of FEMs. This reduces challenging thermal issues in the design of Wi-Fi equipment for multi-user multiple-input multiple-output (MU-MIMO) environments. The FEM's power efficiency also enables applications that use Power over Ethernet (PoE), which is critical in regions of the world where output power is regulated.

"Our FEM powers Qualcomm Technologies' IPQ8072 chipset solution for this milestone carrier gateway, delivering ever-increasing Wi-Fi throughput and expanded range," says Cees Links, general manager of Qorvo's Wireless Connectivity business unit, which develops wireless semiconductor system solutions for connected devices and Wi-Fi integrated front-end solutions, offering a range of RF chips and software for smart-home data communications and the Internet of Things (IoT). "Qorvo's 802.11ax products are improving the experience of end users around the world, as more and more connected devices are used by everyone in the home," he adds.

Market research firm IHS Markit estimates that global 802.11ax-enabled device shipments will reach nearly 200 million units by 2021.

www.qorvo.com/products/integrated-products/wifi

Qorvo completes offering of $500m senior notes

Qorvo has completed its offering of $500m of its senior notes maturing in 2026. The notes will pay interest semi-annually at a rate of 5.50%, and will mature on 15 July 2026 (unless earlier redeemed in accordance with their terms).

The notes were issued to qualified institutional buyers and to certain non-US persons (in accordance with Regulation S under the Securities Act).

Qorvo expects to use the net proceeds of the offering to purchase, in connection with its recently announced tender offers, up to $300m of its 7.00% senior notes due 2025 (increased from the $150m announced on 10 July), to pay related fees and expenses of the offering and the tender offers, and for general corporate purposes.

www.qorvo.com

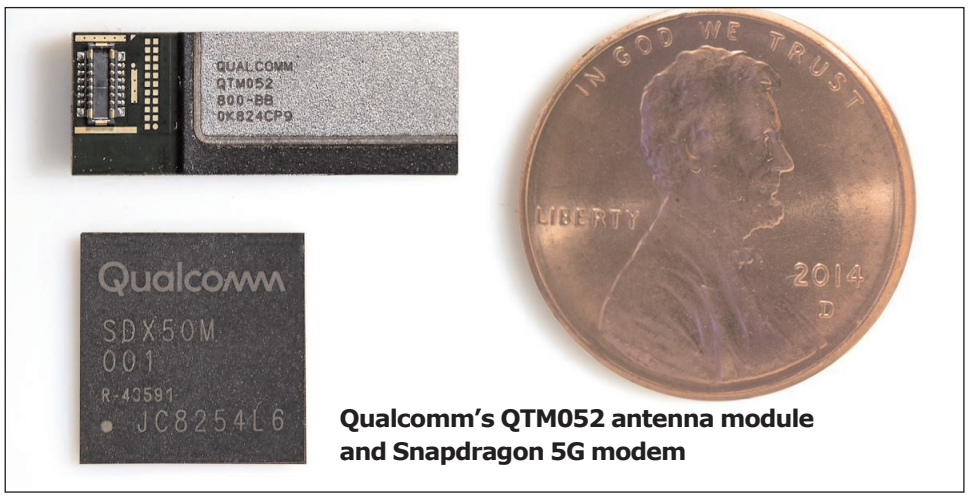
Qualcomm delivers 5G NR millimeter-wave and sub-6GHz RF modules for mobile devices

New family of mmWave antenna modules makes mobile mmWave viable in smartphone form factor, supporting large-scale commercialization

Qualcomm Technologies Inc, a subsidiary of Qualcomm Inc of San Diego, CA, USA, has unveiled what it claims is the first fully integrated 5G NR millimeter-wave (mmWave) and sub-6GHz RF modules for smartphones and other mobile devices. The QTM052 mmWave antenna module family and the QPM56xx sub-6GHz RF module family pair with the Snapdragon X50 5G modem to deliver modem-to-antenna capabilities across several spectrum bands, in a compact footprint suitable for integration in mobile devices.

"Qualcomm Technologies' early investment in 5G has allowed us to deliver to the industry a working mobile mmWave solution that was previously thought unattainable, as well as a fully integrated sub-6GHz RF solution," says Qualcomm Inc's president Cristiano Amon. "Now, these types of modem-to-antenna solutions, spanning both mmWave and sub-6GHz spectrum bands, make mobile 5G networks and devices, especially smartphones, ready for large-scale commercialization," he adds. "With 5G, consumers can expect gigabit-class Internet speeds with unprecedented responsiveness in the palm of their hands."

To date, mmWave signals have not been used for mobile wireless communications due to the many technical and design challenges they pose, which impact nearly every aspect of device engineering, including materials, form-factor, industrial design, thermals, and regulatory requirements for radiated power. As such, many in the mobile industry considered mmWave highly impractical for mobile devices and networks, and thus unlikely to materialize, says Qualcomm.



Qualcomm's QTM052 antenna module and Snapdragon 5G modem

The QTM052 mmWave antenna modules work in tandem with the Snapdragon X50 5G modem, as a comprehensive system, to help overcome the challenges associated with mmWave. They support advanced beam forming, beam steering and beam tracking technologies, drastically improving the range and reliability of mmWave signals. They feature an integrated 5G NR radio transceiver, power management IC, RF front-end components and phased antenna array. They support up to 800MHz of bandwidth in the 26.5–29.5GHz (n257) as well as the entire 27.5–28.35GHz (n261) and 37–40GHz (n260) mmWave bands. Most importantly, the QTM052 modules integrate all these capabilities in a compact footprint, so that up to four of them can be integrated in a smartphone. This allows OEMs to continue evolving the industrial design of their mobile devices, offering attractive form factors combined with the benefits of extremely high speeds from mmWave 5G NR, and making such devices available for launch as early as first-half 2019, says Qualcomm.

While mmWave is best suited for providing 5G coverage in dense urban areas and crowded indoor environments, broad 5G NR coverage will be achieved in sub-6GHz spectrum bands. As such, the QPM56xx RF module family (including the QPM5650, QPM5651, QDM5650 and QDM5652) is designed to allow smartphones based on the Snapdragon X50 5G modem to support 5G NR in sub-6GHz RF bands. The QPM5650 and QPM5651 feature an integrated 5G NR PA/LNA/switch and filtering subsystem. The QDM5650 and QDM5652 feature an integrated 5G NR LNA/switch and filtering subsystem for diversity and MIMO support. All four modules offer integrated SRS switching required for optimum massive MIMO applications and support for 3.3–4.2GHz (n77), 3.3–3.8GHz (n78) and 4.4–5.0GHz (n79) sub-6GHz bands. Qualcomm says that these sub-6GHz RF modules provide mobile device makers with a viable path to delivering on the promise of 5G NR massive MIMO technology in mobile devices.

Both the QTM052 mmWave antenna module family and the QPM56xx sub-6GHz RF module family are now sampling to customers.

www.qualcomm.com

Custom MMIC achieves ISO 9001:2015 certification

Monolithic microwave integrated circuit developer Custom MMIC of Chelmsford, MA, USA says that its growing corporate facility at 300 Apollo Drive has been certified by Nemko as meeting the standards of ISO 9001:2015, representing an evolution from its previous certification to ISO 9001:2008 standards in 2012 and 2015.

"As we continue to add team members and equipment, having these systems and controls in place will ensure our continued achievement of awards such as our most recent 5 Star Supplier Excellence Award from Raytheon," says Erik Sauve, director of quality.

Custom MMIC continues its expansion with the recent acquisition of additional high-volume production equipment. The new network analyzers, test handlers and automatic die probers will position it for servicing high-volume orders.

www.custommmic.com/resources/iso9001-exp2021.pdf

Custom MMIC adds to LNA and phase-shifter MMIC portfolio

Custom MMIC has added to its low-noise amplifier (LNA) and phase-shifter MMIC portfolio with the CMD270P3 and CMD174.

Housed in a leadless 3mm x 3mm plastic surface-mount package, the CMD270P3 is a C-band, 4–8GHz LNA that delivers greater than 16dB of gain with a corresponding P1dB (output power at 1dB compression point) of +18dBm and a noise figure of 1.7dB. The CMD270P3 is a 50Ω matched design, eliminating the need for external DC blocks and RF port matching.

The CMD270P3 is suitable for electronic warfare (EW) and communications receivers where high performance, small size and low power consumption are needed. It can also be used as an alternative to the CMD185P3, based on pin and performance compatibility.

The CMD174 die is a GaAs MMIC 5-bit phase shifter that operates at 3–6GHz and provides 0–360° of monotonic phase coverage, with a LSB of 11.25°. The device is controlled with negative logic of 0 and –3V and features an insertion loss of 7.6dB and a phase error of ± 2°. The CMD174 is a 50Ω matched design, and is suitable for phased-array radar applications.

www.custommmic.com/cmd270p3-low-noise-amplifier

www.custommmic.com/cmd174-phase-shifter

Custom MMIC hires Tom Rosa as chief financial officer

Monolithic microwave integrated circuit developer Custom MMIC of Chelmsford, MA, USA has hired Thomas M. Rosa as senior VP & chief financial officer, effective 1 June. Rosa, who has been consulting with the firm for 14 months prior to his hiring, will lead all aspects of finance and accounting operations.

Rosa has more than 30 years of progressively more responsible financial management experience at public and private companies, with significant experience at companies focused on materials and material-based solutions. His primary strengths lie in capital markets, investor/analyst relations, SEC filings, mergers and acquisitions, budgeting and long-range planning, manufacturing cost accounting, and government accounting.

Since 2014, Rosa has been the consulting CFO at several small, private companies undergoing significant growth, working in partnership with company senior management to improve operations, sales, backlog, profitability, and cash flow.

Custom MMIC's new chief financial officer Tom Rosa.

From 2008 to 2013, Rosa was CFO & senior VP of Bruker Energy & Supercon Technologies, a subsidiary of Bruker Corp, where he oversaw an increase in annual sales from $39m to $136m in five years through organic growth and a successful acquisition in Germany. Prior to 2008, he worked for 14 years at American Superconductor Corp (AMSC), rising to CFO and helping to grow AMSC from $3m in annual revenues to about $100m.

Rosa also served in financial management positions at Lockheed, Wang Labs and Prime Computer. Collectively, he has helped various companies raise over $350m in financing. He received his MBA in finance from Northeastern University in 1982.

"We're delighted to have Tom to join us in a lead management role as we continue to expand our business," says Custom MMIC's president Paul Blount. "The time is right to bring on a CFO to support the continuing development and maturation of our company," he adds. "Tom has been supporting us for over a year now as our consulting CFO. He has been a CFO at several Massachusetts-based companies, and his experience in fast-growth business environments suits us perfectly, as we continue along our rapid growth curve," says Blount.

www.custommmic.com

TowerJazz announces RF SOI 65nm ramp in 300mm Japan fab

Supply of tens of thousands of SOI wafers per year secured under long-term partnership with SOITEC

Specialty foundry TowerJazz (which has fabrication plants at Tower Semiconductor Ltd in Migdal Haemek, Israel, and at its US subsidiaries Jazz Semiconductor Inc in Newport Beach, CA and TowerJazz Texas Inc in San Antonio, TX, and at TowerJazz Japan Ltd) has announced a ramp for its radio-frequency silicon-on-insulator (RF SOI) 65nm process in its 300mm fab in Uozu, Japan. TowerJazz has signed a contract with long-term partner SOITEC of Bernin, near Grenoble, France (which makes engineered substrates including SOI wafers) to guarantee a supply of tens of thousands of 300mm SOI silicon wafers, securing wafer prices for the next few years and ensuring supply to its customers, despite a very tight SOI wafer market.

"We are delighted to see the strong adoption of 300mm RF SOI through this large capacity and supply agreement with TowerJazz to augment our already significant 200mm RF SOI partnership," says SOITEC's CEO Paul Boudre. "TowerJazz was the first foundry to ramp our RFeSI products to high-volume production in 200mm," he adds.

With what are claimed to be best-in-class metrics, TowerJazz's 65nm RF SOI process enables the combination of low-insertion-loss and high-power-handling RF switches with options for high-performance low-noise amplifiers (LNAs) as well as digital integration. The process can reduce losses in an RF switch, improving battery life and boosting data rates in handsets and Internet of Things (IoT) terminals.

According to market research firm Mobile Experts LLC, the mobile RF front-end market will grow from an estimated $16bn in 2018 to $22bn in 2022. TowerJazz says that its RF SOI technology continues to support this high-growth market and is poised to take advantage of next-generation 5G standards which will boost data rates and provide further content growth opportunities in the coming years.

TowerJazz has also announced its relationship with Maxscend Microelectronics Co Ltd of WuXi, China, a provider of RF components and IoT integrated circuits, ramping in this new technology.

"We chose TowerJazz for its advanced technology capabilities and its ability to deliver in high volume while continuously innovating with a strong roadmap," comments Maxscend's CEO Zhihan Xu. "We specifically selected its 300mm 65nm RF SOI platform for our next-generation product line due to its superior performance, enabling low insertion loss and high power handling," he adds.

www.soitec.com
www.towerjazz.com/sige-bicmos_rf-cmos.html

Infineon ships 5 billionth bulk-CMOS RF switch

After beginning volume production of its first bulk-CMOS radio frequency (RF) switch in 2008, Infineon Technologies AG of Munich, Germany has now reached an annual run-rate far exceeding 1 billion and a cumulative shipments of 5 billion RF bulk-CMOS switches.

"With its proven expertise and legacy in semiconductor manufacturing, Infineon became a preferred partner of all original equipment and design manufacturers and chipset distributors," claims Philipp von Schierstaedt, VP & general manager for Radio Frequency Systems at Infineon.

Since the introduction of solid-state technology in the 1960s, design technologies for RF switches have fallen into two categories: electro-mechanical switches (MEMS) and solid-state switches. Low switching speed, weak repeatability and reliability exclude MEMS automatically from being an ideal candidate for 5G applications, says Infineon.

In the meanwhile, scientific efforts have furthered solid-state technology with several technology options. Compared with gallium arsenide (GaAs) and gallium nitride (GaN), transistor-to-transistor logic based on bulk-CMOS has provided the best integration capabilities, ultimately enabling space-constrained designs on printed circuit boards. Unlike other alternatives, bulk-CMOS wafer processing requires neither an extra oxide layer nor different materials, implying direct economic benefits.

In addition to the ever accelerating pace of the industry overall, the advent of 5G telecoms is placing great challenges on an array of technical parameters in the hands of original equipment manufacturers (OEMs) and original design manufacturers (OMDs), says Infineon. The firm adds that it is developing more products that foster RF designers' ambitions.

The electrical performance is proven by available samples of the next-generation bulk-CMOS RF switches (the new antenna swapping devices BGSX22G5A10 and BGSX33MA16).

Volume production will start in late summer 2018.

www.infineon.com/rfswitches

Akoustis completes technology qualification for pre-production of single-crystal BAW RF filter products

Firm shifts focus to customer acquisition & high-volume manufacturing

Akoustis Technologies Inc of Charlotte, NC, USA — which designs and manufactures patented BulkONE single-crystal piezoelectric bulk acoustic wave (BAW) high-band RF filters for mobile and other wireless applications — has completed qualification of its first-generation XBAW wafer technology and the underlying single-crystal materials process at its commercial 120,000ft^2 wafer fabrication plant in Canandaigua, NY (which includes class 100/class 1000 cleanroom space).

The proprietary XBAW-1 (XB1) process establishes what is claimed to be the first single-crystal BAW technology for the expanding RF filter market for 4G/LTE, 5G mobile, 5G infrastructure, WiFi, military radar and other applications. The XB1 process features:

- novel MEMS wafer manufacturing;
- high-frequency RF performance spanning 1.5-7GHz;
- high-linearity and wide-bandwidth performance; and
- compatibility with conventional and flip-chip packaging

"Reaching this critical milestone, we have moved from pure R&D to the commercialization of our patented single-crystal BAW technology," says founder & CEO Jeff Shealy. "We are now positioned to concentrate on the delivery of high-performance RF filters for current customer engagements to support WiFi, mobile devices and infrastructure, radar and other wireless applications," he adds. "We expect to achieve full product qualification of our first three announced products, the AKF-1252, the AKF-1938 and the AKF-1652 later this calendar year."

The Akoustis technology development process consists of the following five phases:

- pre-alpha — demonstrate basic feasibility/capabilities;
- alpha — develop stable recipe (process freeze) with limited product development;
- beta — complete technology qualification (process qualification) in factory to enable product design;
- pre-production — demonstrate lead product production capabilities, release final design tools; and
- production — continual improvement of process and parametric performance.

In March, Akoustis announced completion of the alpha-phase for its XB1 process and now it has completed beta-phase qualification for both XB1 and the single-crystal materials process. This shortens the development cycle time for new catalog and custom components as each new product will start in the pre-production phase and will not require end-to-end qualification.

Since March, Akoustis has processed multiple XB1 wafer lots and, using the data from these lots, it has established all the necessary controls and supporting documentation within its ISO9001:2015-certified quality management system to ensure the robustness and repeatability of the process as the pre-production phase of development begins for multiple products.

"These qualifications are a major milestone towards introducing this technology to the market," says Joel Morgan, director of quality. "The speed at which the XBAW process was conceived, developed and qualified is quite remarkable," he reckons. "This provides confidence that the next steps of product qualification and release, along with the rollout of design support tools for potential foundry customers, will result in the rapid release of products, beginning later this year."

www.akoustis.com

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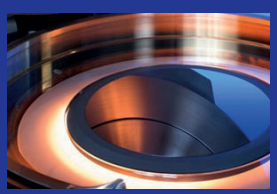

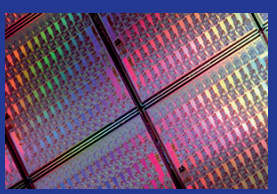

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Baylin Technologies acquires Alga Microwave; announces $35m bought-deal offering

Toronto-based Baylin Technologies Inc has acquired Alga Microwave Inc for $27m, consisting of $21m in up-front cash, $4m in Baylin shares (at $3.40 per share) and $2m in deferred earn-out payments (if certain criteria are met over the two years after the acquisition). Baylin has also acquired Alga's operational facilities in Kirkland, Quebec, for $6.2m.

In connection with the acquisition, Baylin has entered into an agreement on a 'bought deal' basis with a syndicate of underwriters led by Raymond James Ltd for an offering of 6,451,613 subscription receipts of the company at a price of $3.10 each (yielding gross proceeds of $20m) plus $15m of 6.5% extendible convertible unsecured debentures of the company at a price of $1000 each, giving total gross proceeds of $35m.

Alga designs and develops RF and microwave components, and supplies RF and microwave solid-state power amplifiers, pulsed amplifiers for radar applications, transmitter and transceiver products as well as RF passive components and systems. Products cover all major frequency standards.

"The addition of Alga is synergistic with our recent acquisition of Advantech, helping us to further expand our rapidly growing radio frequency and microwave components business. Alga's new state-of-the-art facility, situated close to Advantech, will set the stage for a robust platform for future growth," says Baylin's president & CEO Randy Dewey. "We look forward to working with the team at Alga to incorporate their top-of-the-line products into Baylin's broad offering," he adds.

"As a market leader in radio frequency and microwave, we are a natural fit in helping Baylin achieve its vision of becoming the frontrunner in data transmission," believes Alga's CEO Michael Perelshtein. "Alga will be able to leverage Baylin's world-class sales force and relationships with tier-one customers to expand the reach of our products," he adds. .

"This acquisition is a key strategic move that is expected to benefit both operations in a significant way," comments Advantech's president John Restivo. "Alga's modern factory and precision machining capability will allow us to control more of the supply chain and provide for rapid product development. Additionally, Alga brings extensive high-frequency passive microwave component capability, expanding our addressable markets. Bringing together both Advantech's broad portfolio, sales and marketing channels along with Alga's manufacturing efficiencies, products and passive capabilities will allow us to address a wider, more diversified market and provide our customers with broader networking solutions."

Expected benefits of the acquisition for Baylin include:

- cost synergies;
- accretive to 2018 earnings per share;
- enhancement of one of Baylin's faster-growing segments (Satellite Connectivity Products); and
- expansion of Baylin's RF and microwave components business (begun with the acquisition of Advantech Wireless Inc in January).

Alga's principals have taken on executive positions at Baylin.

Alga's president & CEO Michael Perelshtein has taken on the role of chief operating officer of Alga, with oversight of both Advantech and Alga operations. He was previously at Wavesat Telecom and C-Mac/Selectron, and has much business development experience.

Alga's chief operating officer Frank Panarello is now VP operations of Alga, with oversight of both Advantech and Alga operations. Prior to a decade at Alga he worked at Nortel Networks.

www.baylintech.com

Baylin's Alga Microwave receives order from NATO customer for GaAs-based block up-converters

Toronto-based Baylin Technologies Inc says that its subsidiary Alga Microwave of Kirkland, Quebec, Canada has received an order worth over half a million dollars from a NATO customer for its satellite communication (SatCom) gallium arsenide (GaAs)-based block up-converters (BUCs).

"Our customers appreciate the exceptional linearity and operating efficiency," claims Baylin's president & CEO Randy Dewey. "The GaAs Ku-band line of block up-converters (BUCs) from Alga is extremely versatile, offering compact size, light weight and superior phase noise."

Baylin says that Alga's latest generation of Ku-band GaAs-based BUCs are extremely adaptable and suited to harsh environments, Satcom on the Move (SOTM) and man-pack terminal deployments. The Ku-band GaAs-based BUCs are built for VSAT stabilized platforms and mobile stations while also offering benefits for fixed-site and offshore drilling applications. Weighing less than five pounds each, the smaller BUCs are fully integrated units that enable new terminal designs for both mobile and on-the-halt tactical communication systems.

www.alga.ca

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GaN Systems launches 100W and 300W power amplifiers for wireless charging

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) has unveiled two wireless power amplifiers for wireless charging in high-power consumer, industrial and transport applications: a 100W power amplifier (with ranges from 70W to 100W) and a 300W power amplifier (with ranges from 150W to 1kW).

GaN Systems says that, as wireless charging goes mainstream, gallium nitride is removing the limitations by enabling new higher-power system designs that provide the spatial freedom and faster charge times.

The 100W power amplifier [GSWP100W-EVBPA] are suitable for applications in the consumer market for items such as laptop computers, recreation drones, domestic aide robots, power tools, and fast-charging of multiple smart phones.

The 300W power amplifier [GSWP300W-EVBPA] is targeted at industrial and transportation markets including delivery drones, warehousing robots, medical units, factory automation, contractor power tools, eBikes, and scooters.

Both power amplifiers have a range of features including current or voltage control, built-in protection circuitry, EMI filtering, and configurable output power. The amplifiers combine GaN Systems' power transistors with high-frequency GaN E-HEMT drivers from pSemi Corp of San Diego, CA, USA.

"Our GaN solutions are creating opportunities for the development of high-power, high-efficiency power systems in applications such as wireless power transfer and charging," says Paul Wiener, VP strategic marketing. "The power ecosystem has changed. There is now availability of high dv/dt level-shifters, fast response IC sensing and control, low-loss high frequency magnetics, and high-performing GaN transistor and amplifier capabilities that are enabling smaller, lighter, lower-cost and more efficient power systems."

www.gansystems.com

pSemi launches GaN FET driver for solid-state LiDAR

Murata company pSemi Corp of San Diego, CA, USA (formerly Peregrine Semiconductor) — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has announced availability of the PE29101 gallium nitride (GaN) field-effect transistor (FET) driver for solid-state light detection and ranging (LiDAR) systems.

The PE29101 high-speed driver has what is claimed to be the industry's fastest rise times and a low minimum pulse width, enabling design engineers to extract the full performance and switching speed advantages of GaN transistors. In solid-state LiDAR systems, faster switching translates into improved resolution and accuracy in the LiDAR image.

"As GaN is proving its relevance in applications like solid-state LiDAR, design engineers are using pSemi high-speed drivers to maximize the fast-switching benefits of GaN," says chief technology officer Jim Cable. "Because of its rise and fall speed, the PE29101 enables the highest possible resolution imagery — something the industry needs for LiDAR to reach its fullest potential."

LiDAR operates on the same principles as radar but instead uses pulsed lasers to precisely map surrounding areas. Traditionally used in high-resolution mapping, LiDAR is now used in advanced-driver assistance programs (ADAS) and is widely seen as an enabling technology to fully autonomous vehicles. Further, solid-state LiDAR has emerged as the future leader in the commercialization of LiDAR systems, largely due to its affordability, reliability and compact size compared with mechanical sensors.

In LiDAR systems, the pulse laser's switching speed and rise time directly impacts the measurement's accuracy. To improve resolution, the current must switch as quickly as possible through the laser diode. pSemi says that GaN technology offers LiDAR systems superior resolution and a faster response time because of its very low input capacitance and its ability to switch significantly faster than silicon MOSFETs.

GaN FETs must be controlled by a very fast driver to maximize their fast-switching potential. Increasing the switching speed requires a driver with fast rise times and a low minimum output pulse width. The PE29101 offers these key performance specifications, enabling GaN technology to improve LiDAR resolution, says pSemi.

The PE29101 is a half-bridge FET driver that controls the gates of GaN transistors. The driver outputs are capable of providing switching transition speeds in the sub-nanosecond range for switching applications up to 40MHz. The PE29101 has a rise/fall time of 1ns with 100pF load and a minimum output pulse width of 2ns. It operates from 4V to 6.5V and can support a high-side floating supply voltage of 80V. The PE29101 has an output source current of 2A and an output sink current of 4A.

Offered as a flip-chip die, PE29101 volume-production parts, samples and evaluation kits are available now.

www.psemi.com
www.gansystems.com

EPC launches Class 4 wireless power demonstration kit

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA — which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications — has made available a complete Class 4 wireless power demonstration kit.

Transmitting up to 33W while operating at 6.78MHz (the lowest ISM band), the EPC9129 kit comes complete with two receivers, each with a regulated output _ one capable of delivering 5W and a second capable of delivering 27W at 19V.

The purpose of the demonstration kit is to simplify the evaluation process of using eGaN FETs for highly efficient wireless power transfer. The EPC9129 utilizes the high-frequency switching capability of EPC GaN transistors to facilitate wireless power systems with full power efficiency between 80% and 90% under various operating conditions.

The EPC9129 wireless power system consists of four boards:

- source board (transmitter or power amplifier) EPC9512 featuring the EPC8010, EPC2038 and EPC2019;
- Class 4 AirFuel-compliant source coil (transmit coil);
- Category 5 AirFuel-compatible receive device EPC9514 featuring the EPC2016C; and
- Category 3 AirFuel-compatible receive device EPC9513 featuring the EPC2019.

The popularity of highly resonant wireless power transfer is increasing rapidly, particularly for applications targeting large power-transmitting surface areas, with the capability to place receiving devices anywhere on the surface, and the ability to simultaneously power (or charge) multiple devices placed on the surface. The end applications are varied and evolving quickly, from cell-phone charging to powering handheld tablets and laptop computers. Delivering up to 33W supports all of these applications.

Source (amplifier) board

The source (amplifier) board is a highly efficient zero voltage switching (ZVS) Class-D amplifier configured in an optional half-bridge topology (for single-ended configuration) or default full-bridge topology (for differential configuration), and includes the gate driver(s), oscillator and feedback controller for the pre-regulator. This allows for compliance testing that operates to the AirFuel Class 4 standard over a wide load range. The amplifier board is available separately as EPC9512 for evaluation in existing customer systems.

Device (receiving) boards

The Category 5 EPC9514 (19V, 27W) and Category 3 EPC9513 (5V, 5W) device or receiving boards included in the wireless power demonstration kits are also available separately for those who have their own source boards or who want to work with multiple receiving devices simultaneously. The efficiency of these first-generation systems is about 87% from input to the transmitter to the output of the receiver (end-to-end) and, with future improvements in architecture and GaN IC technology, this can reach the 95% range. As with the demonstration kits, these boards operate to the Airfuel standard, excluding Bluetooth Low Energy (BLE) communications.

With the wide range of efficient receivers that can be used to power anything from lamps to laptops to tablets, while remaining compatible with cell-phone charging, the system designer now has all the tools needed to create an entire wireless power, large-area, efficient system, says EPC.

www.epc-co.com
/epc/Products/
DemoBoards/EPC9129.aspx
www.epc-co.com/epc/Products/

FLOSFIA demos first gallium oxide normally-off MOSFET

Production of GaO series power devices to start with Schottky barrier diodes in TO220 packages, then MOSFETs

Generating annual sales of more than $20bn, silicon currently dominates the market for power semiconductor devices. However, when deployed in power systems, 10% of electrical energy can be wasted as heat. Addressing this weakness is not easy, because silicon devices are approaching their theoretical limit. Industry has therefore been targeting higher efficiencies using new semiconductor materials.

Gallium oxide (Ga_2O_3) is a promising material for next-generation low-loss power devices. It comes in five different phases, with its β-phase (which takes the corundum crystal structure) having the most attractive material properties. With a wide bandgap of 5.3eV and high electric breakdown field strength, β-Ga_2O_3 can better withstand high-voltage applications, making it possible to replace existing silicon and silicon carbide (SiC) power semiconductors.

Kyoto University demonstrated the first single-crystal growth of β-Ga_2O_3 on sapphire in 2008. In 2015 an β-Ga_2O_3 Schottky barrier diode (SBD) showing record low specific on-resistance of 0.1mΩcm^2 was fabricated by FLOSFIA Inc (a spin-off from Kyoto University in 2011 specializing in forming thin films by mist chemical vapor deposition, which is being commercialized as MISTDRY technology). FLOSFIA then made a big step toward commercialization by launching an engineering sample of an β-Ga_2O_3 SBD in a TO220 package.

Another challenge is to demonstrate an β-Ga_2O_3 metal-oxide-semiconductor field-effect transistor (MOSFET). However, in 2016 FLOSFIA and Kyoto University jointly discovered that p-type iridium oxide (Ir_2O_3), which has the same corundum structure as the β-Ga_2O_3, could be expected to form a Ga_2O_3-based power MOSFET.

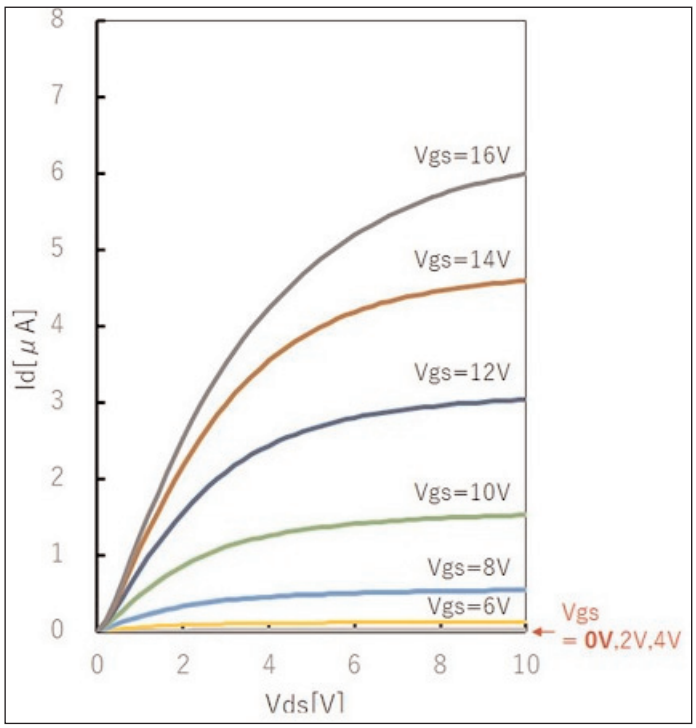

Figure 1. I–V curve of normally-off Ga_2O_3 MOSFET.

FLOSFIA has subsequently demonstrated the first β-Ga_2O_3 normally-off MOSFET (see Figure 1). This consists of an N+ source/drain layer, a p-type well layer, a gate insulator, and electrodes (Figure 2 and Figure 3) The gate threshold voltage (extrapolated from the I–V curve) was 7.9V. The device is made of a novel p-type corundum semiconductor that functions as an inversion layer. FLOSFIA claims that this is groundbreaking since there has been no theoretical study predicting p-type material that is compatible with n-type Ga_2O_3 until it discovered the p-type Ir_2O_3.

FLOSFIA plans to develop its own production lines for manufacturing 'GaO' series β-Ga_2O_3 power devices, starting with SBDs in TO220 packages and then MOSFETs, for use in AC adapters, robot driver circuits, electric vehicles, home appliances, power conditioner for solar cells etc. It is reckoned that GaO has the potential to shrink inverter size tenfold and to halve cost while maximizing conversion efficiency.

www.flosfia.com

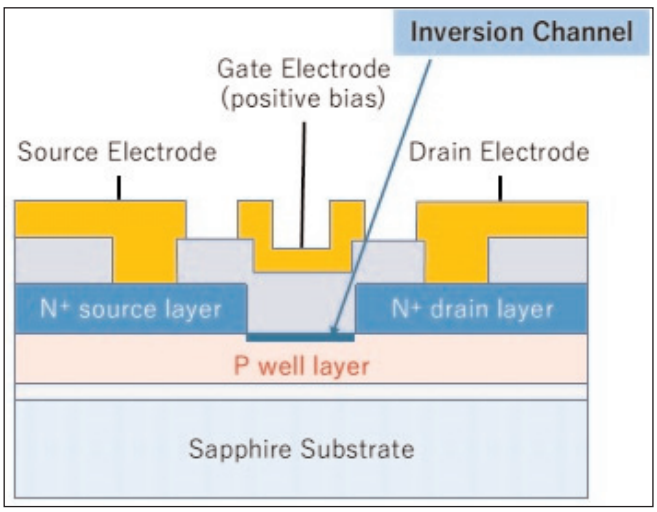

Figure 2. Cross-sectional schematic of device.

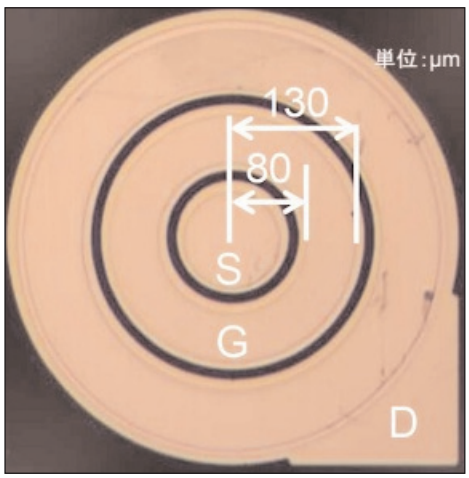

Figure 3. Optical micrograph of normally-off Ga_2O_3 MOSFET.

Reedholm collaborates with Texas State University on production test of wide-bandgap devices

Reedholm Systems of Georgetown, near Austin, TX, USA (which provides parametric and reliability test systems, including those designed for high-power wide-bandgap requirements) has formally engaged with The Piner Research Group on the Texas State University Campus to develop reliability methods and standards for production test of wide-bandgap (WBG) devices as well as to provide technical consulting services to Reedholm Systems.

The group of Dr Eddie Piner is principally focused on research and technology development in the growth and characterization, semiconductor fabrication, and performance optimization and reliability of wide-bandgap materials for solid-state device applications.

Prior to joining Texas State University, Piner spent a decade as director of Advanced Technology for WBG device maker Nitronex LLC. He also worked as a research engineer and project manager at ATMI, specializing in III–nitride epitaxial processes.

The parties recognize the unique needs and challenges faced by WBG device makers and Reedholm's need to refine its measurement instrumentation and long-term reliability stress capabilities specifically for the gallium nitride (GaN), silicon carbide (SiC), GaN-on-Si and other WBG devices and materials.

The terms of the agreement with The Piner Research Group also call for Reedholm to install one of its 10kV/50A WBG Parametric Test Systems for process control and die sort measurements of WBG devices. The system can also be extended for reliability stress test requirements for high-temperature operation lifetime (HTOL), high-temperature reverse bias (HTRB) and high-temperature gate bias (HTGB) requirements for WBG research projects undertaken by Reedholm Systems personnel, the Piner Research Group and Texas State University PhD students.

www.reedholmsystems.com
www.msec.txstate.edu/Research/TETF-Laboratories/Piner-Research-Group.html

AKHAN appoints interim CFO

Dan Gravelle has assumed the role of interim chief financial officer of AKHAN Semiconductor Inc of Gurnee, IL, USA — which specializes in the fabrication and application of lab-grown, electronics-grade diamond as functional semiconductors.

Gravelle, an executive with experience of transforming businesses, will support investments that the firm is making to scale production of its Miraj diamond products and introduce innovative approaches that aim to strengthen its competitive position. He has over 25 years of start-up and late-stage business and financial experience in areas including corporate strategy and finance, mergers and acquisitions, treasury and balance sheet management and new business development. He also has a track record of driving shareholder value creation, strong financial performance, deal-making and building teams.

"We have built a strong executive leadership team, introducing game-changing technology into the global market," says founder & CEO Adam Khan. Gravelle will "support our company in the next-phase of our strategic plan and in building our global enterprise. I look forward to working with him in bridging the ecosystems of Silicon Valley and the Diamond Prairie we are growing in our Northern Illinois headquarters."

www.akhansemi.com

Cadence and NI collaborating to simplify next-gen RFIC and module development and test

Cadence Design Systems Inc of San Jose, CA, USA and RF/microwave electronic design automation (EDA) software provider NI (formerly AWR Corp) of El Segundo, CA, USA have announced a broad-ranging collaboration to improve the overall semiconductor development and test process of next-generation wireless, automotive and mobile integrated circuits (ICs) and modules.

To meet needs for a streamlined and comprehensive solution, Cadence and NI have pursued projects that integrate key design tool technologies into a common user environment to improve the design, analysis and testing of analog, RF and digital ICs and system-in-package (SiP) modules spanning from pre-silicon design to volume production test. To further enhance RF development, Cadence has also launched the new Virtuoso RF Solution, which enables RF engineers to design, implement and analyze entire RF modules and RFICs from within the Virtuoso custom IC design platform.

Integration between Cadence's new Virtuoso RF Solution and NI's AXIEM 3D Planar EM software

Traditionally, each major stage in the IC development process has operated in isolation supported by a unique and dedicated set of design tools, models, languages and data formats, which can cause design failures due to the manual translation of data between numerous disjointed tools. To address this issue and streamline the RFIC and RF module design flow, Cadence delivered the following capabilities within the new Virtuoso RF solution:

- RFIC and RF Module co-design: provides a robust design environment enabling simultaneous editing of multiple ICs on a complex RF module while streamlining design to manufacturing tasks;
- Single 'golden' schematic: offers schematic-driven layout implementation, EM analysis and simulation and physical verification checks of RFIC and RF module design through a single schematic source, reducing design failures;
- Smart electromagnetic (EM) simulation interface: includes an integration between the Cadence Sigrity PowerSI 3D EM Extraction Option and the Virtuoso RF Solution, which automates hours of manual work required to run critical passive component and interconnect EM simulations so users can run multiple in-design experiments.

As part of the collaboration between the two firms, the Cadence interface has been extended to include integration with NI's AXIEM 3D planar EM simulator, within the Cadence Virtuoso RF Solution design environment. The AXIEM software's fast solver technology readily addresses passive structures, transmission lines, large planar antenna and patch array problems with more than 100,000 unknowns, providing the accuracy, capacity and speed engineers need to help them ensure design integrity upon the first attempt. It also incorporates NI's proprietary full-wave planar Method of Moments (MoM) technology that enables discrete- and fast-frequency sweeps.

Cadence and NI are jointly working to deliver common transistor models, ensuring consistent simulation behavior of GaAs, GaN and silicon transistor models between Microwave Office circuit design software and the Cadence Spectre simulation platform

The integrated Cadence and NI EM solutions equip engineers with a variety of EM analysis methods for designing RFICs and RF modules.

Common semiconductor models

Compatible models are critical to ensuring correlated results across different simulation tools. Cadence and NI are jointly working to deliver common transistor models, ensuring consistent simulation behavior of gallium arsenide (GaAs), gallium nitride (GaN) and silicon transistor models between Microwave Office circuit design software and the Cadence Spectre simulation platform.

"With customers beginning to design the next generation of RF products for 5G, autonomous vehicles and other vertical markets, we saw a need to deliver a comprehensive RF solution that creates more efficiencies and drives innovation," says Tom Beckley, senior VP & general manager in Cadence's Custom IC & PCB Group. "Based on the trusted Virtuoso custom IC design platform, the new Cadence Virtuoso RF Solution streamlines design and analysis for RFIC and RF modules. The collaboration between Cadence and NI and the integration of our tools can enable customers to seamlessly analyze and simulate their chip and package, reducing design cycle time and improving quality of results," he adds.

"Customers are continuously seeking new approaches to accelerate their product development cycles," says Kevin Ilcisin, NI's VP of strategy and corporate development. "The collaboration with Cadence allows us to embed our AXIEM 3D Planar EM software directly into the Virtuoso RF Solution, enabling customers to easily design analog, mixed-signal, RFIC and RF modules."

The new Virtuoso RF Solution with the integrated AXIEM 3D planar EM solver technology will be sold and supported exclusively by Cadence to leverage years of development and customer deployment expertise.

www.cadence.com/go/virtuosorfni
www.awrcorp.com/products

VTT orders latest-generation EVG120 automated resist processing system for 'More than Moore'

EV Group of St Florian, Austria — a supplier of wafer bonding and lithography equipment for semiconductor, micro-electro-mechanical systems (MEMS) and nanotechnology applications — has received an order for its EVG120 automated resist processing system from VTT Technical Research Centre of Finland Ltd.

An existing customer of EVG's wafer bonding and alignment systems, VTT is among the first to place an order for the newest version of the EVG120 system, which has been enhanced to provide greater reliability, throughput and process performance compared with the previous-generation platform. VTT will use the new system to increase capacity for supporting parallel R&D projects involving new and different coating materials, as well as to enable new research applications in 'More than Moore' technology areas like MEMS, optoelectronics, photonics and compound semiconductors.

"After a thorough product evaluation of lithography coating systems, VTT selected the EVG120 in a competitive tender, with coating uniformity and repeatability of coating thickness among the key evaluation criteria," says Heini Saloniemi, manager, process engineering, at VTT. The new EVG120 system "will enhance our lithography process capabilities and allow us to explore new avenues of research," she adds.

EVG says that the EVG120 system provides reliable and high-quality coating and developing processes in a universal platform. Its versatility and flexibility, as well as its low cost of ownership, makes it a suitable system for research environments where many development projects may be running in parallel, while its high throughput enables its use in volume production.

The updated EVG120 platform maintains all capabilities of the previous-generation platform, including: compact design for minimal footprint; customizable module configurations for spin and spray coating, developing, bake and chill; EVG's CoverSpin technology, which provides optimized coating uniformity of odd-shaped and square substrates; proprietary OmniSpray technology for conformal coating of extreme topographies; and wafer-edge handling.

In addition, new features on the updated platform include:

- separation of wet processing modules to enable constant conditions chamber to chamber;
- an integrated chemistry cabinet for resist pumps and bottles (including support for high-viscosity resists) for improved process control and short dispense cycles;
- a new robot handling system that provides the highest reliability and increased throughput; and
- optional humidity and temperature control for constant environmental conditions.

"As the leading research institute in Finland, VTT has a strong global network of industry partners throughout the world to transform breakthrough research into new products and services in renewable energy, health care, smart industry and smart city, as well as beyond," comments product management director Thomas Wagenleitner. "EVG is working tirelessly to support our key customers such as VTT in these endeavors," he adds. "As part of that effort, we have leveraged more than 20 years of experience in resist processing to drive continuous improvements to our industry-benchmark EVG120 platform. This allows us to enable even greater levels of coating performance for our customers at a lower cost of ownership, which is critical for both production fabs and research labs at the cutting edge of technology like VTT."

www.vttresearch.com
www.evgroup.com

SDK plans third expansion of high-grade SiC epi production in two years

Current expansion from 5000 to 7000 wafers per month by September to be followed by increase to 9000wpm by February

Tokyo-based Showa Denko K.K. (SDK) is to further expand its capacity for producing high-quality-grade silicon carbide (SiC) epitaxial wafers for power semiconductors — marketed as 'High-Grade Epi' (HGE) — following the current expansion work on HGE production facilities. When the current work finishes in September, HGE production capacity will have increased from 5000 wafers per month (equivalent, for 1200V-breakdown power devices) to 7000 wafers per month. After the additional expansion work, scheduled to finish in February 2019, capacity will have increased to 9000 wafers per month.

Compared with conventional silicon-based semiconductors, SiC-based power semiconductors operate under higher-temperature high-voltage and high-current conditions, while conserving energy substantially. These features enable device makers to produce smaller, lighter and more energy-efficient next-generation power control modules, which allow dispersion-type power sources to utilize new energy sources. Used in power modules for servers in data centers and inverter modules for railcars, SiC-based power semiconductors are also replacing conventional semiconductors in on-board battery chargers and rapid charging stations for electric vehicles (EVs), with the rapid expansion of the EV market.

SDK claims that its SiC epiwafer business is rated by power semiconductor manufacturers for the lowest incidence of crystal defects and the highest wafer homogeneity. In the last two years, SDK has begun expansions of its HGE production facilities twice, in September 2017 and January 2018. The firm has now decided to expand further in response to growing demand, resulting from rapid growth in the market for SiC-based power semiconductors.

www.sdk.co.jp

GTAT opens new silicon carbide manufacturing plant, corporate headquarters and R&D center

Highly scalable plant will meet growing demand for SiC material

GTAT Corp of Hudson, NH, USA (which produces crystal growth equipment for the solar, power electronics and optoelectronics industries as well as sapphire material for precision optics and other specialty industries) has opened its new silicon carbide (SiC) manufacturing plant with a ribbon-cutting ceremony attended by state and local officials. The facility also includes the firm's new corporate headquarters as well as its advanced R&D center.

"The opening of our new silicon carbide production facility represents a significant milestone for the company's transition from an equipment provider to a materials company," says president & CEO Greg Knight. The facility "positions us as one of the only companies in the world with the know-how and capacity to offer high-quality SiC material for a growing number of power electronics applications in high-growth markets," he adds. "Our expertise in crystal growth equipment, managing supply chains and deep domain knowledge in a number of advanced materials has given us a competitive advantage in meeting the growing demand for wide-bandgap semiconductors," he reckons.

GTAT opens SiC manufacturing facility (from left to right): board member Alexandre Zyngier; chief technology officer Dr P.S. Raghavan; president & CEO Greg Knight; VP global operations Joe Loiselle; VP & chief financial officer Michele Rayos; and Whitebox Advisors LLC portfolio manager Amit Patel.

GTAT says that it is continuing to commercialize other technologies such as its new tube filaments used to lower the cost of producing polysilicon and its continuous Cz feeder, which lowers the cost of producing monocrystalline silicon wafers for the solar industry.

www.gtat.com

SILTECTRA reports application of COLD SPLIT wafer thinning technology to GaAs

Same thinness and near-zero material loss shown as for SiC, GaN, sapphire and silicon

At the SEMICON West 2018 tradeshow and conference in San Francisco (10–12 July), wafering technology firm SILTECTRA GmbH of Dresden, Germany revealed new enabling and cost-of-ownership (CoO) advantages for its COLD SPLIT laser-based wafer thinning technology. Collectively, the benefits aim to further enable manufacturers of power semiconductors.

Enabling wafering solution for diverse materials

In the latest demonstration of COLD SPLIT's capabilities, SILTECTRA says that, when applied to gallium arsenide, COLD SPLIT achieved the same thinness and near-zero material loss as previously shown for silicon carbide, gallium nitride, sapphire and silicon.

The data comes from a recent study (funded by the State Government of Saxony) to establish if COLD SPLIT could achieve full crack propagation across the laser plane when applied to GaAs. Participants included a leading materials supplier and a renowned laser institute, as well as SILTECTRA. The results validated COLD SPLIT as a high-performance thinning solution for GaAs and demonstrated that the technique can thin a range of diverse materials with complex properties.

Cost-of-ownership benefits for SiC-based devices

The data builds on feedback from COLD SPLIT customers who found that the novel thinning technique is demonstrating strong CoO advantages compared with traditional grinding. Not only can COLD SPLIT thin wafers to 50μm and below in minutes, it produces virtually no material loss. Grinding is a slower process and can incur material waste of up to 90%. Now, due to the adaptation of 'twinning', COLD SPLIT users can reclaim substrate material generated (and previously wasted) during backside grinding and create a fully optimizable bonus wafer. SILTECTRA believes that these benefits can cut consumables costs by 50% and reduce overall wafering costs by as much as 30%.

"Significantly lower consumables costs are a key driver of COLD SPLIT's compelling CoO, especially for SiC-based devices," says chief technology officer Dr Jan Richter. "While the industry is starting to adopt SiC for power semiconductors, it is an extraordinarily hard substance. Every single micron must be ground and polished, micron-by-micron. Grinding involves expensive diamond-based consumables, and when coupled with the technique's inherent material waste, costs can be high," he adds. "In contrast, COLD SPLIT produces almost no waste, which vastly reduces consumables costs. And because the technique can save virtually every micron of SiC and turn surplus material into a bonus wafer, CoO is further boosted."

Potential electrical performance improvement for power semiconductors

The new data may also have performance implications for end-user devices. "Take low-voltage SiC-based Schottky diodes, for example," says CEO Dr Harald Binder. "With these diodes, low resistance is essential to reducing electrical losses in end-user applications. The thickness of the final device influences resistance. The thinner the device, the lower the resistance. Reducing thickness, therefore, can decrease resistance and reduce electrical losses. This means that, in addition to low-cost/high-speed wafer thinning, COLD SPLIT can potentially also improve the electrical performance of low-voltage devices," he adds.

"Much of our new data is occurring in real time as the industry shifts fast to new materials. That said, the innovation has been happening at SILTECTRA for many years and is protected by 70 patent families covering technology, manufacturing equipment, materials and expertise," Binder continues. "It is gratifying to see our discoveries exceeding even their original promise as we collaborate with manufacturers to help them achieve aggressive roadmap goals."

www.SILTECTRA.com

Leti and Soitec launch Substrate Innovation Center as part of latest five-year partnership

Leti campus aims to be hub for foundries, fabless and system companies prototyping engineered substrates

Grenoble-based micro/nanotechnology R&D center CEA-Leti and Soitec of Bernin, France, which makes engineered substrates including silicon-on-insulator (SOI) wafers, have announced a new collaboration and five-year partnership agreement to drive R&D on advanced engineered substrates, including SOI and beyond.

The agreement extends the traditional Leti–Soitec partnership to include the launch of a prototyping hub associating equipment partners to pioneer new materials. Located on Leti's campus, the Substrate Innovation Center will feature access to shared Leti–Soitec expertise around a focused pilot line. Key benefits for partners include access to early exploratory sampling and prototyping, collaborative analysis, and early learning at the substrate level, eventually leading to streamlined product viability and roadmap planning at the system level.

Leading chip makers and foundries worldwide use Soitec products to manufacture chips for consumer applications targeting performance, connectivity and efficiency with extremely low energy consumption. Applications include smart phones, data centers, automotive, imagers, and medical and industrial equipment, but this list is growing, along with the need for flexibility to explore new applications starting at the substrate level. At the Substrate Innovation Center, Leti and Soitec engineers will explore and develop innovative substrate features, expanding to new fields and applications with a special focus on 4G/5G connectivity, artificial intelligence, sensors and display, automotive, photonics, and edge computing.

Leti's Emmanuel Sabonnadière and Soitec's Paul Boudre at Semicon West.

"The Substrate Innovation Center will unleash the power of substrate R&D collaboration beyond the typical product roadmaps, beyond the typical constraints," says Soitec's CEO Paul Boudre. "The Substrate Innovation Center is a one-of-a-kind opportunity open to all industry partners within the semiconductor value chain."

Whereas a typical manufacturing facility has limited flexibility to try new solutions and cannot afford to take risks with prototyping, the mission is to become the world's preferred hub for evaluating and designing engineered substrates to address the future needs of the industry, inclusive of all the key players, from compound suppliers to product designers. Using quality-controlled cleanroom facilities and the latest industry-grade equipment and materials, Leti and Soitec engineers will conduct testing and evaluation at all levels of advanced substrate R&D.

"Leti and Soitec's collaboration on SOI and differentiated materials, which extends back to Soitec's launch in 1992, has produced innovative technologies that are vital to a wide range of consumer and industrial products and components," comments Leti's CEO Emmanuel Sabonnadière. "This new common hub at Leti's campus marks the next step in this ongoing partnership. By jointly working with foundries, fabless, and system companies, we provide our partners with a strong edge for their future products."

www.soitec.com
www.leti.fr
www.leti-cea.com

Silvaco relocates headquarters within Santa Clara

Silvaco Inc of Santa Clara, CA, USA — which provides electronic design automation (EDA) and IP software tools for process and device development and for analog/mixed-signal, power IC and memory design — has moved to new corporate headquarters at 2811 Mission College Boulevard on the sixth floor of one of the towers of the Mission Corporate Center in the heart of Silicon Valley in Santa Clara.

After 34 years, Silvaco has moved from its company-owned Patrick Henry campus, where it occupied five buildings, to a facility with workspace for all employees under one roof.

The milestone is "aligned with our progress in our leadership for advanced nodes, power and display," says the firm's chief executive officer Dave Dutton. "The new layout allows for a modern-style collaborative working environment to help accelerate our pace of innovation," he adds. "This move will allow us to accommodate our future growths plans."

www.silvaco.com

IQE expects first-half 2018 revenue of £73m, with double-digit sales growth in each primary market

Wireless capacity at Taiwan plant to be expanded by over 40% in 2019

In a trading statement, epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK says that for first-half 2018 it expects revenue of £73m, up 3.7% on £70.4m in first-half 2017, despite a currency headwind of 9.5%. On a constant-currency basis, this reflects double-digit sales growth year-on-year in each of the firm's three primary markets.

The Wireless segment has shown strong growth of nearly 11%, as IQE delivered on its intention to replenish wireless inventory channels following the capacity allocation made to vertical-cavity surface-emitting laser (VCSEL) production in second-half 2017. The Wireless segment remains in a strong position and has been underpinned by the renewal of the supply agreement with its largest customer. This contract has been extended for a further 15 months' supply in addition to expanding to cover a wider range of products and increased share of the customer's epiwafer requirements to IQE.

As a consequence of this extended agreement, together with additional qualifications recently completed with other Wireless customers, IQE's board has approved an expansion program to increase Wireless capacity at the firm's plant in Hsinchu, Taiwan by more than 40% in 2019. This should have two benefits:
(i) delivering further production efficiencies and capacity improvements in the USA for Photonics materials, and
(ii) eliminating cost inefficiencies incurred in converting and re-converting reactors between the two materials systems.

The Photonics segment is expected to deliver growth of 30% year-on-year on a constant-currency basis. Revenue from the largest Photonics customer was broadly flat year-on-year, as the supply chain absorbed inventory following a very steep production ramp up for VCSELs relating to 3D sensing applications in second-half 2017. Excluding revenue from this customer, underlying Photonics revenue is up about 40%. IQE says that this demonstrates the traction it is experiencing across a number of VCSEL chip makers, who took advantage of capacity availability to embark on a significant number of production qualifications, in addition to growth in other parts of the Photonics business.

The Infrared segment delivered growth of about 11% year-on-year, and is expected to show further strong growth in second-half 2018.

"Our highly successful second-half 2017 ramp of 6-inch VCSEL production for a major customer has established IQE as the go-to materials solution provider for this technology," says chief executive Dr Drew Nelson. "It is widely recognised that, with more than 25 years' experience of working with VCSELs and a clear, visible, commitment to world-leading manufacturing capacity on two continents, we are and will remain the premier preferred manufacturer of these materials," he adds. "First-half 2018 has seen a very significant increase in the number and extent of our engagements with VCSEL chip customers." IQE is now engaged with over 20 VCSEL chip makers in Asia, North America and Europe on qualifications for mobile, sensing, automotive and datacom applications. It is already fully qualified and in mass production with six of these companies and in final qualification stages with six more.

"Furthermore, as detailed in our announcement of 9 July, we reached a production milestone for our NIL [nano-imprint lithography] technology, which demonstrates our ability to bring to market some of the leading materials solutions that we have been showcasing and sampling to our customers," says Nelson. "We have significant engagements for our other core technologies, including gallium nitride on silicon (GaN-on-Si), cREO [crystalline rare earth oxide] and QPC, and these are proceeding as planned. The second-half 2018 ramp for Photonics has already started and we look forward to the rest of 2018 and in particular the further ramp up which is expected in 2019."

The capacity expansion at the firm's new 'Mega Foundry' plant in Newport, South Wales, UK is proceeding according to plan. The first five reactors, which will be qualified for Photonics, are now installed and are at various stages of acceptance testing, commissioning and qualification. Initial results on quality and reactor performance remains encouraging, says the firm. A further five reactors will be delivered in second-half 2018, with acceptance testing, commissioning and qualification expected to commence immediately after delivery. Phase one of the build out at the Newport facility will provide 20 fully serviced reactor bays, which should be fully operational during first-half 2019. Further reactors are planned to be installed through the remainder of 2019.

IQE says that it continues to trade in line with current market expectations. The previous guidance provided in the statement of June's annual general meeting (AGM) for a 40:60 H1:H2 2018 revenue split remains unchanged, accompanied by a shift back from Wireless to Photonics, which has already begun during June.

IQE expects to report its half-year 2018 results on 29 August (earlier than the previously announced 5 September due to a number of conflicting events).

www.iqep.com

IQE's Wireless business unit renews contract with tier-1 customer

IQE has renegotiated its long-term supply contract with a premier tier-one customer for the supply of wafer products used in wireless applications, while extending the range of products covered and increasing its overall share of the customers' epiwafer requirements. The contract is estimated to be worth about $60m through to September 2019.

IQE says that the supply contract guarantees it about 80% of the customer's demand for epiwafers and underlines the strength of the long-term customer relationship that it has developed over many years, having consistently been recognized as one of the customer's best performing suppliers.

IQE's Wireless segment continues to leverage its global manufacturing facilities to fulfill the supply contract from its North American facilities in Massachusetts and North Carolina, as well as its main wireless manufacturing site in Taiwan.

The contract covers epiwafer products for RF applications including power amplifiers (PAs), low-noise amplifiers (LNAs) and switches used in a wide range of connected devices such smartphones, tablets, PCs, routers and other Internet of Things (IoT) devices. Demand for compound semiconductor-enabled devices is expected to underpin the roll-out of 5G over the coming years.

"IQE's epiwafer products have been behind the global adoption of 4G/LTE and WiFi systems, and this major supply contract underlines the world-leading performance which IQE products provide for current- and next-generation wireless applications including the global roll-out of 5G," says Daily Hill, head of IQE's Wireless business unit.

www.iqep.com

IQE's NIL technology production qualified by DFB laser manufacturer; first production order received

IQE says that its proprietary nano-imprint lithography (NIL) technology has been production qualified by a leading supplier of distributed feedback (DFB) lasers for the telecoms industry, and the first production order for $250,000 has been received. Production commences immediately.

As critical enabling transmission components for high-speed data communications across the whole fiber-optic network (including intercontinental communications, broadband fiber-to-the-home and -premises, and ultra-high-speed transmission links in hyper-scale data-center applications), exponential future demand for DFB lasers in this sector is expected to be driven by 5G connectivity and the adoption of Internet of Things (IoT).

In addition, says IQE, the high optical quality of the DFB device makes it the edge-emitting laser of choice for commoditization in the consumer sector for a wide range of emerging sensing applications such as 3D sensing, environmental emissions and air-quality monitoring, chemical weapons and explosives detection, and disease diagnosis via breath and blood vessel monitoring.

In addition to DFB applications, IQE is also engaged in multiple other qualification programs incorporating its nano-imprint lithography technology across a range of wafer sizes and end applications.

Suited to mass manufacturing of wafers at 100mm, 150mm and 200mm sizes (and even scalable to 300mm), nano-imprint lithography is a powerful technology for the large-scale and low-cost manufacturing of submicron features in a variety of materials, including compound semiconductors, silicon, glass, oxides and flexible materials such as polymers. IQE says that its proprietary technology can achieve the complex patterns typically produced using expensive and slow-throughput electron-beam lithography, but at a much lower cost and much higher throughput. Applications include a multitude of photonics products, including gratings for DFB lasers, micro- and patterned sapphire substrate (PSS) LEDs, diffractive optical elements (DOE), and quasi-photonic crystals. Using NIL technology, cost-effective, high-volume fabrication of complex photonic and quasi-photonic crystals (QPC) can be realised, unlocking unique and powerful photonic performance at a wafer level.

Regarding the new qualification, the DFB laser manufacturer has found that using IQE's proprietary NIL gratings provides greater precision and dimensional control (which have resulted in higher performance in side-mode suppression ratio (SMSR), a key performance measure of DFB lasers), better pitch and duty-cycle uniformity, and narrower lasing wavelength within the wafer compared with conventional interference holography. All other performance characteristics were similar or better than the conventional holographic production.

"This production qualification marks a significant milestone in the introduction of IQE's proprietary NIL technology into the mainstream telecoms industry," believes Dr Rodney Pelzel, VP global technology at IQE. "Coupled with a wide range of new and exciting technologies such as crystalline rare earth oxides (cREO) and quasi-photonic crystals, which are also manufactured using the nano-imprint lithography technology, IQE's IP portfolio is gaining significant traction, allowing the company to offer new, disruptive technologies to the broad semiconductor marketplace," he adds.

www.iqep.com

Riber opens China subsidiary in Shanghai

Riber S.A. of Bezons, France — which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells — has opened its subsidiary Riber Semiconductor Technology Shanghai.

Located in the Baoshan district of Shanghai, the subsidiary is intended to strengthen Riber's presence in the whole Chinese market and provide Chinese customers with commercial services, after-sales services, in-house and on-site maintenance solutions, completed with an extensive inventory of spares parts and accessories.

The subsidiary will serve Riber's customer base for both MBE and evaporators activities. The firm currently has 21 MBE customers in China, including six industrial customers, comprising an installed base of 48 MBE systems, of which eight are production systems (the largest installed MBE base in China, representing a market share of more than 75%). Regarding evaporators, Riber already has more than a thousand evaporators installed at four customers manufacturing organic light-emitting diodes (OLEDs) and solar cells.

Riber says that, after more than 30 years of commercial success in China, the opening of the subsidiary is an important strategic step to position Riber closer to its customers as well as to grasp the growth opportunities in China's MBE and evaporator markets.

www.riber.com

China's Acken Optoelectronics orders Riber MBE production system

Riber has received an order for an MBE 6000 production system for delivery in 2019 to China's Acken Optoelectronics, which develops laser systems for very-high-speed communications networks.

The MBE system will contribute to the development of new optoelectronic systems serving the Chinese and international markets for 5G, fiber-optic interconnections and data centers.

Riber says that this latest sale in China highlights how its technology offers an effective response to production requirements for the deployment and distribution of 5G on the Chinese market by 2020.

Delft orders Veeco ALD system for researching materials for renewables, storage and advanced energy

Veeco Instruments Inc of Plainview, NY, USA says that the Materials for Energy Conversion and Storage Group (MECS) of Delft University of Technology in The Netherlands has ordered a Fiji F200 plasma-enhanced atomic layer deposition (PE-ALD) system for research on materials for renewables, storage and advanced energy solutions.

"Our colleagues with the Kavli Nanolab at Delft have reported great success working with the Fiji F200 for their nanotechnology R&D, and we are confident the system's capabilities will also serve us well as we pursue new materials for sustainable energy applications," says Fokko Mulder, professor of applied sciences and integrated energy systems at Delft. "In particular, we were drawn to the Fiji's world-class reputation, flexible PE-ALD system architecture, and excellent service and support backed by the technical expertise of Veeco's ALD scientists. After evaluating different options, the Fiji F200 proved the best platform to meet our advanced experimentation needs."

The Fiji series is a modular, high-vacuum ALD system that accommodates a wide range of thermal and plasma-enhanced deposition modes using multiple configurations of precursors and gases. With over 500 systems installed worldwide, Veeco's ALD platforms are used in a wide variety of research and industrial environments, including 3D nanofabrication, electronics, batteries, solar cells, energy and compound semiconductors, as well as new applications to solve some of the world's most pressing technology and resource challenges.

"The MECS group is one of the top research departments in the world working to meet the growing demand for renewable sources and energy storage solutions," comments Gerry Blumenstock, VP & general manager of MBE and ALD products at Veeco. "We look forward to helping professor Mulder and his team at Delft to maximize the benefits of ALD for this important research."

According to the US Energy Information Administration, global energy consumption will increase by 28% between 2015 and 2040, and renewables are the fastest-growing energy source, with adoption expected to increase by an average of 2.3% each year through 2040. The intermittent nature of renewables is also driving the importance of advanced energy storage research and solutions. The global market for energy storage of renewables is predicted by Navigant Research to grow exponentially from its current nascent stage to reach $23bn by 2026.

www.veeco.com
www.tudelft.nl

NexGen using Aixtron's AIX G5 HT MOCVD platform for vertical GaN-on-GaN transistors

Deposition equipment maker Aixtron SE of Herzogenrath, Germany is providing high-end metal-organic chemical vapor deposition (MOCVD) technology to NexGen Power Systems Inc of DeWitt, NY, USA (which was founded in 2017) for the continued development of gallium nitride (GaN)-based electronic devices enabling more compact, lighter and cost-efficient power conversion systems. NexGen has ordered Aixtron's AIX G5 HT planetary platform, scheduled for shipment in third-quarter 2018.

Aixtron claims that, as the only MOCVD system on the market embedding wafer-level control, the AIX G5 is highly efficient for the epitaxy of GaN-on-GaN, GaN-on-Si and GaN-on-SiC for power electronic and RF applications. The fully automated tool offers in-situ cleaning for the best process robustness and defect control while it is also equipped with the latest Laytec InSide P400 UV pyrometer for non-contact temperature measurement. Coupled with Aixtron's Auto Feed-Forward (AFF) individual on-wafer temperature control, this enables a matching of all epitaxial wafers — within a run as well as run-to-run.

"Our disruptive True GaN VJFET (vertical junction field-effect transistor) technology is able to outperform silicon, silicon carbide or GaN-on-silicon technology by providing higher breakdown voltage, lower on-resistance and higher switching frequency," claims NexGen's CEO Dinesh Ramanathan. "NexGen's True GaN power devices enable the design of compact power conversion systems while increasing their efficiency with applications in data-center power supplies, motor drivers, solar inverters and electric car drive-trains. Aixtron's planetary technology in combination with its batch reactor concept will provide us both the performance control we need as well as the cost effectiveness to ensure a rapid adoption of our groundbreaking power devices," he believes.

"We are looking forward to support NexGen's efforts to revolutionize existing power conversion systems," comments Aixtron's president Dr Felix Grawert. "In recent years, our AIX G5 HT planetary tools have built a solid reputation as precise, reliable and cost-efficient manufacturing equipment in the semiconductor industry — unlocking a more rapid adoption of GaN devices against their silicon equivalents," he adds.

www.nexgenpowersystems.com
www.aixtron.com

Changelight orders further Aixtron AIX 2800G4-TM MOCVD systems to expand ROY fine-pitch and mini-LED capacity

Aixtron is supplying several more AIX 2800G4-TM cluster metal-organic chemical vapor deposition (MOCVD) systems (for delivery between third-quarter 2018 and first-quarter 2019) to Chinese optoelectronic manufacturer Xiamen Changelight Co Ltd, which is expanding its production capacities for arsenide-phosphide-based red, orange and yellow (ROY) LEDs and solar cells.

All production systems have a wafer configuration of 15x4-inches, enabling maximum yield at the highest quality level. Aixtron claims that, due to the unique production performance and high manufacturing capacity of its automated Planetary Batch Reactor concept, the AIX 2800G4-TM has established itself as a reference system for the production of red, orange and yellow LEDs in recent years.

Aixtron's AIX 2800G4-TM MOCVD system.

"We have been using Aixtron's equipment technology to manufacture advanced optoelectronic devices for years and therefore have great confidence in the AIX 2800G4-TM," comments Changelight's president Jin Zhangyu. "The outstanding performance of the system in terms of wafer homogeneity and efficiency in material consumption combined with maximum flexibility and versatility in production will help us to position Changelight as one of the world's leading suppliers of ROY LED for fine-pitch, mini-LED and micro-LED applications," he reckons.

"Aixtron is the largest supplier of MOCVD systems for the production of ROY LEDs and laser diodes worldwide," says the firm's president Dr Bernd Schulte. "The strategic partnership with Changelight, the largest customer for gallium arsenide-based MOCVD systems in China, helps us to consolidate and expand our leading market position. We will continue to actively support Changelight with our know-how in the future."

www.changelight.com.cn/en

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AES showcases Industry 4.0-ready gas delivery equipment control technology

At SEMICON West in San Francisco (10–12 July), Applied Energy Systems (AES) of Malvern, PA, USA — which provides high- and ultra-high-purity gas delivery systems, services and solutions (including design, manufacturing, testing, installation and field services) — showcased Industry 4.0-ready control technology for its SEMI-GAS ultra-high-purity gas delivery systems.

"With so much discussion in the semiconductor industry centered around Industry 4.0 techniques and how they can be adopted to transform manufacturing processes, we felt it was the perfect time to highlight our control technology," says general manager Jim Murphy. "These controllers are what allow our SEMI-GAS systems to interface with each other, as well as with other machines and facility management systems used across the fab, to share system performance data and enable the interconnectivity that drives Industry 4.0 efficiencies."

AES had three of its SEMI-GAS GigaGuard Controllers on display at its booth, including GSM and GSM-V Gas Safety Monitor Controllers, which are used to manage the continuous, safe delivery of process gases, and the programmable logic controller (PLC), which can be programmed to monitor customer-specific inputs and perform automatic safety functions and switchover related to ultra-high-purity process gas delivery. All of AES' GigaGuard Controllers are engineered for use in advanced semiconductor, electronics and high-tech manufacturing environments, and conform to SEMI S2 standards. Continuous data collection and remote system monitoring capabilities make them SCADA-ready and able to provide fab operators with instantaneous insights into system performance in order to increase production uptime. Additionally, the controllers are also Industry 4.0 compatible and can be easily integrated with other systems used to monitor and manage production processes.

"Our GigaGuard Control Technology is optimized to support smart manufacturing in fabs, giving operators the control to maintain system efficiency, the data to facilitate uninterrupted production, and the communications link needed to ensure operations involving gas delivery are seamlessly integrated within the larger production process," says Murphy.

www.semiconwest.org
www.appliedenergysystems.com/

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3D-Micromac unveils microPREP 2.0 laser-based high-volume sample prep system for failure analysis

At SEMICON West in San Francisco (10–12 July), 3D-Micromac AG of Chemnitz, Germany (which provides laser micromachining and roll-to-roll laser systems for the semiconductor, photovoltaic, medical device and electronics markets) launched the microPREP 2.0 laser ablation system for high-volume sample preparation of metals, semiconductors, ceramics and compound materials for microstructure diagnostics and failure analysis (FA).

Built on a highly flexible platform with a small table-top footprint, the microPREP 2.0 allows for easy integration into FA workflows, says the firm. Developed jointly with Fraunhofer Institute for Microstructure of Materials and Systems (IMWS) in Halle (Saale), Germany, the microPREP 2.0 complements existing approaches to sample preparation such as focused ion beam (FIB) micromachining, offering up to 10,000 times higher ablation rates and therefore an order-of-magnitude lower cost of ownership (CoO) compared with FIB, it is reckoned. As what is claimed to be the first stand-alone, ultrashort pulsed laser-based tool for sample preparation, the microPREP 2.0 has additional unique capabilities such as enabling large-area and 3D-shape sampling to allow for more comprehensive testing of complex structures.

Cutting and preparing samples from semiconductor wafers, dies and packages for microstructure diagnostics and FA is an essential but time-consuming and costly step. The primary method of sample preparation used in semiconductor and electronics manufacturing currently is FIB micromachining, which can take several hours to prepare a typical sample. FIB only allows for very small sample sizes, and FIB time is wasted by 'digging' excavations needed for cross-sectional imaging in a scanning electron microscope or making a TEM lamella. Reaching larger depths or widths is severely restricted by the limited ablation rate.

3D-Micromac says that its microPREP 2.0 significantly accelerates these critical steps. By off-loading the vast majority of sample prep work from the FIB tool and relegating FIB to final polishing or replacing it completely depending on application, microPREP 2.0 reduces time to final sample to less than 1 hour in many cases, it is reckoned.

"This award-winning tool brings unprecedented flexibility into sample prep. We at Fraunhofer IMWS are facing the need for targeted, artifact-free and most reliable preparation workflows to be able to serve our industry customers with cutting-edge microstructure diagnostics," says Thomas Höche of Fraunhofer IMWS. "Made for diverse techniques like SEM inspection of advanced-packaging devices, x-ray microscopy, atom probe tomography and micro mechanics, microPREP was developed jointly with 3D-Micromac to close gaps in preparation workflows."

Last month, 3D-Micromac and Fraunhofer IMWS received the TUV SUD Innovation Award for their collaboration on the development of microPREP 2.0. The annual prize honors cooperation between small- and medium-size enterprises and research institutions. It is administered by TUV SUD, a technical service corporation serving the industry, mobility and certification segments.

Key benefits of microPREP 2.0 are:

- much higher ablation rate compared with FIB (by several orders of magnitude);
- high degree of automation due to a recipe-based, ergonomic user interface;
- extremely high energy densities can be focused in very small areas (allowing for operation in the multi-photon absorption regime needed to machine at-wavelength-transparent materials and enabling stable process windows);
- virtually no structural damage from local heating due to the platform's very short pulse lengths (pico-second range);
- providing larger-sized samples with micron-level precision — enabling multi-site FA on whole chip or package areas in a much shorter period of time and a multitude of workflows delivering samples for various FA techniques;
- enables the creation of samples with complicated/3D shapes to enable more comprehensive analysis of certain structures, such as through-silicon vias (TSVs) or even complete systems-in-package (SiP);
- laser processing without elemental contamination.

3D-Micromac says that microPREP 2.0 can be used for a variety of sample preparation applications, including: in-plane geometries and bulk samples; cross-sections; box milling (e.g. for diagnostics of electrical connections and 3D chip-level structures); and full line cut (for complex investigations of complete devices). Samples can be moved between microPREP 2.0 and FA tools using the same pin stubs and holders, which provides even greater ease of use and time savings.

"The growing complexity of microelectronics manufacturing is driving the need for faster, more reliable and cost-effective, and artifact-free sample preparation techniques at the micron scale," says chief sales officer Jan Klinger. "Building on our extensive expertise in laser micromachining, 3D-Micromac can now offer an optimal sample preparation solution for this market," he adds. "By off-loading the coarse and time-consuming task of sample preparation to a simple and fast support tool, microPREP frees up our customers' time to focus their efforts on fab-critical issues like trouble-shooting process and yield problems."

www.imws.fraunhofer.de
http://3d-micromac.com/laser-micromachining/products/microprep

3D-Micromac introduces selective laser annealing system

3D-Micromac AG of Chemnitz, Germany (which provides laser micromachining and roll-to-roll laser systems for the semiconductor, photovoltaic, medical device and electronics markets) has unveiled the microPRO RTP, its new laser annealing system designed to enable several key process steps in semiconductor, power device and MEMS manufacturing. Combining a laser optic module with 3D-Micromac's modular semiconductor wafer processing platform, the microPRO RTP provides selective annealing with high repeatability and throughput in a versatile system.

The microPRO RTP features a line-scan option for vertical selective annealing and a step-and-repeat spot option for horizontal selective annealing, as well as three optional laser wavelengths (near-infrared, green and ultraviolet). It addresses applications including:

- Dopant activation for insulated-gate bipolar transistors (IGBTs), as well as activation of backside-illuminated (BSI) CMOS image sensors and amorphous silicon (a-Si) — the microPRO RTP uses a high-speed line scan with what is claimed to be excellent energy homogeneity and repeatability to provide precise localization of the field stop layer, which minimizes heat transference to the front-side of the wafer.
- Ohmic contact formation in silicon carbide (SiC) power devices to improve resistance - using spot scanning with short laser pulses, microPRO RTP can process the entire metalized backside of SiC wafers, forming ohmic interfaces and curing grinding defects, while preventing the generation of large carbon clusters and heat-related damage to the front-side of the wafer.
- Giant magneto resistive (GMR) and tunneling magneto resistive (TMR) sensor manufacturing - using a selective step-and-repeat spot and variable laser energy, microPRO RTP can selectively heat functional areas on the sensor to form and orient the magnetic fields for these MEMS sensor types.

"As microelectronics adopt 3D/stacked architectures to achieve more functionality, manufacturers need annealing solutions that can process the surface layers of their devices without affecting buried structures underneath," says product manager Hans-Ulrich Zühlke. "The migration to new materials and heterogeneous integration adds even more complexity to the annealing process, driving the need for selective exposure of functional areas, which only selective laser annealing can provide," he adds. "Leveraging our years of experience in providing laser solutions to the semiconductor and microelectronics market, 3D-Micromac is pleased to offer our new microPRO RTP laser annealing solution, which provides the selectivity, flexibility and throughput our customers need to meet their unique annealing requirements."

Advantages that the microPRO RTP is said to provide compared with existing annealing methods include:

- high precision and repeatability in both X and Y directions;
- high selectivity to different substrates and films, with multiple options for laser pulse length, energy and overlap to ensure no damage to the area surrounding the target site;
- very high energy homogeneity'
- precise process monitoring; and
- flexibility to handle substrate diameters ranging from 50mm up to 300mm.

3D-Micromac exhibited the new system at the SEMICON West 2018 tradeshow in San Francisco, CA, USA (10–12 July).

https://3d-micromac.com/laser-micromachining/products/micropro

Nitride Semiconductor files patent infringement lawsuit against Digi-Key and RayVio in Tokyo

On 12 July, Nitride Semiconductor Co Ltd of Tokushima, Japan filed a patent infringement lawsuit with the Tokyo District Court against US-based electronic component distributor Digi-Key Corp (trading as Digi-Key Electronics), which sells ultraviolet light-emitting diode (UV-LED) products on the Internet that are manufactured by UV-LED maker RayVio Corp of Haywood, CA, USA.

Nitride is seeking injunction (including destruction of infringing products) and damages, asserting that Digi-Key and RayVio infringe Nitride's patent (JP 3,285,341, 'Method for Manufacturing Gallium Nitride Compound Semiconductor') by manufacturing and selling the UV-LED products.

Based on the US patent corresponding to the above Japanese patent, on 23 May 2017 Nitride has previously filed a patent infringement lawsuit with the US District Court, Northern District of California against RayVio, and on 22 September 2017 Nitride filed a patent infringement lawsuit with the US District Court for the District of Minnesota against Digi-Key.

Nitride says that, with professor Shiro Sakai at Japan's Tokushima University, in 2000 it succeeded in developing the first highly efficient UV-LED, and has since continued to manufacture and sell UV-LEDs involving huge investment in R&D. The firm says that it will take resolute actions to against infringers in any country, where appropriate and necessary, to protect its patents and other intellectual property rights.

www.digikey.com
www.rayvio.com
www.nitride.co.jp

Seoul Viosys' Violeds UV LED technology used in Yuhan's mosquito trap

Seoul Viosys Co Ltd says that its Violeds UV LED technology has been applied in the mosquito trap of South Korean pharmaceutical company Yuhan Corp.

Products with Violeds technology were first launched in summer 2016, when Zika virus was prevalent around the world. Violeds has also been used in NASA's International Space Station (ISS).

Applied to the mosquito trap, Violeds represents eco-friendly insect attraction technology that can eliminate harmful insects such as mosquitoes and fruit flies using a UV LED light source. It has the advantage of being harmless to the human body because the amount of UV rays is two-thousandths that of sunlight and one-tenth that of fluorescent lighting.

"The product is harmless to the environment and human body as it does not contain chemical components and it attracts mosquitoes using a UV LED light source, unlike mercury-based mosquito traps," says Seoul Viosys' UV sales vice president Sang Kwon Park.

The performance verification test by professor Dong Kyu Lee of Kosin University (advisor for the Malaria Control Center at the Korea Centers for Disease Control and Prevention) showed that the capability of Violeds to attract mosquitoes is up to four times higher than that of conventional mosquito traps.

In addition, University of Florida entomologist professor Philip Koehler has proved that products using Violeds technology are more than thirteen times more attractive for yellow fever mosquito and more than nine times more attractive for anopheline-type mosquitoes than the standard device of the US Centers for Disease Control (CDC). Seoul Viosys says that it also got the same result from mosquito attraction performance tests conducted with professors in South Korea, Vietnam and Indonesia.

www.seoulviosys.com/en/technology/violeds

Monocrystal wins Russia's Industria-2018 award

During the international industrial expo 'Innoprom-2018' in Ekaterinburg on 9 July, Monocrystal Inc of Stavropol, Russia (which manufactures large-diameter synthetic sapphire substrates and ingots for LED, optical products and RFIC applications) received the 'Industria-2018' national industrial award of the Russian Federation from vice-primeminister Dmitriy Kozak.

The Industria-2018 award was established in 2014 by Russia's Ministry of Industry and Trade to promote the introduction of advanced technologies in industrial production, and for public recognition of best practices of Russian companies in the field of industrial development.

The award was given governmental status in 2015. Nominees are evaluated according to four main criteria: technological novelty, economic effect, cross-sectoral nature of the project, and focus on the global market.

www.monocrystal.com

RIT's Jing Zhang wins NSF CAREER award for research on novel UV photonics technology

Jing Zhang, a faculty member at Rochester Institute of Technology, has received a CAREER award from the US National Science Foundation (NSF) for work to develop new, highly efficient ultraviolet light sources.

Zhang's NSF award of $500,145 is for five years for "Development of high-efficiency ultraviolet optoelectronics: physics and novel device concepts". The project's goal is to realize high-efficiency UV photonic devices. The Faculty Early Career Development (CAREER) Program is one of the NSF's most prestigious awards in support of early-career faculty who have the potential to serve as academic role models in research and education and to lead advances in the mission of their department or organization.

Devices that Zhang's research group are creating have the potential to demonstrate that a deeper, fairly unrealized range of the UV light spectrum is as efficient as existing near-UV used in today's LED lights. Increasing the efficiencies of optoelectronic devices, specifically using ultraviolet LED technologies, could advance important applications in photolithography, 3D printing, purification systems and sensing applications.

The further along the UV range, the less efficient the technology being produced; however, preliminary physics analysis and tests on device prototypes show promise, Zhang explains.

Jing Zhang.

"What I propose to do is on semiconductor-based UV optoelectronic devices, which are efficient, compact and the lifetime of the devices is very long compared to mercury-based, UV light sources," says Zhang, an assistant professor in the electrical and microelectronic engineering department in RIT's Kate Gleason College of Engineering. "Semiconductor materials are environmentally friendly compared to mercury-based UV bulbs. That is why this new type of device we are developing is very promising — if we can deliver higher efficiencies toward those devices."

The UV light spectrum is being explored further because differing aspects react well with certain bio and chemical agents, which are beneficial for biomedical applications. UV light has also been used for air and water purification systems and to cure resins for 3D printers. Advancing these technologies is becoming more important, but the efficiencies of the UV LEDs are low compared to existing visible LEDs, a mature technology that has been commercially available for more than two decades.

"Shorter wavelengths with the UV devices have efficiencies less than 10%, sometimes even as low as 1%," notes Zhang. "This is the reason why we really don't have reliable, commercially available UV LEDs based on semiconductors yet," she says, adding that the material used for existing LED chips is indium gallium nitride — a narrower-bandgap material. In this new project, Zhang will explore use of the much wider-bandgap material aluminum gallium nitride.

However, AlGaN is less developed because the material is more difficult to grow and often has more defects and dislocations. Zhang has been able to make inroads in this area.

RIT has capabilities in its Semiconductor Manufacturing and Fabrication Laboratory (SMFL), located in the engineering college. In 2016, Zhang also attained an NSF grant to acquire an inductively coupled plasma reactive ion etching (ICP-RIE) system. Researchers can therefore fabricate prototype devices in-house at RIT.

"We have already developed the fabrication process for the UV LEDs; it is already mature in our group," says Zhang, whose research expertise is in III–nitride semiconductors for photonics and energy applications. "We have developed the physics, and we have promising preliminary results on very initial UV LEDs," she adds. "We are going to continue the research with these results and see how we can achieve optimized novel device structures."

www.smfl.rit.edu

Cree's chief financial officer Mike McDevitt retires

Cree Inc of Durham, NC, USA (which makes lighting-class LEDs, LED lighting and power semiconductors) says that executive VP & chief financial officer Mike McDevitt is retiring from his executive positions following a transition period. He is staying until his successor is appointed, after which he will be available as a consultant during the transition of leadership roles.

Since joining Cree in 2002, McDevitt has held many executive financial positions, helping to grow it from less than $200m to about $1.5bn in annual revenue, with about 6900 staff worldwide. McDevitt has served as CFO since May 2012.

"Mike has made significant contributions to the continued success of the company during his role as CFO, and we appreciate his dedication to helping us solidify and introduce the new business strategy," says CEO Gregg Lowe. "Now that we have made our pivot, we are gaining traction in the market with the new strategy and believe that we have collectively positioned the company to support our growth plans and achieve a successful future," he adds.

"It is the appropriate time to begin this CFO transition as the team continues executing the new strategic direction," says McDevitt. "It has been a privilege working with Cree's many talented employees and our board for the last 16 years, first driving the adoption of LEDs, then LED Lighting and more recently our Power and RF products."

www.cree.com

Cree names Neill Reynolds as chief financial officer

Cree has appointed Neill Reynolds as chief financial officer (from 27 August), succeeding Mike McDevitt.

He joins from NXP Semiconductors N.V., where he serves as senior VP of finance, strategy & procurement, and has led global teams to develop and drive profitability initiatives to expand profit margins and deliver on growth objectives.

His career includes over 15 years as a finance leader with international technology firms including General Electric, where he held CFO roles in various businesses and served on management teams that consistently delivered profit enhancements for global industrial and manufacturing businesses, spanning multiple technology industries.

"Neill is an exceptional leader with vast experience within the markets Cree serves," comments CEO Gregg Lowe. "Neill's industry knowledge will help position Cree for continued success and support our growth plans," he believes.

"We thank Mike for his substantial contributions to Cree's success over the past 16 years."

Cree boosts output by 25% and efficacy by 9% with new version of XLamp XP-G2 LED

LED chip, lamp and lighting maker Cree Inc of Durham, NC, USA has launched the new high-efficacy (HE) version of the XLamp XP-G2 LED that delivers improved performance compared with standard XP-G2 LEDs, with higher output and greater efficiency to enable smaller, lighter, lower-cost designs.

The original XLamp XP-G2 LED pioneered a broad set of LED applications, including outdoor and area lighting, and has since served for manufacturers requiring superior output, efficacy and optical control. The new XP-G2 HE extends this with a drop-in upgrade for existing XP-G2 LED systems, allowing designers to quickly implement Cree's newest Dmax high-power LED chip technology while maintaining the color quality and optical control demanded by applications such as outdoor, indoor, architectural and portable.

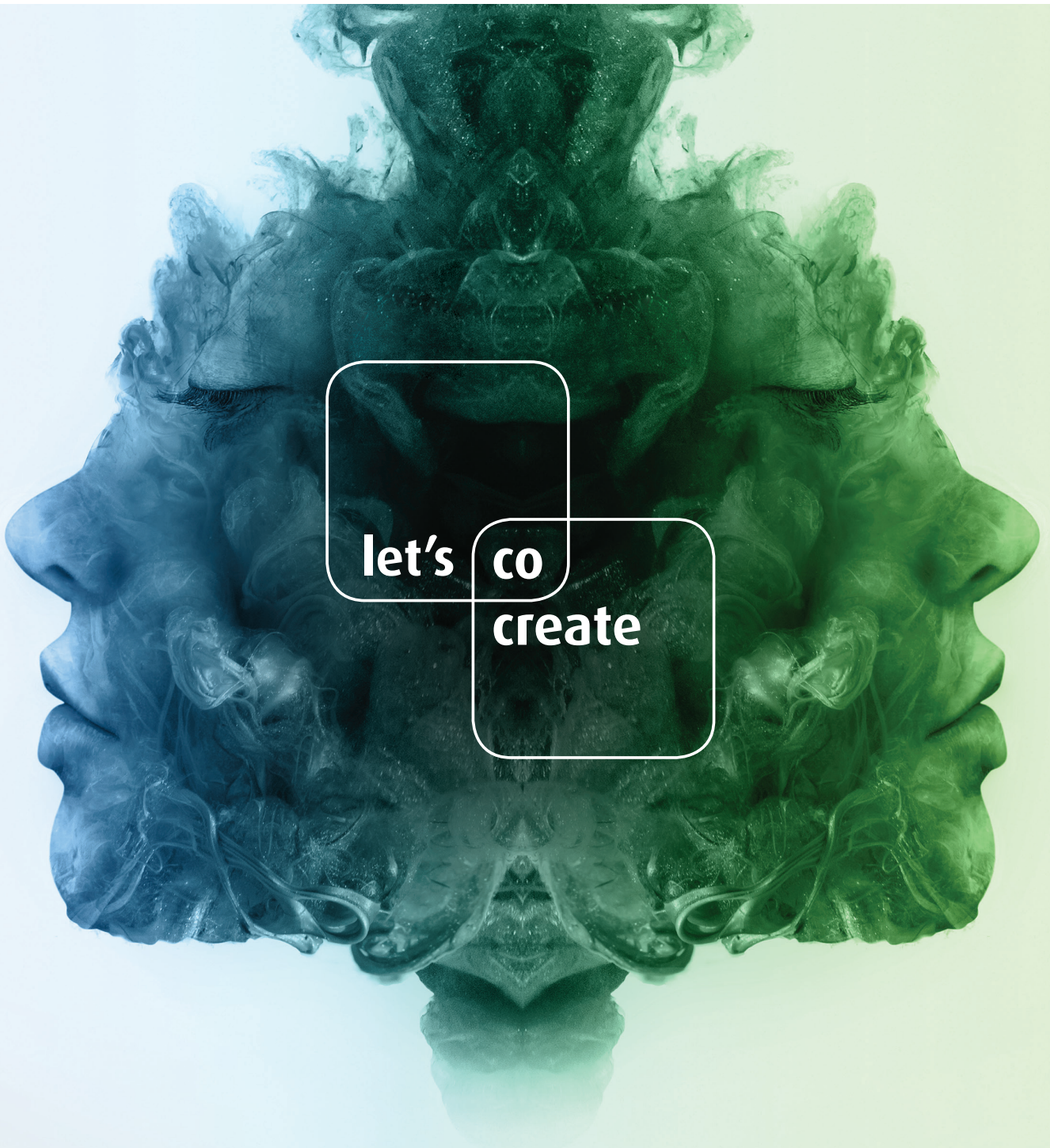
"Our architectural and high-end outdoor lighting products are used in very demanding environments where long lifetime and perfect light output are required," comments Dante Cariboni, CEO of Cariboni Group. "The quality of light and optical control of the XLamp XP-G2 LED make it the ideal light source for our designs to meet these tough requirements," he adds. "Cree's new XP-G2 HE enables us to easily upgrade existing designs for greater efficacy and exceptional color quality."

The XP-G2 HE LED leverages Cree's latest chip technology to deliver 25% greater output via a higher maximum current of 2000mA, plus up to 9% higher efficacy and lower thermal resistance.

"The XLamp XP-G2 LED served as a breakthrough product that enabled a broad set of new LED applications. Today, Cree continues our commitment to make our latest LED technology available in form factors that are easy for our customers to use while enabling smaller, lighter, lower-cost designs and delivering the color quality that Cree is known for," says Dave Emerson, executive VP & general manager, Cree LEDs. "Cree's new XP-G2 HE further strengthens the industry's best 3.45mm high-power LED portfolio, which delivers leading lumen density and reliability for high-power general lighting applications."

Product samples are available now and production quantities are available with standard lead times.

www.cree.com/led-components/



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Osram Continental joint venture begins operation

The 50:50 joint venture Osram Continental GmbH between Munich-based semiconductor-based lighting firm Osram GmbH and Hannover-based automotive technology firm Continental AG (which is fully consolidated through Osram) has completed negotiations and the issuance of merger control approvals. Effective 2 July, the new firm is actively doing business with a focus on intelligent lighting solutions in the automotive market.

Planning to move its headquarters from Munich to Garching, Germany, within the next year, Osram Continental will initially employ about 1500 people in 16 locations worldwide. It aims to generate annual sales in the mid-triple-digit-million-euro range, then to grow at up to double digits annually for the next five years, based on strong growth in the market for LEDs as well as laser-based lighting modules and solutions and associated electronics. The initial products from the joint venture are expected to be ready for series production by 2021.

"Over the past few months, we have laid down a number of milestones, allowing us to create a new company that will revolutionize the future of automotive lighting," says CEO Dirk Linzmeier. "Building on these fundamentals, Osram Continental will provide a significant boost to the market," he adds.

"With our team of experts from both companies, we will increase the efficiency, innovation and integration of our products," says Harald Renner, chief financial officer and member of the general management of Osram Continental.

The market for vehicle lighting in the automotive industry is currently in a period of transition as it moves toward semiconductor-based lighting technologies, so software and electronics are becoming increasingly influential. By partnering, Continental and Osram are combining their strengths to develop headlamp modules and solutions for tail and interior lighting for both automotive manufacturers and suppliers.

The joint venture aims to utilize advances in digitalization to produce intelligent car lighting solutions, allowing multi-functionality from a single source. With its optimized approach, and by combining lighting and intelligent electronics, Osram Continental also aims to ensure market penetration of LED technology into all vehicle segments.

The joint venture will not only use software-based solutions to create a configurable light distribution system — for anti-glare dipped headlamps and high beam headlamps, for example — but it is also developing intelligent lighting functions. Using data from the navigation system and sensors, vehicles equipped with these solutions in the future will, for example, be able to project warning messages for other road users while driving.

www.osram.com

Epistar spinning off foundry subsidiary Jingcheng Semiconductor

Focus on VCSELs and GaN-on-Si targeted at boosting parent company's revenue, profitability and return on equity

The board of directors of Taiwan-based LED epitaxial wafer and chip manufacturer Epistar Corp has passed a resolution to allocate NT$1bn in enterprise value (about US$33m) to its newly established subsidiary in exchange for 100 million shares of Jingcheng Semiconductor, whose newly issued common stock will be traded at NT$10 per share. Jingcheng's president will be Dr Ming-Jiunn Jou, who has hence stepped aside as president of Epistar.

Beginning operation on 1 October, the spin-off's task is to commit itself to professional services and better resource allocation. With the aim of boosting the parent company's revenue, profitability and return on equity, Jou will exploit Epistar Group's core technologies to concentrate on the development of foundry business including 4-inch and 6-inch epitaxial wafers for vertical-cavity surface-emitting lasers (VCSELs) and gallium nitride on silicon (GaN-on-Si) power electronics.

Epistar has been led by two presidents - for its first 10 years by Dr Biing-Jye Lee (now chairman) and for the last 10 years by Dr Ming-Jiunn Jou — during which time the firm has undergone several mergers in the LED industry and become the world's largest manufacturer of LED epiwafers and chips.

Effective 16 July, for 'Epistar 2.0', Jou will be succeed as president of Epistar by vice president Chin-Yung (Patrick) Fan, who has been working at the firm for 20 years including being in charge of aluminium gallium indium phosphide (AlGaInP) and indium gallium nitride (InGaN) production, quality management, and marketing. Epistar says that, with his extensive leadership and industry experience, he will establish and execute a vision for the firm going forward, extending to different businesses based on Epistar Group's core technologies (evolving from 'Actualize LED Potential' to 'Actualize III-V Semiconductor Potential').

www.epistar.com.tw

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FerroTec

InteGreat yields new approaches to LED production

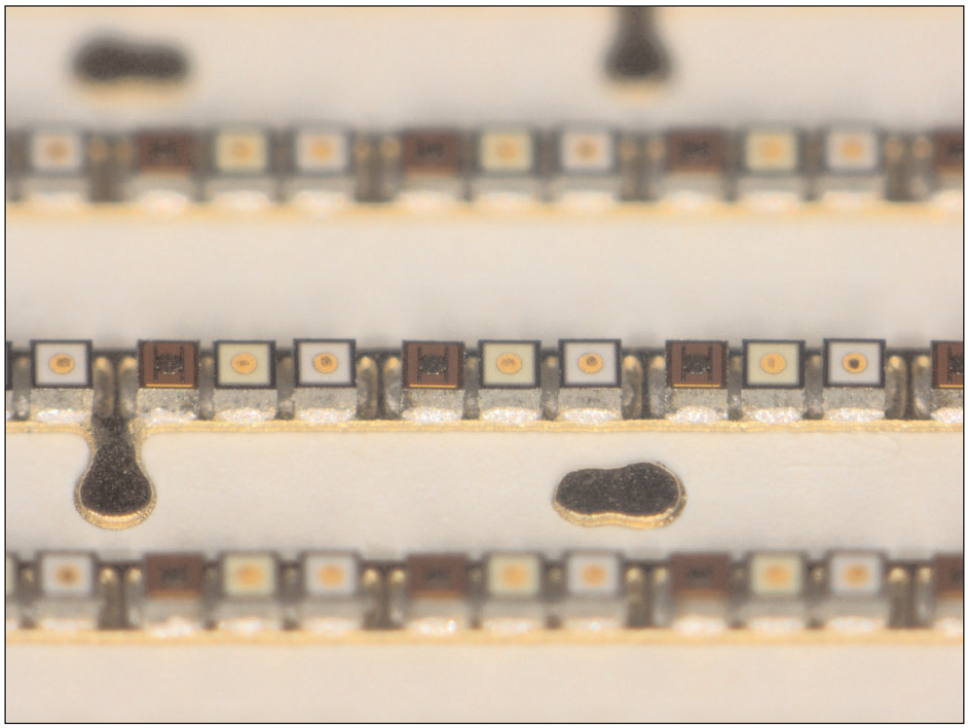
Replacing bond wire by thin flat metal connection moves emitter to surface of package

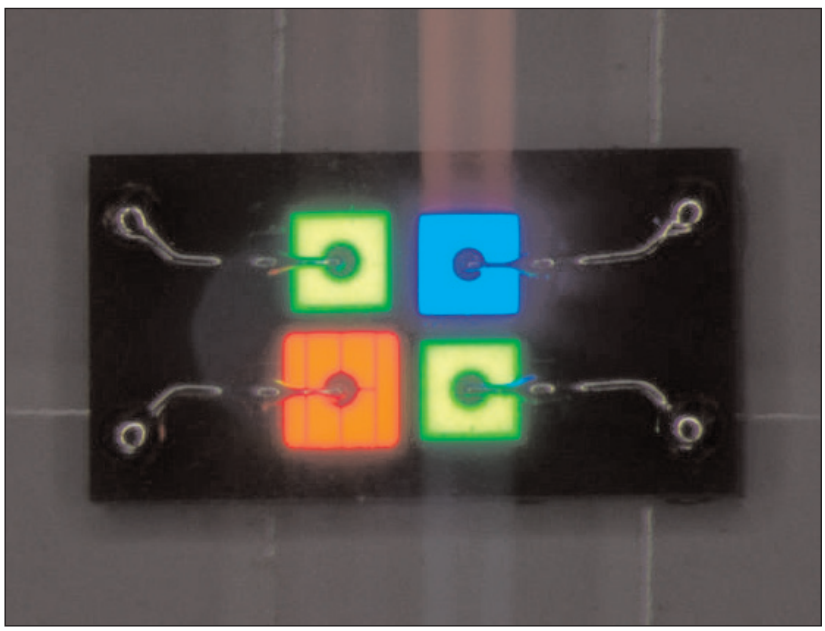
Results have been announced for the research project 'Integrated High-Volume Production along the LED Value-Added Chain for Large Wafers and Panels' (InteGreat), which ran between December 2014 and February 2018 supported by the German Ministry for Education and Research (BMBF) as part of the 'Photonic Process Chains' initiative.

The project consortium comprised seven partners from science and industry: Osram Opto Semiconductors GmbH of Regensburg, Germany (project coordinator), Osram, the Fraunhofer Institute for Integrated Systems and Device Technology (IISB), the Fraunhofer Institute for Reliability and Microintegration (IZM), Würth Elektronik, LayTec AG and Mühlbauer GmbH & Co KG.

The partners investigated time-honored manufacturing approaches and know-how along the entire LED production process with the aim of identifying potential areas for optimization. New approaches that were investigated included manufacturing very small surface-emitting LED chips and packaging technologies, among other things. The insights allow for LED products to be given additional properties that would have been difficult or even impossible to achieve with the technologies previously used to produce LEDs.

At the heart of the project was wafer-level packaging as well as investigations into planar contacts. One of the pioneering approaches to emerge from the project is planar interconnect technology in which the bond wire is replaced by a thin flat metal connection. This moves the surface emitter to the surface of the package. The light can therefore be used more directly, unlike with conventional components. This leads to smaller losses in efficiency and luminance and consequently to greater brilliance and cost savings in operation. Other new technologies along the entire value-added chain for functional full-color video wall modules with a 1mm pixel pitch were successfully demonstrated.





The results of the project can be applied not only to large-format video walls but also to new applications such as in ambient lighting and sensor systems. Due to the modular structure of the project comprising four work packages, many results can now be quickly transferred to product development and production. The integration of LEDs in industrial applications and also in areas such as the mobility of the future can therefore be accelerated, it is reckoned. The results also open up potential in infotainment.

"Our powerful consortium of partners from science and industry has delivered extraordinary achievements in three years," believes Frank Singer, predevelopment group leader at Osram Opto Semiconductors.

www.osram.com

SLD Laser achieves first UL certification for laser lighting

SLD Laser of Goleta, CA, USA (a spin-off from LED lighting firm Soraa Inc that is commercializing visible laser light sources for automotive, specialty lighting and display applications) says that its LaserLight SMD product line has achieved UL certification for the solid-state lighting safety standard ANSI/UL 8750.

The LaserLight products won top honors at May's LightFair exhibition in Chicago in the category 'LED/OLED, Chips & Modules'. They also recently received Gold Innovators Award from Laser Focus World, announced at the CLEO conference in San Jose, CA.

LaserLight is said to deliver the benefits of solid-state illumination such as minimal power consumption and long lifetime, with the highly directional output that has been possible only with legacy technology. LaserLight SMD delivers 500 lumens of white light and 1000 candela per square mm output from a 7mm surface-mount device (SMD) lighting package. The sources utilize the firm's proprietary and patented semi-polar gallium nitride (GaN) laser diodes combined with phosphor chip technology and novel high-luminance packaging.

"SLD has achieved the world's first UL certification of a laser based lighting source," says SLD Laser co-founder & president Dr James Raring. "We are driven by the vision that laser diodes are lighting's future — we are thrilled to see regulatory acceptance and adoption of our LaserLight products in so many of our customer's lighting applications," he adds.

"These products were evaluated per the applicable requirements of UL 8750 — the standard for LED equipment for LED lighting," notes Bahram Barzideh, principal engineer at UL. "Additionally, based on request from SLD Laser, UL performed testing per IEC TR 62778:2014 to assess risk group (RG) levels for blue light hazard," he adds. "With the results of these two evaluations, SLD Laser can now identify specific construction and performance characteristics for the LaserLight product line which will allow OEMs to more easily integrate these components into lighting products and systems, help reduce the need for end-product testing and accelerate time to market."

LaserLight SMD is claimed to be the first laser-based commercial lighting product, delivering over 10 times higher luminance than LEDs, and enabling safe, highly collimated, white light output with high optical control from miniature optics or high-efficiency fiber optics.

www.SLDLaser.com

CST Global shares iBROW and WiPHi project findings at University of Glasgow's THz Electronics Workshop

The most recent THz Electronics Workshop at Scotland's University of Glasgow shared research findings and discussed current and future trends in terahertz electronics, which is currently breaking into many major application fields such as wireless, medical, non-destructive materials testing, radar, security, food processing and space.

Chaired by Dr Edward Wasige (High Frequency Electronics Group Leader at the University of Glasgow) and attended by over 100 scientists and engineers from across Europe, the THz Electronics Workshop provided a platform for presenting the findings of two ongoing wireless-over-fiber projects: iBROW and WiPHi. Both projects are collaborations between the University of Glasgow and III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Blantyre (near Glasgow), and both are managed by the university's

Horacio Cantu.

Dr Edward Wasige and Dr Horacio Cantu (research engineer at CST Global).

iBROW is an European Union (EU)-funded Horizon 2020 project, completing in June. "It has helped establish optimal, wireless, mm-wave carrier frequencies for high-speed communications using 84–300GHz," notes Horacio. "It has also investigated wireless baseband to optical domain conversion at wavelengths of 1270, 1310 and 1550nm. The baseband data rates investigated were 10Gbps and above," he adds.

WiPHi is a UK government-funded Innovate UK project (running from January to December) with the additional commercial partner Optocap Ltd. The project is focused on 60GHz wireless transmission and baseband conversion for optical domain networks using RTD–LD (resonant tunneling diode-laser diode) drivers, which include distributed feedback (DFB) lasers made by CST Global. WiPHi is investigating 1310nm and 1550nm wavelengths for indoor communications using the existing V-band communications framework. The data rate possible with WiPHi technology is around 7Gbps, with low-latency, increased transmission speed, immunity from interference, enhanced security, and a reduction in component count and antenna size.

Academic speakers at the THz Electronics Workshop included professor Elliott R. Brown of Wright State University and professor Imran Mehdi of JPL-NASA in the USA, and professor Masahiro Asada of Tokyo Institute of Technology and professor Tadao Nagatsuma of Osaka University in Japan.

http://ibrow-project.eu
www.CSTGlobal.uk

CST Global's principal device development engineer presents at European Summer School on PICs for Optical Interconnects

At the 3rd European Summer School on PICs for Optical Interconnects at the Aristotle University of Thessaloniki (AUTH) in Greece (jointly organized by Ireland's Tyndall National Institute), one of the guest speakers was Susannah Heck — principal device development engineer at III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK.

Chaired by professors Nikos Pleros, Liam O'Faolain and Amalia Miliou, the summer school forms part of the European Union (EU) Horizon 2020-ICT framework

Susannah Heck.

projects ICT-STREAMS and COSMICC. The audience comprised postgraduate students, post-doctorate students and academics from across Europe; engineers from NTT in Japan; and engineers developing optical systems and subsystem in commercial organizations.

"The Summer School is focused on integrated photonics and optical interconnect technologies and architectures, across different hierarchy levels, in data centers and high-performance computing systems," says Heck. "I presented an overview of CST Global's 100mm indium phosphide (InP) wafer platform, which is used to design and fabricate distributed feedback (DFB) lasers in high volumes for data center, PON [passive optical network] and 4G/5G applications," she adds. "Next-generation DFB lasers are currently being developed at CST Global as part of the Innovate UK, government-funded DilaN and Super8 research projects."

www.oi-summerschool.eu
www.ict-streams.eu
www.h2020-cosmicc.com
www.CSTGlobal.uk

Finisar opens Texas 3D sensing VCSEL fab

Finisar Corp of Sunnyvale, CA, USA, which manufactures optical communication modules and vertical-cavity surface-emitting lasers (VCSELs) for 3D sensing applications, held a ribbon-cutting ceremony on 9 July to celebrate its new manufacturing facility in Sherman, Texas, with speakers from its executive management team (including CEO Michael Hurlston) as well as local community leaders.

Finisar will use the site to increase production capacity of its VCSELs and related 3D sensing technologies, used in a wide range of applications.

Formerly owned by MEMC and SunEdison, the building has been under renovation since December 2017 and is on target to begin production by the end of 2018. It is currently certified as cleanroom operational and the first production tooling has been installed and qualified. Finisar has hired nearly

200 employees, including the operations and support staff necessary to begin production. Finisar expects to expand hiring further later this year to support the anticipated ramp to high-volume production.

The new facility will "expand critical production capacity of our VCSEL products needed to support customer requirements," says Hurlston. "We are also pleased to create hundreds of manufacturing jobs in the US and to hire talent from the local area as we work together to make Sherman the VCSEL capital of the world."

Finisar's experience with VCSEL technology spans more than two decades of engineering research, development, design and manufacturing, producing more than 300 million VCSEL die. Originally used in its optical communication products, Finisar says that VCSEL technology is extending into consumer and scientific applications including 3D facial recognition, augmented reality, automotive in-cabin sensing and automotive light detection & ranging (LiDAR).

www.finisar.com

ams' IR VCSEL arrays bring face recognition for first time to Android-based smartphones

ams of Premstaetten, Austria, which designs and makes high-performance sensor and analog solutions, a supplier of high performance sensor solutions, says that its PMSIL low-power IR VCSEL laser emitter is enabling what is reckoned to be the first implementation of user face recognition in a smartphone based on the Android platform.

The Mi8 Explorer Edition, the new flagship smartphone from the fast-growing Chinese brand Xiaomi, includes a face recognition system that uses infrared (IR) vertical-cavity surface-emitting laser (VCSEL) arrays from ams. The PMSIL is a complete VCSEL flood illuminator system with integrated eye-safety interlock, offering very high optical efficiency and minimizing the drain on the phone's battery when emitting.

The PMSIL incorporates the emitter die and a diffuser in its compact 3mm x 3mm x 1mm package. It features high spectral stability over temperature, as well as a narrow spectral width of <1nm. The engineered beam profile can be precisely configured to the needs of specific smartphone applications.

In the Mi8 Explorer Edition, the PMSIL operates in always-on mode for face detection and recognition. The IR VCSEL emitter in the structured lighting system, the CS115, is also supplied by ams. The IR emitter is an IR chip-on-substrate VCSEL array, and has a small footprint and high optical efficiency.

ams says that its VCSEL technology is the result of 15 years of development that has resulted in many optimizations of the VCSEL fabrication process technology, materials and packaging. Customers can also draw on what is claimed to be the industry's most comprehensive and exhaustively validated test data and performance models, providing predictable performance characterizations and accurate quality and reliability data.

The ams relationship with Xiaomi extends beyond the provision of IR laser arrays: ams also supplies the TMD27253 ambient light sensor and proximity detection module in the Mi8 and Mi8SE models.

"Xiaomi is a stand-out performer in the Chinese smartphone market and, increasingly, globally because of its bold and innovative design approach and its ability to implement advanced technologies in beautiful, sleek phones," comments Hui Nie, general manager for the VCSEL product line at ams. "To fit the slim, bezel-less design of the Mi8 Explorer Edition, Xiaomi's designers wanted to build the smallest possible face recognition system, which led them to evaluate the ams IR VCSEL arrays," he adds.

www.ams.com

Imec demos hybrid FinFET-silicon photonics technology for ultra-low power optical I/O

40Gb/s NRZ optical modulation achieved with dynamic power consumption of 230fJ/bit in 0.025mm² footprint

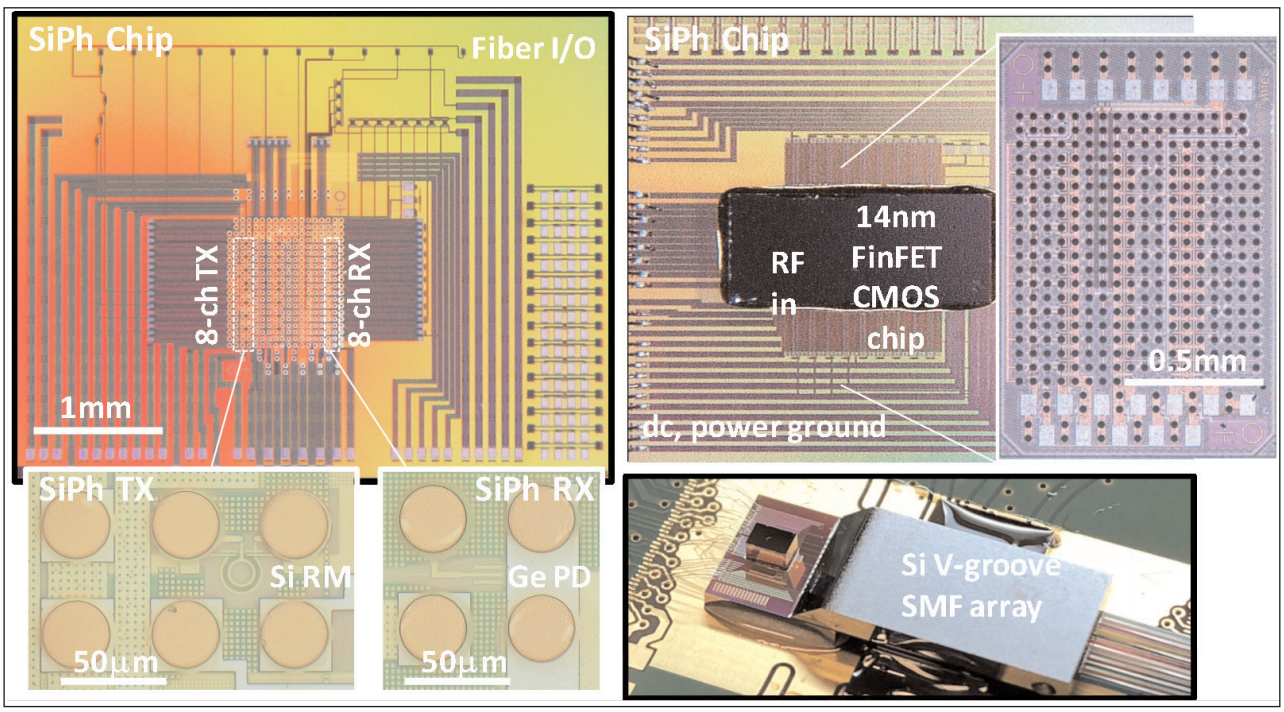
At its Imec Technology Forum USA in San Francisco, nanoelectronics research centre imec of Leuven, Belgium announced that it has demonstrated ultra-low-power, high-bandwidth optical transceivers through hybrid integration of silicon photonics and FinFET CMOS technologies. With a dynamic power consumption of only 230fJ/bit and a footprint of just 0.025mm^2, the 40Gb/s non-return-to-zero (NRZ) optical transceivers are said to represent a milestone in realizing ultra-dense, multi-Tb/s optical I/O solutions for next-generation high-performance computing applications.

The exponentially growing demand for I/O bandwidth in data-center switches and high-performance computing nodes is driving the need for tight co-integration of optical interconnects with advanced CMOS logic, covering a wide range of interconnect distances (1m–500m+), says imec. In the presented work, a differential FinFET driver was co-designed with a silicon photonics ring modulator, and achieved 40Gb/s NRZ optical modulation at 154fJ/bit dynamic power consumption. The receiver included a FinFET transimpedance amplifier (TIA) optimized for operation with a germanium (Ge) waveguide photodiode, enabling 40Gb/s NRZ photodetection with an estimated sensitivity of –10dBm at 75fJ/bit power consumption. High-quality data transmission and reception was also demonstrated in a loop-back experiment at 1330nm wavelength over standard single-mode fiber (SMF) with 2dB link margin. Finally, a 4x40Gb/s, 0.1mm^2 wavelength-division multiplexing (WDM) transmitter with integrated thermal control was demonstrated, enabling bandwidth scaling beyond 100Gb/s per fiber.

"The demonstrated hybrid FinFET-silicon photonics platform integrates high-performance 14nm FinFET CMOS circuits with imec's 300mm silicon photonics technology through dense, low-capacitance copper (Cu) micro-bumps," says Joris Van Campenhout, director of the Optical I/O R&D program at imec. "Careful co-design in this combined platform has enabled us to demonstrate 40Gb/s NRZ optical transceivers with extremely low power consumption and high bandwidth density," he adds. "Through design optimizations, we expect to further improve the single-channel data rates to 56Gb/s NRZ. Combined with wavelength-division multiplexing, these transceivers provide a scaling path to ultra-compact, multi-Tb/s optical interconnects, which are essential for next-generation high-performance systems."

The work has been carried out as part of imec's industrial affiliation R&D program on optical I/O and was presented in a 'late news' paper at the 2018 Symposia on VLSI Technology and Circuits (18–22 June) in Honolulu, HI, USA. The 200mm and 300mm silicon photonics technologies are available for evaluation by companies and academia through imec's prototyping service and the iSiPP50G multi-project wafer (MPW) service.

www.vlsisymposium.org
www.imec.be



FinFET-silicon photonics transceiver assembly.

Intel wins SEMI's 2018 Award for the Americas for process and integration of silicon photonics transceiver

At SEMICON West in San Francisco (10–12 July), Intel has been presented with SEMI's 2018 Award for the Americas for "pioneering process and integration breakthroughs that enabled the first high-volume integrated silicon photonics transceiver".

SEMI's Americas Awards recognize technology developments with a major impact on the semiconductor industry and the world.

The Intel Silicon Photonics 100G CWDM4 (coarse wavelength division multiplexing 4-lane) QSFP28 optical transceiver, a highly integrated optical connectivity solution, combines the power of optics and the scalability of silicon. The small-form-factor, high-speed, low-power-consumption 100G transceivers are used in optical interconnects for data communications applications, including large-scale cloud and data centers, and in Ethernet switch, router and client telecoms interfaces.

The award was accepted on behalf of Intel by Dr Thomas Liljeberg,

Dr Thomas Liljeberg receiving the award at Semicon West.

senior director of R&D for Intel Silicon Photonics, who is one of the technologists responsible for bringing the firm's silicon photonics 100G transceivers to high-volume production.

"Every year SEMI honors key technological contributions and industry leadership through the SEMI Award," says David Anderson, president, SEMI Americas. "Intel was instrumental in delivering technologies that will influence product design and system architecture for many years to come," he comments.

"The 2018 Award recognizes the enablement of high-volume manufacturing through technology leadership and collaboration with key vendors in the supply chain," says Bill Bottoms, chairman of the SEMI Awards Advisory Committee. "Intel's collaboration is a model for how the industry can accelerate innovation in the future."

SEMI established the SEMI Award in 1979 to recognize outstanding technical achievement and meritorious contributions in the areas of Semiconductor Materials, Wafer Fabrication, Assembly and Packaging, Process Control, Test and Inspection, Robotics and Automation, Quality Enhancement, and Process Integration.

The SEMI Americas award is the highest honor conferred by the SEMI Americas region. It is open to individuals or teams from industry or academia whose specific accomplishments have a broad commercial impact and widespread technical significance for the entire semiconductor industry. Nominations are accepted from individuals of North American-based member companies of SEMI.

www.semiconwest.org
www.intel.com
www.semi.org/semiaward

II-VI to expand 980nm pump laser manufacturing capacity by end-2018

Expansion to meet demand for data-center interconnects & ROADMs

To address increased demand for its differentiated product portfolio. engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA plans to expand the capacity of its 980nm pump laser production lines, including wafer fab and chip-on-carrier assembly in Zurich, Switzerland and in Calamba, Philippines, and pump laser module assembly in Shenzhen, China. The firm has also completed the extension of the existing facility lease in Shenzhen, China.

Specifically, II-VI will increase its production capacity to meet the strong demand for data-center interconnects (DCI) and the growing demand for reconfigurable optical add-drop multiplexers (ROADMs). The new production capacity is expected to be operational by the end of 2018.

"As our company has previously discussed, we are seeing increased demand for our products for optical communications," says Simon Loten, general manager, II-VI Pump Laser Division. "Our micro-pump lasers, one of our latest innovations, have set new standards in miniaturization, enabling transceiver embedded amplifiers for next-generation data-center interconnects."

II-VI's laser chips are designed and manufactured in Zurich leveraging a high-reliability legacy that spans more than 20 years. The firm's manufacturing facility in Calamba houses automated assembly lines for laser sub-assemblies that are shipped to II-VI's operations in Shenzhen to complete the pump laser module assembly. The Shenzhen operations have shipped more than 3 million pump lasers, mostly under the II-VI brand.

www.ii-vi-photonics.com

Inphi samples first 100Gbps Porrima single-lambda PAM4 platform solution for QSFP28 and SFP-DD 100GBASE-DR/FR optical modules

Inphi Corp of Santa Clara, CA, USA (a provider of high-speed mixed-signal ICs for communications, computing and data-center markets) has expanded its 16nm Porrima single-lambda pulse amplitude modulation (PAM4) platform family with the complete 100Gbps/56GBaud platform solution for 100G QSFP28 and SFP-DD DR/FR optical modules for wired network infrastructure including hyperscale cloud data-center, service provider, wireless 5G and enterprise networks.

The 16nm Porrima 100G platform includes field-proven PAM4 digital signal processor (DSP) technology, a linear transimpedance amplifier (TIA) and a driver for PAM4-based client optical modules. Built from the same foundation as the 400Gbps 16nm PAM4 DSP announced at March's Optical Networking and Communication Conference & Exhibition (OFC 2018) in San Diego, the new 100Gbps variant has all the benefits, including experience from five generations of DSP development (each of which have been field deployed starting 2016), optical platform expertise and an API-based DSP software suite that can achieve quick time to market with the right trade-offs in power and performance.

The Porrima 100G platform enables the anticipated fast ramp of 100G DR QSFP optics inside megascale cloud data centers and wireless 5G deployment. Porrima 100G DSP supports all relevant IEEE PCS and KR/KP FEC options for legacy support and backward compatibility with 3.2T and 6.4T switches with 25G NRZ I/O.

"The industry shipped upwards of 3 million 100Gbps optical modules last year and is expected to double that in 2018, with the largest share of them being four-laser 100Gbps CWDM modules for single-mode fiber," comments Dale Murray, principal analyst for LightCounting Market Research. "The Inphi 100G Porrima platform will enable single-laser, full-duplex single-mode 100Gbps optical modules that could be more cost effective than the four-laser variants and will also support breakout with 400G-DR4 for dense 100Gbps fabrics," he adds.

"The Porrima 100G is ideally suited for both QSFP and SFP module form factors, offering our customers both legacy QSFP support and an upgrade path to higher-density 100Gbps with the upcoming 12.8T switches," says Siddharth Sheth, Inphi's senior VP, Networking Interconnects.

Key attributes of the new Porrima 100G PAM4 platform include:

- low power consumption for next-generation 100Gbps module applications, enabling <3.5W DR/FR optical modules per IEEE standards and MSA;
- enables the DR/FR optical modules for legacy 3.2/6.4T switches while offering an effortless upgrade path for 12.8T switches;
- optimally designed DSP and TIA receive chain for power-performance trade-offs;
- enables customers to develop a 100Gbps optical interconnects in a compact form factor for applications with up to 10km;
- the supporting IN5630DE linear driver and IN566x linear TIA provide packaging flexibility for excellent linearity, high bandwidth, adjustable gain to optimize the PAM4 system performances and wide dynamic range to meet the different performance and link requirements for optical applications;
- implemented in small form factor and power efficiency on proven, high-volume 16nm process technology node, ensuring fastest time to production.

The Porrima 100G PAM4 DSP IC provides a full bi-directional interface with host ASICs that have 28GBaud PAM4and NRZ electrical interfaces while bridging to 56GBaud optics. The product family can support PAM4 or NRZ signaling, with packaging options specifically designed for the following optics modules:

- Porrima 100G – 4x25Gbps NRZ <-> 1x100Gbps PAM4 for 100G QSFP28 DR;
- Porrima 100G – 2x50Gbps PAM4 <-> 1x100Gbps PAM4 for QSFP28/uQSFP/SFP-DD.

Additional Porrima technical features include:

- a fifth-generation InphiNity DSP engine with a unique mixed-mode DSP architecture for high-performance, low-power applications needing adaptability and configurability;
- numerous self-test and loopback modes that allow diagnostic monitoring of channel and system parameters;
- modular API software suite that covers link margin and stress testing along with data and error analytics;
- forward error correction (FEC) functionality for 100Gbps optics are integrated and software configurable.

The IN5630DE is a 56GBaud low-power single-channel linear driver for PAM4 optical modules. Features include what is claimed to be excellent linearity, high bandwidth and adjustable gain to optimize the PAM4 system performances, as well as a low-power modulator driver in bare die form.

The IN5661TA is a 56GBaud low-power single-channel linear TIA for PAM4 optical modules. Features include: wide dynamic range (to meet the different performance and link requirements for optical applications), excellent signal integrity necessary for PAM4 modulation schemes, and low power and small form factor.

www.inphi.com

Kaiam initiates strategic transceiver reserve for data-center applications

US Cloud data-center firms vulnerable to import restrictions on Chinese-made optical transceivers

Kaiam Corp of Newark, CA, USA (which makes optical transceivers for hyperscale data centers) has initiated a strategic transceiver reserve program intended to protect US and European data centers from the effects of the incipient US–China trade war.

The Trump administration has recently enacted broad-based tariffs that could impede the import of Chinese-made optical transceivers into the USA. Kaiam says that, because US Cloud data-center companies are largely dependent on a supply of Chinese-made transceivers, they are highly vulnerable to collateral damage from the increasingly turbulent US–Chinese relationship. The firm reckons that, as one of the few remaining US-based optical transceiver companies, it is immune to the ill effects of US–China trade tensions. Kaiam is hence building a strategic reserve of transceivers that its customers can draw down in response to a dwindling Chinese transceiver supply. It will populate this reserve with units fabricated in its large-scale manufacturing facility in Livingston, Scotland, UK, and welcomes partners to add to this reserve.

"In today's global economy, it is easy to assume goods will flow seamlessly across borders indefinitely. We sometimes forget that the optical components that power Cloud companies like Google, Facebook, Amazon, and others are virtually all made in China and are thus susceptible to trade tensions. As patriots, we believe a transceiver reserve is necessary for our domestic security," says Jeremy Dietz, VP of global sales & marketing.

"Our advanced technology and manufacturing process allows us to easily build a buffer to protect our nation in case of an embargo or even a natural disaster. We are currently exploring secure underground locations in states such as Utah and Nevada," he adds.

It is easy to assume goods will flow seamlessly across borders indefinitely. Optical components that power Cloud companies like Google, Facebook, Amazon, and others are virtually all made in China

"Our Constitution implicitly guarantees the fundamental right to engage in online activities ranging from the sublime to the abject on a 24/7 basis," comments chief technology officer Rob Kalman. "We view it as our patriotic duty to protect these rights, for it is more true than ever that the price of freedom is eternal vigilance!," he adds.

"All humor aside, we are seeing the benefits of our $80m investment in the automated UK line, and have the capacity to serve a large fraction of the high-performance optical transceiver market. The MEMS-based micro-packaging technology, together with our recent massive investments in automation and infrastructure, provides our Western customers with a secure source, free of potential trade issues," says president & CEO Bardia Pezeshki. "We aim to serve the Asian market, with a similar local source, through our partnership with Broadex [announced in May]. This dual strategy eliminates any potential supply issues on both sides of the globe."

www.kaiam.com

Oclaro stockholders approve merger agreement with Lumentum

Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) says that, based on the vote tally from their Special Meeting, stockholders have approved the merger agreement (of 12 March) under which Lumentum Holdings Inc of Milpitas, CA, USA (which makes photonics products for optical networking and commercial lasers for industrial and consumer markets) will acquire Oclaro. Stockholders also approved other proposals relating to the transaction.

About 96.2% of voting Oclaro stockholders cast their votes in favor of the proposal to approve the merger agreement, representing about 65.6% of the firm's outstanding common stock.

"Together, we will be an even stronger player in fiber-optic components and modules for high-speed communications and a market leader in 3D sensing," reckons CEO Greg Dougherty.

The two firms continue to expect the transaction to close in second-half 2018, subject to receipt of regulatory approval in China and the satisfaction of customary closing conditions.

www.oclaro.com
www.lumentum.com

Alta Devices raises its GaAs single-junction solar cell efficiency world record to 28.9%

The US National Renewable Energy Laboratory (NREL) has certified that Alta Devices of Sunnyvale, CA, USA (a subsidiary of Hanergy Thin Film Power Group Ltd of Beijing, China since 2014) has raised its own world record for gallium arsenide single-junction solar cell energy conversion efficiency from 28.8% to 28.9%.

"Alta Devices goal is to continue to lead the industry in solar technology and to enable a broad range of autonomous systems," says CEO Jian Ding. Every time an autonomous system or vehicle has to stop to refuel or recharge, it requires intervention and is no longer truly autonomous. Alta focuses on developing the solar technology specifically for autonomous power, allowing vehicles to seamlessly recharge while in motion.

Alta has set the record for GaAs single-junction solar cell efficiency five times since 2010. "Achieving a new record for this class of devices is a landmark because a 1-sun, 1-junction cell is the archetypal solar cell," says co-founder professor Harry Atwater of California Institute of Technology (CalTech). "The fact that Alta is breaking its own record is also significant since many other teams have been actively attempting to break this record," he adds.

"Alta has the first solar cell based on internal luminescence extraction, which has enabled Alta to remain ahead of others," reckons co-founder professor Eli Yablonovitch of the University of California Berkeley. "This scientific principle will be in all future high-efficiency solar cells."

The firm recently launched its Gen4 AnyLight commercial technology, demonstrating a significant weight reduction from the previous version, resulting in an improved power-to-weight ratio of 160%. This is critical for future autonomous unmanned aerial vehicles (UAVs), electric vehicles (EVs) and sensors, as it can be used to generate substantial power over small surfaces without compromising design criteria.

www.altadevices.com

NREL/CAISO/First Solar win Smarter E Award

At the Intersolar Europe 2018 conference in Munich, Germany (19–22 June), cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA has received the inaugural Smarter E Award for an Outstanding Project. The award recognized a test conducted jointly by First Solar, the US Department of Energy's National Renewable Energy Laboratory (NREL) and grid operator California ISO (CAISO) on a newly built 300MW utility-scale photovoltaic (PV) power plant in California that demonstrated its ability to provide highly responsive services essential for maintaining reliability of the grid.

"The study proves that more solar can be integrated into the grid, enabling even further growth in the PV industry," said First Solar's VP of systems development Mahesh Morjaria on accepting the award.

The tests demonstrated the role of advanced power controls in leveraging solar PV's value from simply an intermittent energy resource to providing services, including spinning reserves, load following, voltage support, ramping, frequency response, variability smoothing, frequency regulation, and improved power quality.

"The project team carried out a pioneering demonstration concept to show how various types of active and reactive power controls can leverage PV generation's value from being a simple variable energy resource to a resource that provides a wide range of essential reliability services," said Vahan Gevorgian, chief engineer in NREL's Integrated Devices and Systems group and principal investigator with the project.

The tests demonstrated that solar plants can react rapidly to grid signals regarding frequency regulation, and more accurately than conventional generation such as thermal, hydro or gas turbines — and can be tightly regulated.

Criteria for the Outstanding Project 2018 Award included demonstration that the nominated project was exemplary for global future applications and was unique in its realization. Emphasis was placed on innovation and a pioneering spirit in the exploration of renewable energy applications. The Smarter E Awards program was introduced at the 2018 InterSolar EU conference as a way to recognize groundbreaking work in the energy transition towards a low carbon future.

The Smarter E review jury cited the NREL/CAISO/First Solar study as a "proof of concept… a game-changer for large-scale solar plants" that demonstrated how "solar power plants can not only reduce the need for carbon-emitting resources, but can also improve system performance and operate with significantly higher levels of variable generation."

"The results of this project can be used as a door opener to convince stakeholders that utility-scale solar can contribute to the reliability and stability of the grid and provide essential grid services that are today often associated with conventional generation," the citation concluded.

www.firstsolar.com

Avancis reopens CIGS PV module production facility in South Korea

Ramping of production scheduled for first-half 2019

Copper indium gallium diselenide (CIGS) thin-film photovoltaic module maker Avancis GmbH of Torgau, Germany has celebrated the reopening of its CIGS PV factory in Ochang, South Korea. The ceremony was held with representatives from Avancis Korea, Avancis Germany and professor Peng Shou — CEO of parent company China National Building Materials Group Corporation (CNBM), which acquired Avancis in 2014 — as well as government representatives from the Korean province of Chungbuk.

Avancis completed the 100MW factories in South Korea in 2012 but did not ramp them up, as conditions for the former joint venture Hyundai-Avancis had been assessed as not optimal. Last year, the South Korean government targeted to cover 20% of the country's total electrical energy production from renewable energy sources by 2030, presaging growth in the South Korean PV market.

"We have worked hard and long to get back to our factory in South Korea," says Avancis' CEO Oliver Just. "Of course, this does not work without a forward-thinking and strong parent company like CNBM. The decisive factor was and still is in times of overcapacities and price declines in PV modules; we are nevertheless experiencing an increasing demand for our aesthetic premium modules in the solar façade sector worldwide," he adds. "With the return of Avancis Korea, we have the opportunity to manufacture and market our high-quality CIGS modules for Korea and the Asian market."

All preparatory measures are in full swing for the start of production at Avancis Korea. As part of the update actions, the general overhaul of the equipment and HR hiring process will be completed by end of 2018. Ramping of production is scheduled for first-half 2019.

www.avancis.de

Singulus wins contract from CNBM to develop new CIGS production system for Avancis

Singulus Technologies AG of Kahl am Main, Germany (which makes production equipment for the optical disc and solar sectors) has signed a new contract for the development of the next generation of manufacturing equipment with its long-standing customer Avancis GmbH of Torgau, Germany, a subsidiary of China National Building Materials (CNBM) that specializes in copper indium gallium diselenide (CIGS) thin-film photovoltaic cells.

Singulus has been working with Avancis since 2008 on the development and optimization of the CISARIS selenization equipment. The common goal is to further reduce production costs in cooperation with the customer and to increase both cell performance and production performance.

"Our CISARIS selenization plants are an important step in the entire production process," says Dr Stefan Rinck, chairman of Singulus' management board. "CNBM's CIGS thin-film technology will meet even greater demands in the future through the use of new equipment," he reckons.

The production capacity for CIGS cells in China is expected to rise significantly in the coming years. Singulus says it is involved with all major investments in China with machines for each CIGS process.

www.Avancis.de
www.singulus.com

Imec's perovskite-silicon tandem cell efficiency of 27.1% beats standalone silicon solar cell

Engineering of perovskite material could raise efficiency over 30%

As a partner in Solliance and EnergyVille, nanoelectronics research centre imec of Leuven, Belgium has reported what it claims is record solar energy power conversion efficiency of 27.1% for its four-terminal perovskite/silicon tandem photovoltaic cell, beating the most efficient standalone silicon solar cell. Further engineering of the perovskite material can raise efficiency over 30%, it is reckoned.

Perovskite microcrystals represent a promising material system for making high-performance thin-film solar cells. They can be processed into thin, light, semi-transparent modules that can achieve high power conversion efficiency, are inexpensive to produce, and have high absorption efficiency for sunlight. Because they can be made semi-transparent, perovskite solar cells and modules can also be used on top of silicon solar cells. When the perovskite is carefully engineered, the absorbance in the perovskite minimizes the thermal losses that occur in the silicon cell. As a result, a perovskite-silicon tandem solar cell can potentially reach power conversion efficiencies above 30%.

Imec's perovskite–silicon tandem solar cell.

Imec's new record tandem cell uses a 0.13cm^2 spin-coated perovskite cell — developed within its Solliance cooperation — stacked on top of a 4cm^2 industrial interdigitated back-contact (IBC) silicon cell in a four-terminal configuration, which is known to have a higher annual energy yield compared with a two-terminal configuration. Additionally, by scaling up the tandem device by using a 4cm^2 perovskite module on a 4cm^2 IBC silicon cell, a tandem efficiency of 25.3% was achieved, surpassing the stand-alone efficiency of the silicon cell.

"We have been working on this tandem technology for two years now, and the biggest difference with previous versions is in the engineering and processing of the perovskite absorber, tuning its bandgap to optimize the efficiency for tandem configuration with silicon," says Manoj Jaysankar, doctoral researcher at imec/EnergyVille.

"Adding perovskite on top of industrial silicon PV may prove to be the most cost-effective approach to further improve the efficiency of photovoltaics," concludes Tom Aernouts, group leader for thin-film photovoltaics at imec/EnergyVille. "Therefore, we invite all companies in the PV value chain that are looking into higher efficiencies to partner with us and explore this promising path."

www.imec.be
www.solliance.eu
www.energyville.be

Solar-Tectic granted US patents for perovskite thin-film solar cells

Solar-Tectic LLC of Briarcliff Manor, NY, USA (which specializes in thin-film solutions for the solar, display, and glass industries) says that two patent applications for perovskite thin-film solar cells have been granted by the US Patent and Trademark Office (USPTO). The inventors are Solar-Tectic's founding manager Ashok Chaudhari and the late Dr Praveen Chaudhari, renowned materials physicist.

The patents US 9,978,532 'Maximizing the Power Conversion Efficiency of a Tin Perovskite/Silicon Thin-Film Tandem Solar Cell' and US ser. 15/157,539 'Methods of Growing Heteroepitaxial Single Crystal or Large Grained Semiconductor Films and Devices Thereon' are part of Solar-Tectic's 'Tandem Series' of solar cell technologies that includes a variety of different proven photovoltaic materials such as III–Vs, copper zinc tin selenide (CZTS) and amorphous silicon (a-Si) for the top layer on top of a silicon (or germanium) bottom layer, on various substrates such as cheap soda-lime glass. Tandem Series cells are claimed to have the potential to surpass the efficiencies of existing thin-film solar cell technologies such as cadmium telluride (CdTe), copper indium gallium diselenide (CIGS) and a-Si as well as incumbent silicon technology (based on poly- and monocrystalline wafers).

Recently perovskite materials have gained much attention as a promising solution to the long-standing problem of solar cell efficiency. While there have been many reports of perovskite/silicon (wafer) tandem solar cells (and extensive intellectual property), there have been none on a perovskite/crystalline silicon thin-film tandem solar cell, until Solar-Tectic's recent development (www.nscj.co.uk/JECM/PDF/3-2-2-Chaudhari.pdf).

Wafer-sized bottom poly- and monocrystalline silicon layers in PERC (passivated emitter and rear cell), PERL (passivated emitter with rear locally diffused), HIT (heterojunction with intrinsic thin-layer), HJ (heterojunction) or perovskite/silicon tandem cells are typically 200–280μm thick, whereas Solar-Tectic's thin-film crystalline inorganic bottom layers can be as thin as 20–30μm with the same or similar efficiency. Moreover, they can be processed at much lower temperatures, lowering production costs significantly. The top perovskite layer is less than just 1μm (an ultra-thin film) and a thin-film crystalline silicon (CSiTF) bottom layer decouples the need for a silicon wafer. If the price of polysilicon rises less, silicon material use will be an additional cost saving.

Tandem perovskite solar cells are theoretically capable of 45% efficiency, although Solar-Tectic has set a more realistic 30% efficiency goal, higher than the 25–26.6% efficiencies for the best silicon wafer technologies such as PERC, PERL, HIT, HJ cells. The efficiencies of existing solar cells on the market in general are 14–25%. Solar-Tectic reckons that a cost-effective 30%-efficient solar cell with a simple design could revolutionize the solar energy industry by dramatically reducing the balance of system (BoS) costs.

Importantly, the entire Solar-Tectic process is environmentally friendly, since non-toxic tin (Sn) or gold (Au) is used to deposit the crystalline silicon thin-film material for the bottom layer in the tandem/heterojunction configuration as well as in the top perovskite layer. The more commonly used toxic materials lead (Pb) is not used in the perovskite.

Also, the manufacturing methods used — sputtering or electron-beam evaporation — are conventional and similar to those used in today's thin-film solar cell industry as well as in the display industry (with which there is much overlap and potential for synergy).

A paper reporting a step in the 'Tandem Series' approach was recently published (www.sciencedirect.com/science/article/pii/S0167577X18302945). In March 2017, Solar-Tectic announced the first patent ever granted for this perovskite/silicon thin-film tandem approach.

A patent for a copper oxide thin-film tandem solar cell has also been granted to Solar-Tectic (US patent 9,997,661), expanding the IP portfolio of the Tandem Series.

R&D on the new perovskite thin-film tandem technology began last year at Maryland-based Blue Wave Semiconductors Inc (which provides thin-film deposition equipment as well as coating services).

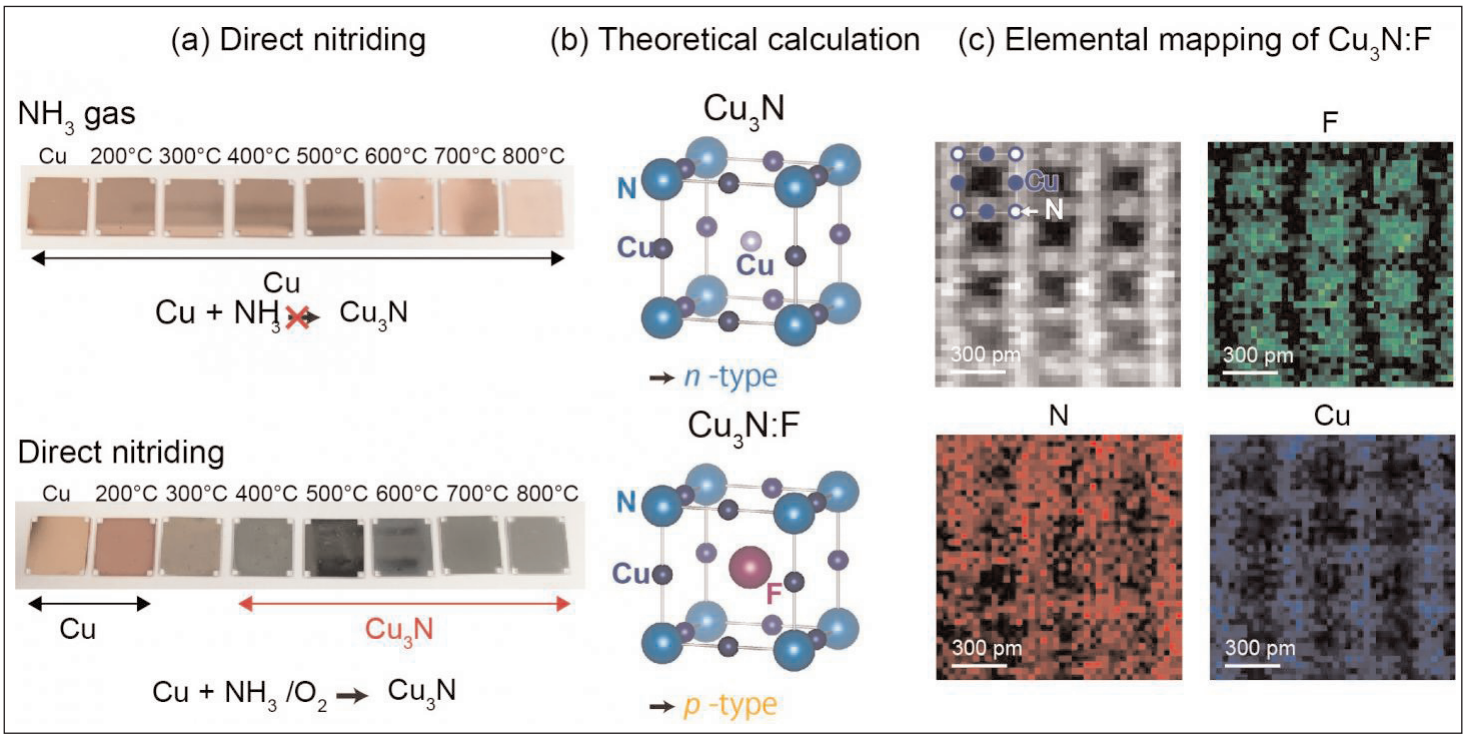
www.solartecticllc.com

Tokyo Institute of Technology develops n- and p-type copper nitride semiconductor for environmentally friendly thin-film photovoltaics

Gaseous direct nitriding for uniform and large-area deposition yields a non-toxic, abundant alternative to CdTe and CIGS.

By using a unique nitriding technique applicable for mass production and a computational search for appropriate doping elements (as well as atomically resolved microscopy and electronic structure analysis using synchrotron radiation), Tokyo Institute of Technology has shown that copper nitride (Cu_3N) acts as an n-type semiconductor, with p-type conduction provided by fluorine doping (Kosuke Matsuzaki et al, 'High-Mobility p-Type and n-Type Copper Nitride Semiconductors by Direct Nitriding Synthesis and In Silico Doping Design'). These n-type and p-type copper nitride semiconductors could potentially replace the conventional toxic or rare materials in photovoltaic cells, it is reckoned.

Compared to market-dominating silicon solar panels, thin-film photovoltaics have equivalent efficiency and



(a) Copper and copper nitride. (b) Theoretical calculation for p-type and n-type copper nitride. (c) Direct observation of fluorine position in fluorine-doped copper nitride. (a) Thin-film copper plates before and after reacting with ammonia and oxygen. Copper metal has been transformed to copper nitride. (b) Copper insertion for n-type semiconductor and fluorine insertion for p-type semiconductor. (c) Nitrogen plotted in red, fluorine in green, and copper in blue. Fluorine is located at the open space of the crystal, as predicted by theoretical calculation.

can cut the cost of materials. The technology allows low-cost and scalable manufacturing routes compared to crystalline silicon technology, even though toxic and rare materials are used in commercialized thin-film solar cells. Tokyo Institute of Technology aims to find a new candidate material for producing cleaner, cheaper thin-film photovoltaics.

The team has focused on a simple binary compound, copper nitride, composed of environmentally friendly elements. However, growing a nitride crystal in a high-quality form is challenging, as history shows from the development of gallium nitride (GaN) blue LEDs. Matsuzaki and his coworkers have overcome the difficulty by introducing a novel catalytic reaction route (gaseous direct nitriding) using ammonia and oxidant gas, applicable to uniform and large-area deposition. This compound — see the photograph in figure (a) — is an n-type conductor with excess electrons. On the other hand, by inserting the element fluorine in the open space of the crystal, this n-type compound was transformed into p-type, as predicted by density functional theory calculations and directly proven by atomically resolved microscopy in figures (b) and (c), respectively.

All existing thin-film photovoltaics require a p-type or n-type partner in their makeup of a sandwich structure, requiring great effort to find the best combination. The p-type and n-type conduction in the same material developed by Matsuzaki and his coworkers are beneficial for designing a highly efficient solar cell structure without such efforts. The material is also non-toxic, abundant and hence potentially cheap — a suitable replacement for cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS) thin-film solar cells. Tokyo Institute of Technology reckons that, with the development of these p-type and n-type semiconductors in a scalable forming technique using simple, safe and abundant elements, the positive qualities will help to bring thin-film photovoltaics to greater prominence. ■

http://dx.doi.org/10.1002/adma.201801968

www.titech.ac.jp/english

NREL develops dual-chamber dynamic HVPE, targeting III–Vs solar cells at $0.20–0.80 per watt

Research continues in order to reduce the cost of both the substrate and the chemical deposition process

The US Department of Energy's National Renewable Energy Laboratory (NREL) is working to refine the hydride vapor phase epitaxy (HVPE) technique, which holds the potential to produce cheaper, more efficient solar cells capable of producing more electricity.

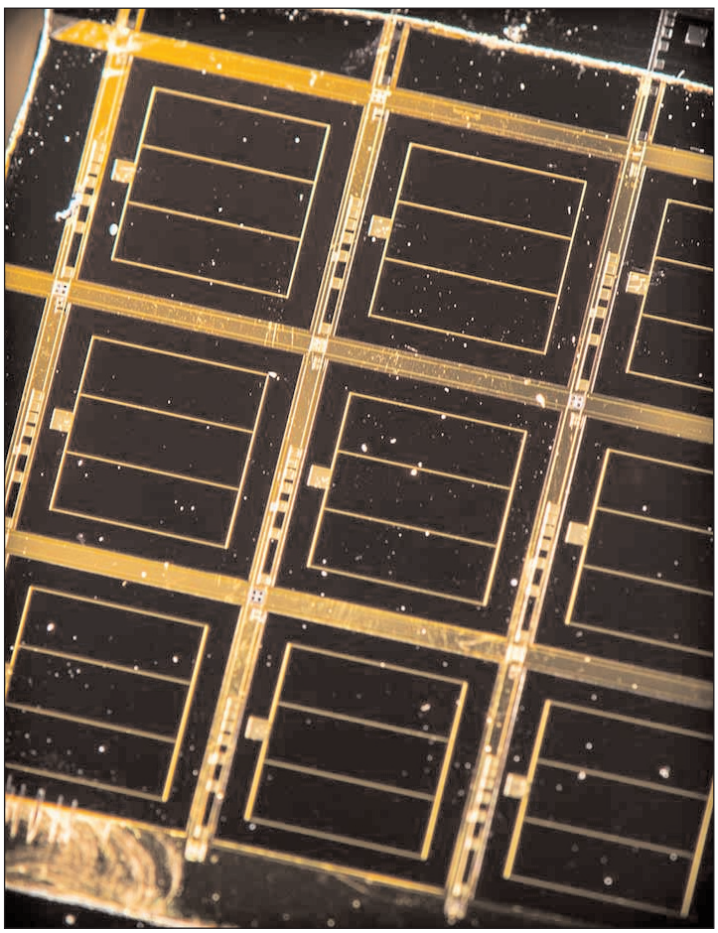
"HVPE has been around since the '50s and '60s. We fondly refer to it as our brand new, 50-year-old growth technique," says Aaron Ptak, a senior scientist who joined NREL in 2001.

Solar panels such as those on NASA's Mars rovers (sent to the planet in 2003) use solar cells made from gallium arsenide (GaAs) and gallium indium phosphide (GaInP), which have high solar energy conversion efficiency about 27%. To apply that same technology on Earth (where the average rooftop solar panel is 15% efficient), the cost would be astronomical. "You can only buy gallium arsenide cells if you're willing to pay $100–300 a watt," says David Young, a senior scientist with expertise in silicon solar cells who joined NREL in 2000.

That is far costlier than what NREL estimates to be the average price of utility-scale solar: less than $1 a watt. Silicon solar cells dominate the market, and scientists calculate that those are nearing the upper practical limit of efficiency, at 27%.

Dual-chamber reactor improves on old process

The existing metal-organic vapor phase epitaxy (MOVPE) process for making III–V solar cells deposits the elements layer by layer in a time-consuming process. "You essentially dose pre-engineered chemicals onto a hot wafer, and they will deposit as thin-film layers with the same lattice spacing as the wafer," says Young. "Multi-layer devices are formed by changing the gas mixture to form different compositions of stacked thin films," he adds. "MOVPE can grow very complicated structures — or devices like solar cells — but it is expensive and slow."

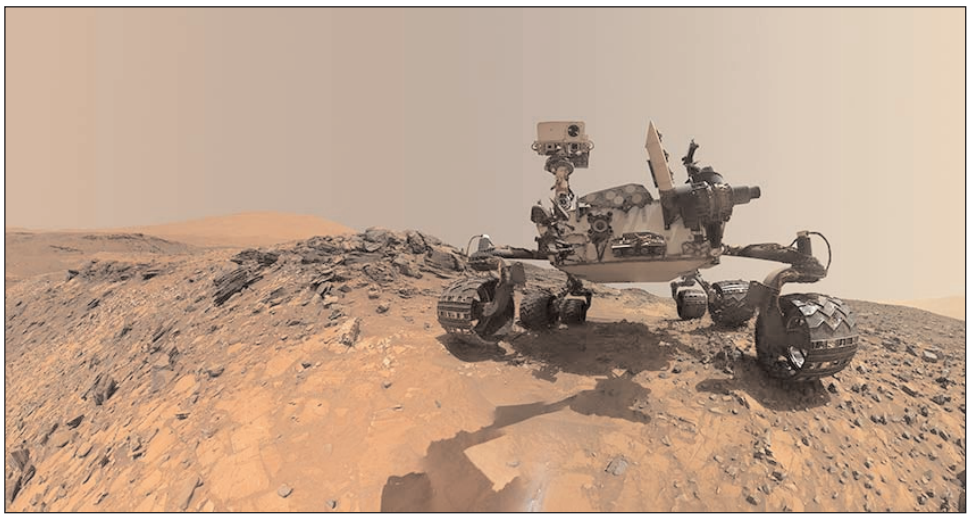


Using D-HVPE, III–V solar cells could enter terrestrial markets, where their high conversion efficiency is desirable. Photo by Dennis Schroeder, NREL

Young and Ptak returned to HVPE, which fell out of favor in the 1960s when MOVPE caught on. HVPE had its difficulties. The process used a single chamber where one chemical was deposited on a substrate, which was then removed. The chemical was then swapped for another, and the substrate returned to the chamber for the next chemical application. The layers

grown atop the wafer had to line up precisely to avoid defects in the solar cell. "If you can't get the interfaces right, you can't build up complex devices like a multi-junction solar cell," says Ptak, an expert in growing III–V solar materials.

The revamped version of HVPE — dynamic HVPE (D-HVPE) — relies on a dual-chamber reactor. The substrate moves back and forth between the chambers, greatly reducing the time to make a solar cell. A single-junction solar cell that takes an hour or two to make using MOVPE can be produced in two minutes by D-HVPE.



NASA's Curiosity rover relies on III–V solar cells. Photo by NASA.

So far, after four years of research and about 3000 samples grown, NREL scientists managed to set the bar at a single-junction GaAs cell with 25.3% efficiency. The record for such a cell is 28.8%, grown using MOVPE by a California company and "using a fancier structure that we can't grow," Ptak says.

"It's actually way higher than we thought we would get in this program," he adds. "When we started this program, we thought, 'OK, we're going to make cheap solar cells and they're going to be kind of bargain-basement solar cells, but they're going to be good.' What we have learned during the course of this project is we need to shoot higher… because the material quality that we're seeing, the device quality that we're seeing, is way better than we expected."

Potential emerging markets for III–V cells

Ptak and Young studied the potential markets for III–V solar cells made by the D-HVPE process at the end of 2016 while participating in Energy I-Corps, a Department of Energy program that helps researchers to determine potential markets for their technologies. Ptak says that the military is interested in the solar cells, which would be thin, lightweight, and flexible. People who operate drones also are interested.

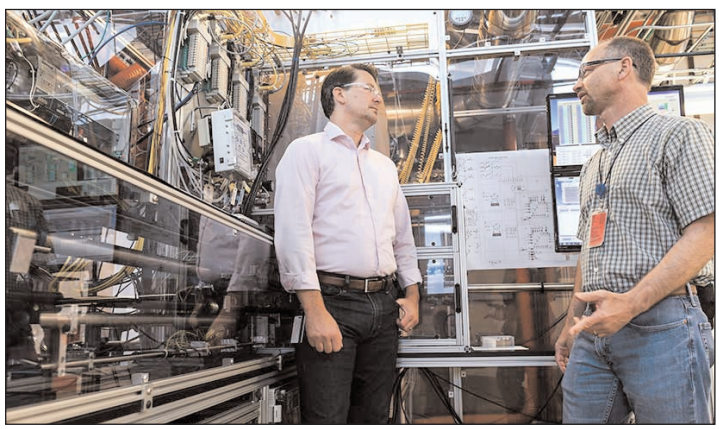
Further research is needed to move D-HVPE beyond the laboratory, but that will require "multiple millions of dollars," Ptak notes. The current funding comes from the Department of Energy Solar Energy Technologies Office and from its Advanced Research Projects Agency-Energy (ARPA-E). "This could spin off into a company. We have an R&D technology that works really, really well. We have designs for a pilot-scale reactor, but we have no way to get from A to B. It's going to be very capital intensive to get to that step," he adds.

"Getting the right people to fund this has been a challenge," says Kelsey Horowitz (part of the Techno Economic Analysis Group in NREL's Strategic Energy Analysis Center), who leads the tech-to-market effort to get HVPE commercialized. She has forecast that solar cells made with D-HVPE technology could generate electricity at 20–80 cents per watt, but that price won't become a reality until D-HVPE solar cells are made in large quantities — and that is at least five years away. Until then, research efforts will continue to reduce both the cost of the substrate used and the chemical deposition process.

Horowitz's list of potential early adopters of D-HVPE solar cells includes big-box retailers with roofs that cannot support heavy silicon panels; bus companies — using regular fuel or electricity — that could turn to the technology to either improve fuel efficiency or range; and the US Army, which could equip soldiers' backpacks with the solar cells to generate power in the field.

"There are these intermediate markets where higher prices can be tolerated," she says. "Right now, III–Vs might be $300 a watt or that ballpark," says Ptak. "If you can get to $100 a watt or $70 a watt, there are large initial markets that you can open up at that price point in order to get your foot in the door, to start scaling up your manufacturing, and get your costs down to $1 a watt or 50 cents a watt," he concludes. ■

www.nrel.gov



Aaron Ptak (left) and David Young think D-HVPE can produce solar cells cheaper and faster than the current method. Photo by Dennis Schroeder, NREL.

Room-temperature PL from III-IV-V semiconductor alloys

MIT researchers claim the first high-quality material grown by metal-organic chemical vapor deposition.

Massachusetts Institute of Technology in the USA claims significant room-temperature photoluminescence (PL) "for the first time in high-quality III–IV–V alloys grown by metal-organic chemical vapor deposition" [Roger Jia et al, J. Appl. Phys., vol123, p175101, 2018]. A modified growth process was used to inhibit phase separation, which can quench PL. Instead, the alloys did exhibit some small-scale composition fluctuation, as seen in many III–V alloys.

The effect of the composition fluctuation was to give a narrower effective bandgap than expected from simple extrapolations between the gap of gallium arsenide (GaAs) and that of the germanium (Ge) or silicon germanium (SiGe) group IV component. In the case of $(GaAs)_{1-x}(Ge_2)_x$, the narrowing limited the bandgap to less than 0.8eV. Adding silicon enabled wider bandgaps to be accessed.

The team writes: "We have apparently created what is effectively a Ge-like solid penetrating a GaAs lattice, resulting in optical properties similar to those of Ge but with a direct-bandgap nature."

The researchers expect III–IV–V alloys to exhibit "interesting electrical, optical and thermoelectric properties on previously unattainable lattice constants."

In terms of potential applications, the team sees potential for a 1eV bandgap, filling a void in multi-junction photovoltaic designs, along with narrower bandgaps for efficient infrared detection using direct-bandgap material. The usual suspects for such bandgaps suffer from lattice mismatches or the need to be grown on very expensive small-diameter substrates.

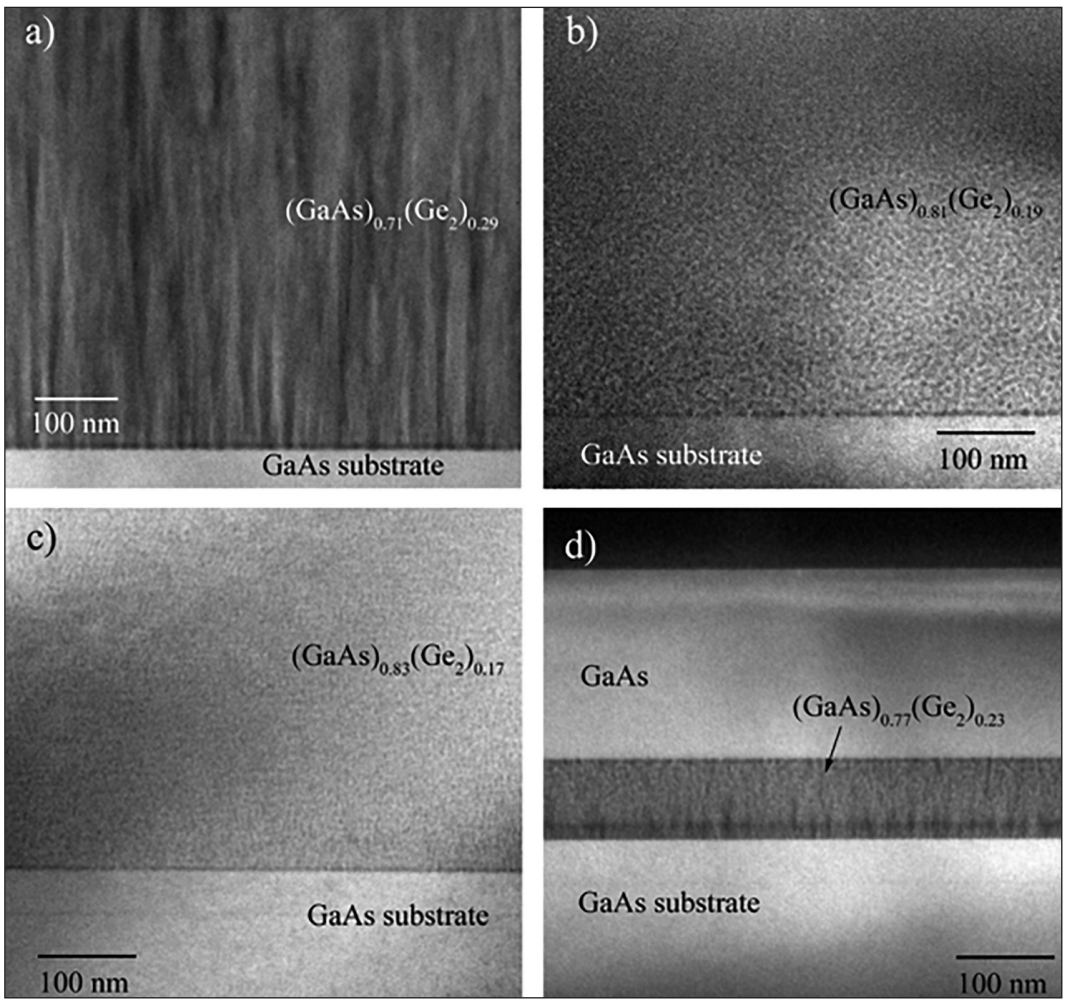


Figure 1. (002) Dark-field XTEM images of $(GaAs)_{1-x}(Ge_2)_x$ alloys. Growth temperature: (a) 700°C, (b) 650°C, (c) 575°C, (d) 650°C. Last image also includes 200nm GaAs overlayer. Relatively darker regions contain more Ge compared to lighter regions.

The epitaxial materials were grown on semi-insulating (001) GaAs substrate. The precursors were trimethyl-Ga ($Ga(CH_3)_3$), along with arsine (AsH_3), silane (SH_4), and germane (GeH_4). The alloy films were deposited after 40nm GaAs homoepitaxy and 20-second anneal in nitrogen (N_2). Various temperatures between 575°C and 700°C were used for the alloy growth, while the pressure was a constant 250Torr.

The team explains: "Our decision to conduct a 20s N_2 ambient anneal prior to depositing the alloy stems from previous studies, indicating that As-rich surfaces are unfavorable for Ge adatom incorporation. Since the

alloys are formed by co-deposition of Ga, Ge and As, an As-rich substrate surface may cause increased segregation of Ge toward the surface as Ga and As incorporate into the film."

Diffraction studies using cross-sectional transmission electron microscopy (XTEM) found single crystal material, but with non-uniform composition. The morphology of the non-uniformity was striated or speckled, according to nominal composition (Figure 1). The difference is believed to be due to varying surface mobility of adatoms, due to the different growth temperatures. Speckled structures arise where the adatoms are less mobile at lower temperatures, giving short-lived variations in composition. Higher mobility allows adatoms to move and feed composition variations in the vertical direction of growth.

Room-temperature photoluminescence (PL) studies revealed peaks at 1550nm (0.8eV), 1720nm (0.72eV) and 1760nm (0.7eV), for samples with 19%, 23% and 29% Ge_2, respectively (Figure 2). Samples with large phase separation did not show PL peaks. At 77K, the 29% striated sample showed several peaks, while the speckled 19% material maintained a single peak. The multiple peaks of the 29% material was attributed to different compositions in the striations.

In addition, a sample with 100nm $(GaAs)_{0.77}(Ge_2)_{0.23}$ alloy layer that was subjected to further growth of 200nm of GaAs was found to be free of anti-phase boundaries (APBs). Such APBs are normally found with GaAs deposition on exact (001) germanium.

The MIT team also grew $(GaAs)_{0.8}(Si_{0.1}Ge_{0.9})_{0.2}$ and $(GaAs)_{0.84}(Si_{0.1}Ge_{0.9})_{0.16}$, using 650°C and 575°C temperatures, respectively. Photoluminescence on these samples gave blue-shifted PL spectra, reflecting the wider bandgap of silicon, compared with germanium. The team comments: "This result suggests the possibility of engineering the range of low bandgaps above 0.8eV using III–IV–V alloys as an alternative to finding the growth conditions needed to fully inhibit composition fluctuations in $(GaAs)_{1-x}(Ge_2)_x$, which thus far remains elusive." ■

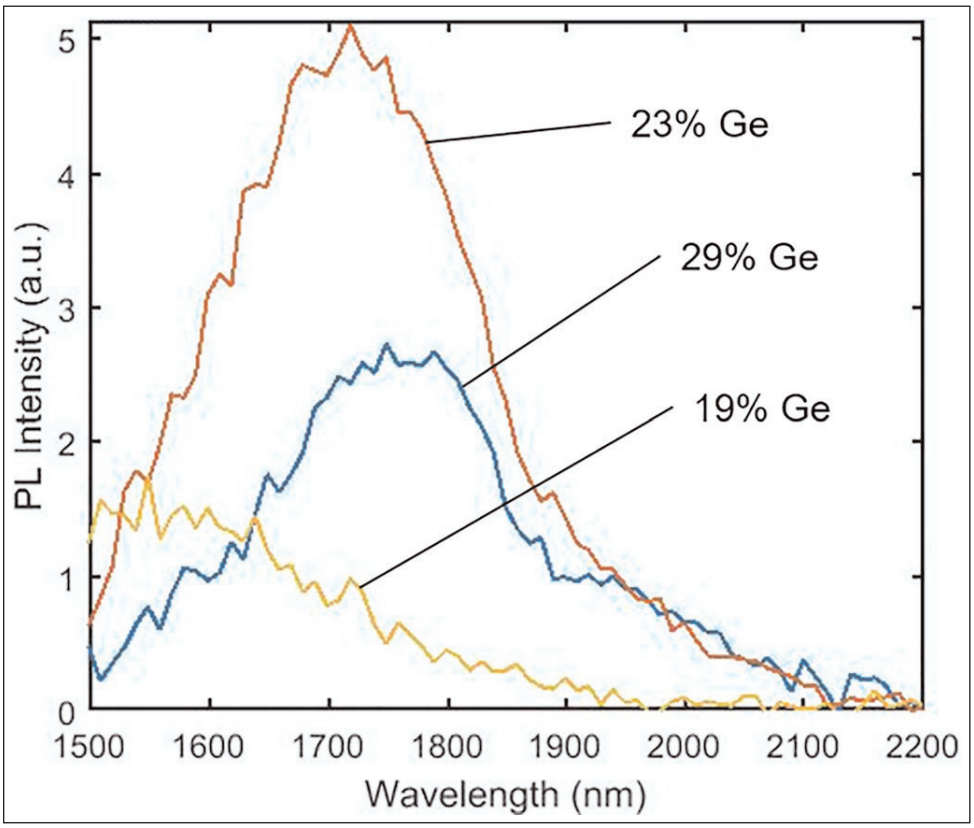


Figure 2. Room-temperature photoluminescence spectra of $(GaAs)_{0.81}(Ge_2)_{0.19}$, $(GaAs)_{0.77}(Ge_2)_{0.23}$ and $(GaAs)_{0.71}(Ge_2)_{0.29}$ alloys.

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Author: Mike Cooke

Monolithic InP on silicon growth for optoelectronics

Hong Kong University of Science and Technology have fabricated near-1.5µm wavelength laser diodes using an on-axis substrate.

Hong Kong University of Science and Technology (HKUST) has been advancing technologies for direct growth of indium phosphide (InP) on silicon (Si) substrate with a view to monolithic integration of optoelectronics on a low-cost platform.

In particular, professor Kei May Lau's group claims the first indium gallium arsenide/indium aluminium gallium arsenide (InGaAs/InAlGaAs multi-quantum-well (MQW) lasers directly grown on on-axis V-grooved (001) Si by metal-organic chemical vapor deposition (MOCVD) [Si Zhu et al, Optics Express, vol26, p14514, 2018]. Miscut silicon substrates are often used to grow III–V materials to avoid defects such as anti-phase boundaries.

Integration of lasers with on-axis silicon is desired for the interconnection of photonic integrated circuits and optical-fiber large-scale networking with the efficient, complex complementary metal-oxide-semiconductor (CMOS) electronics that powers today's communications technologies. Monolithic integration, it is hoped, will reduce the costs arising from additional processing needed for wafer bonding, and also allow the use of larger-diameter substrates for economies of scale.

The V-groove Si was created by etching with potassium hydroxide solution through a silicon dioxide (SiO_2) mask. The parallel stripes were made with a 130nm pitch. The silicon surface was prepared for MOCVD with 800°C thermal desorption of native oxide.

The III–V growth for the laser diode (Figure 1) began with a 10nm GaAs wetting layer on the (111) facets of the grooves at 400°C. The wetting layer was found to avoid non-uniformities and large InP clusters that can be detrimental to further growth and coalescence into thin films.

InP growth began with 435°C nucleation and a 540°C buffer, forming an array of nanowires. The silicon dioxide masking was removed and further 600–630°C InP growth coalesced the film into a 1.5µm-thick layer. This film included an 80nm strained InGaAs dislocation filter. The surface had a 3.31nm root-mean-square roughness, according to atomic force microscopy. There was some evidence of stacking faults with a density of $1.2x10^8/cm^2$. The threading dislocation density ($2.4x10^8/cm^2$) was estimated to be a factor of 3.7 lower than for InP grown on planar silicon ($1.1x10^9/cm^2$).

The InP template was then the basis for the laser structure, with 77nm $In_{0.525}Al_{0.3}Ga_{0.175}As$ separate-confinement heterostructure (SCH) waveguide layers sandwiching the InGaAs/InAlGaAs MQW active region (7x(8nm/23nm $In_{0.54}Ga_{0.46}As/In_{0.53}Al_{0.2}Ga_{0.27}As$)). Cladding layers consisted of InP: 1µm upper p-type, 630nm lower n-type. The p-contact layer was 65nm $In_{0.52}Ga_{0.48}As$. The n-InP contact layer was 120nm thick.

The material was fabricated into ridge-waveguide laser diodes. The ridge widths varied between 2µm and 70µm. The ridge consisted of a narrower mesa and a wider one around the MQW. The aim of the wider regions was to keep the current flow away for the side-walls, avoiding non-radiative surface recombination. Electrical isolation was achieved with 500nm-thick SiO_2. The p- and n-contacts were titanium/platinum/gold and germanium/gold/nickel/gold, respectively.

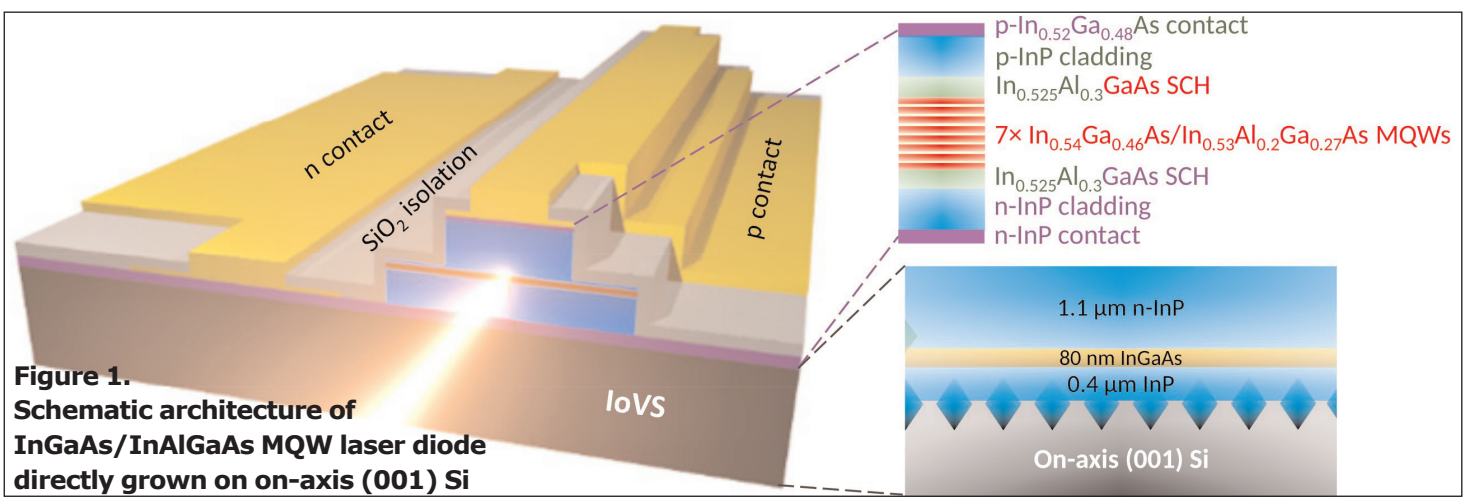

Figure 1. Schematic architecture of InGaAs/InAlGaAs MQW laser diode directly grown on on-axis (001) Si

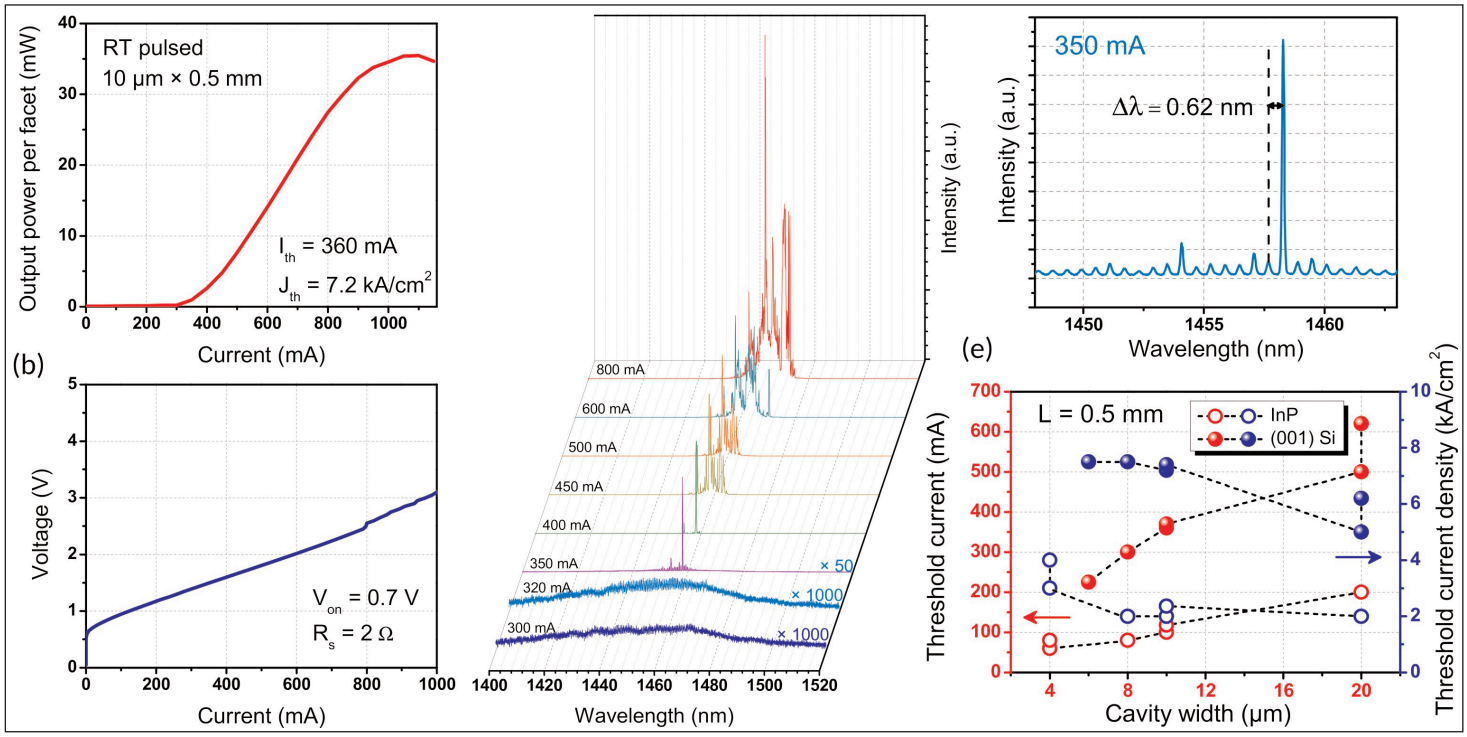

Figure 2. (a) Light output power and (b) current versus voltage characteristics for 20°C. (c) Emission spectra at various injection currents. (d) Enlarged emission spectrum at 350mA current injection. (e) Threshold current and threshold current density as function of laser cavity width with fixed cavity length of 0.5mm on (001) Si and InP substrates.

The final stage of the fabrication involved thinning the wafer to 100μm thick and cleaving into laser bars without surface coatings on the end facets.

The threshold current for lasing in pulsed mode from a 10μmx0.5mm device was 360mA, which corresponds to 7.2kA/cm^2 density (Figure 2). At 1A injection, the output power was 35mW per facet (70mW total).

The main emission peak was at 1.46μm wavelength, but there was some emission from higher longitudinal modes. Similar lasers produced on native InP substrates emit 1.48μm radiation. The researchers attribute the blue-shift on silicon to strain effects arising from thermal expansion mismatches between InP and Si.

Also, the threshold currents of devices on silicon were about three times higher than those produced on InP substrate. "This disparity is mainly due to the penetration of some defects through the QWs on Si, though most of them have been annihilated inside the buffer layers," the team comments. Internal quantum efficiency assessments put the Si-based laser diodes at a 1/2.6 disadvantage compared with devices on InP. Again, defects are blamed. The researchers suggest that more dislocation-reduction approaches, such as thermal cycled growth and multiple dislocation filters (see below), could improve intrinsic performance.

Longer laser diodes allowed lower threshold current density — 3.3kA/cm^2 for a 20μmx2mm device.

Performance measurements at different temperatures gave a characteristic temperature for the threshold (T_0) of 133K in the range 20–40°C and 46.3K for 40–60°C. InP-based devices manage 174K for 20–60°C, 51.5K for 60–75°C and 15.1K for 75–85°C.

Kei May Lau's group at HKUST has also reported on using quantum dots (QDs) as a potential dislocation filter in InP layers on planar silicon (IoPS) [Bei Shi et al, J. Appl. Phys., vol123, p193104, 2018].

MOCVD began with 10nm 400°C GaAs nucleation, 550°C GaAs to smooth the growth front, and 600–630°C high-quality GaAs. The growth rate increased as the temperature was raised. Next, the InP buffer was grown on the GaAs, starting at 435°C, moving through 550°C and ending with 600–630°C MOCVD.

InAs/InP QD dislocation filter layer structures (DFLs) were compared with an $In_{0.58}Ga_{0.42}As$ interlayer (Figure 3). The InAs QD layers and the first part of the InP cap were grown at 510°C. The density of dots was around 3x10^{10}/cm^2. Increased numbers of QD layers were expected to "facilitate the interaction of dislocations and the strain field of the QDs, enhancing the bending effect of propagated dislocations."

However, too many layers could lead to excessive strain that would generate new dislocations. Although theoretical considerations suggested a critical number of InAs/InP QD layers at more than 20, the researchers decided to use just two filter layers with five stacks each. The growth temperature was increased to 600°C to complete the InP cap. The samples B and C differed in the height of the low-temperature InP cap — 2nm and 5nm, respectively.

X-ray analysis suggested upper bounds to the defect

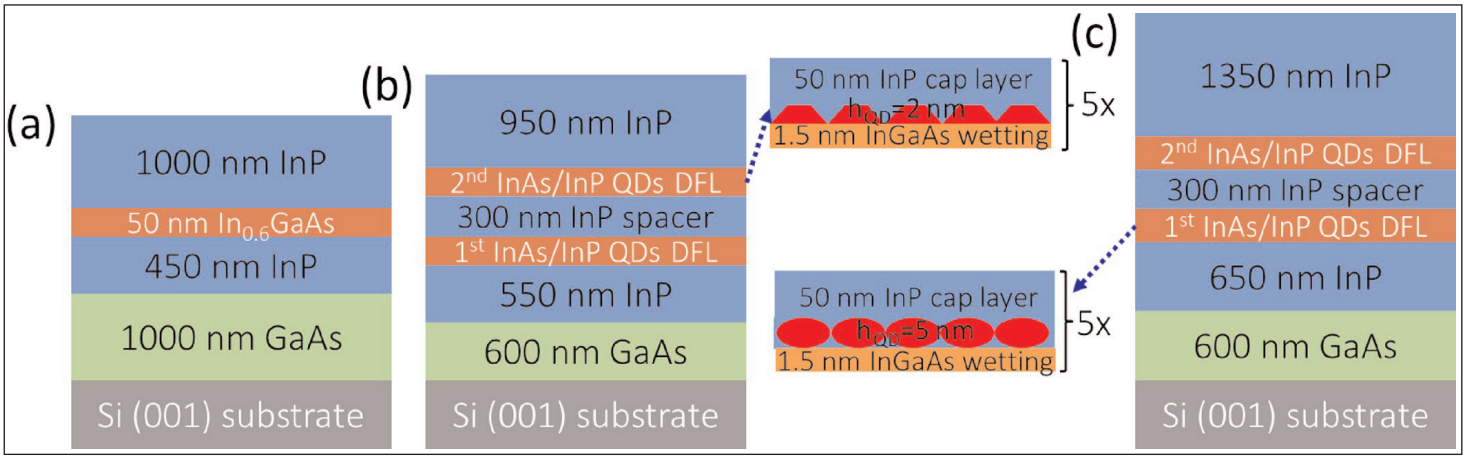

Figure 3. Schematic illustration of InP grown on planar silicon with (a) single strained InGaAs interlayer and two periods of 5-layer InAs/InP QD DFLs with dot height of (b) 2nm and (c) 5nm, respectively.

density of $1.74x10^9/cm^2$, $1.43x10^9/cm^2$ and $8x10^8/cm^2$ for samples A, B and C, respectively. Plan-view transmission electron microscopy gave corresponding threading dislocation densities of $1.2x10^9/cm^2$, $5.5x10^8/cm^2$ and $3.0x10^8/cm^2$. Sample B suffered particularly from stacking faults, which were seen as dashes in the microscopy images. Sample C, however, suffered from regions of extended InAs islands forming during the QD growth process.

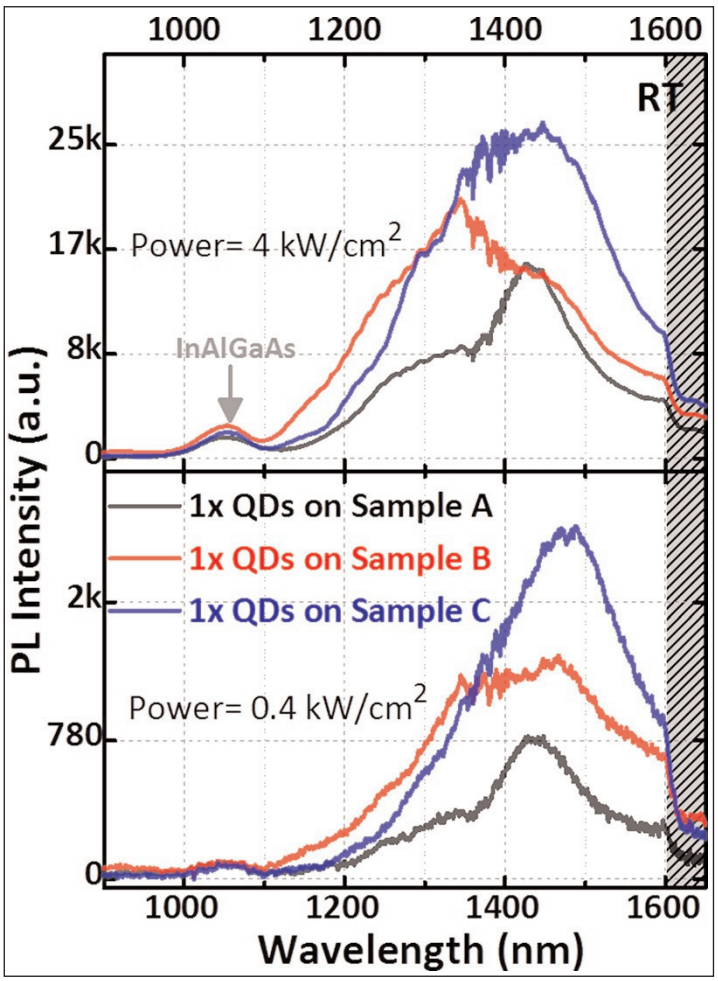

Figure 4. RT-μPL spectra of a sheet of InAs/InAlGaAs QDs on top of the three samples in two different excitation regimes (spectra cutoff beyond 1600nm).

Room-temperature (RT) photoluminescence (PL) experiments were carried out on samples with an extra layer of InAs/InAlGaAs QDs in 200nm InAlGaAs cladding on a 100nm InP buffer layer. Samples A, B and C were used as InP/Si templates. The structure was capped with 1.5nm InGaAs wetting layer and an uncapped layer of InAs QDs. The buried InAs QD layer was grown at 510°C and capped with 1.3nm InAlGaAs. The cladding was grown at 630°C. The dot density was $3.4x10^{10}/cm^2$ on sample A and $3x10^{10}/cm^2$ on C. The researchers hope that similar structures could lead to InAs QD laser diodes on silicon.

The QD layer on template C delivered the highest photoluminescence of all the samples (Figure 4). The linewidth for sample C was a broad 136meV, due to QD inhomogeneity with a bimodal character, giving two peaks. The higher photon energy peak increased in relative intensity at higher excitation power.

The researchers explain: "At RT, the larger QDs dominate the luminescence for two reasons: First, the carrier capture efficiency for larger QDs is higher, compared to the smaller QDs. Second, the thermally assisted tunneling of carriers via coupled excited states (CESs) contributes to the charge carrier transfer to the larger QDs from the smaller ones. However, in a high excitation regime, the excessive carriers can still easily diffuse into the smaller QDs to enhance the shorter wavelength PL emission."

The researchers also assessed internal quantum efficiency by comparing the RT-PL with that at 20K. The RT IQEs for samples A–C were estimated at 12.2%, 13.7% and 17.3%, respectively. The researchers see progress to even better results coming from "optimizing the QD growth condition, minimizing the defect density, and improving the surface smoothness of the IoPS templates." ■

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Mechanism unveiled for strain relaxation in (0001)-oriented III-nitride thin films & heterostructures

3D surface structures and high concentration of shear stress enables nucleation and spread of misfit dislocations in interfacial plane, while critical thickness of films depends on surface morphology and geometry.

A research team in Germany has resolved the fundamental ambiguity behind the formation of misfit dislocations in strained c-plane wurtzite layers (T. Markurt et al, 'A predictive model for plastic relaxation in (0001)-oriented wurtzite thin films and heterostructures', Journal of Applied Physics 124, 035303 (2018)). The new findings could help to optimize, in particular, the growth of aluminium gallium nitride/gallium nitride (AlGaN/GaN) heterostructures for deep-UV emitters and to achieve either films with low defect density or, on the contrary, to intentionally promote plastic relaxation in such structures for strain-engineering purposes.

The researchers at the Leibniz Institute for Crystal Growth in Berlin considered the crucial step of misfit dislocation nucleation and investigated the influence of different growth modes on the strain relaxation process. Their work is reckoned to provide for the first time a reliable quantitative model for the plastic relaxation process of strained c-plane wurtzite films and allows accurate prediction of the critical thickness depending on the actual surface morphology.

Whether relaxing the strain between two layers caused by the lattice mismatch or growing pseudomorphic defect-free heterojunctions, it is critical to understand under which conditions and how misfit dislocations form in the material. Previous quantitative studies of plastic relaxation in wurtzite films adopted the classical models deduced from cubic materials (InGaAs on GaAs, SiGe on Si). In these works, the authors only considered the energy balance aspect,

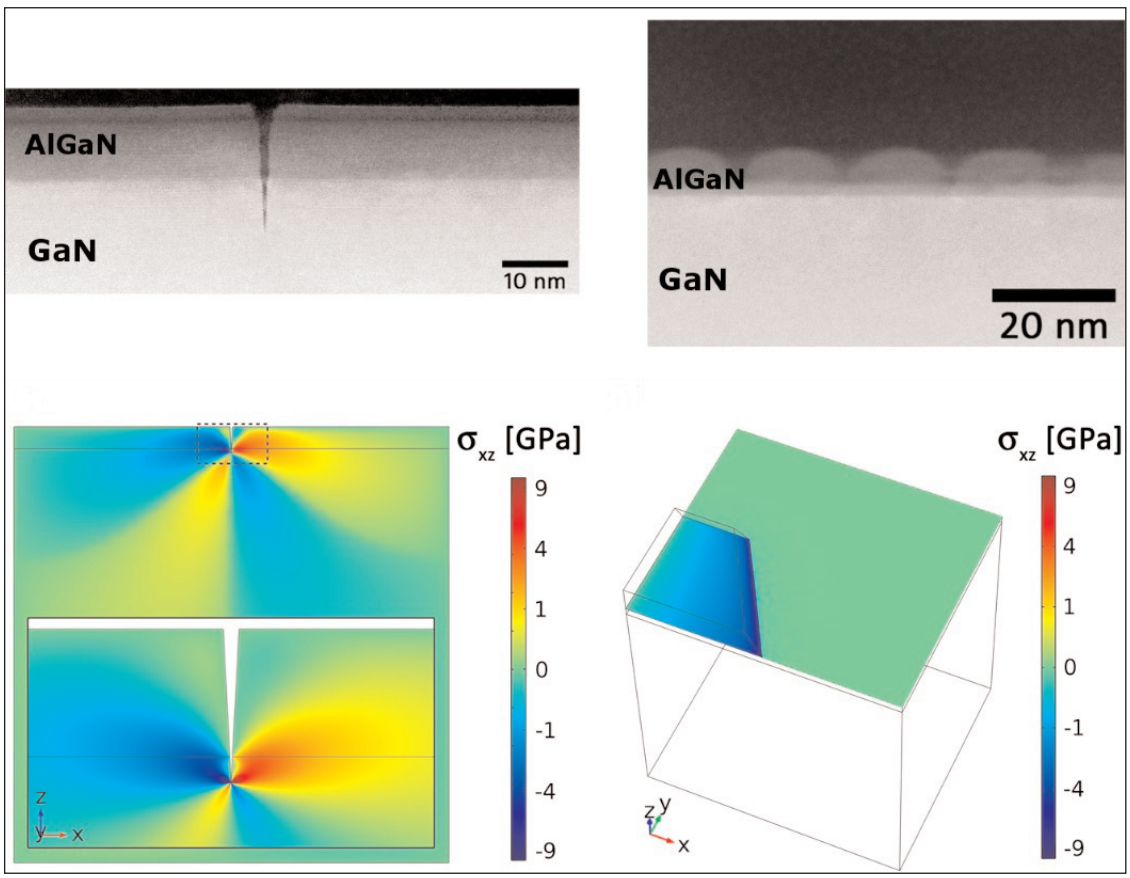

Figure 1: Top: cross-sectional scanning TEM images of AlGaN/GaN heterostructures — two-dimensional layer with a crack (left) and three-dimensional islands (right). Bottom: shear stress calculated for the same surface structures as observed in the experiment.

i.e. the moment when plastic relaxation becomes energetically favourable, while completely neglecting the nucleation process of misfit dislocations itself. However, for wurtzite materials, it is particularly important to consider this process, due to the limitation of how dislocations can move within the wurtzite crystal lattice. As an outcome, a significant discrepancy between theoretical predictions and experimental observations of plastic relaxation in III–nitride thin films has existed for many years.

The current study combines thorough experimental analysis of dislocation formation in AlGaN/GaN heterostructures at each growth step by using transmission electron microscopy (TEM), scanning electron microscopy (SEM) and atomic force microscopy (AFM) techniques, together with theoretical calculations of the stress distribution at the dislocation nucleation sites obtained from the finite-element method.

"We have found that, for c-plane wurtzite films, only the presence of three-dimensional surface structures — islands' edges and corners, crack fronts, surface macro-steps or V-pits — and the high concentration of the shear stress at these sites enables the nucleation and spread of misfit dislocations in the interfacial plane," says author Dr Toni Markurt of the Leibniz Institute for Crystal Growth. "This provides an efficient pathway for the plastic relaxation."

More importantly, according to the authors, the critical thickness of the films strongly depends on the surface morphology and the actual geometry of surface structures: for example, two-dimensional layers with cracks can be grown thicker than films with three-dimensional islands, before undergoing plastic relaxation.

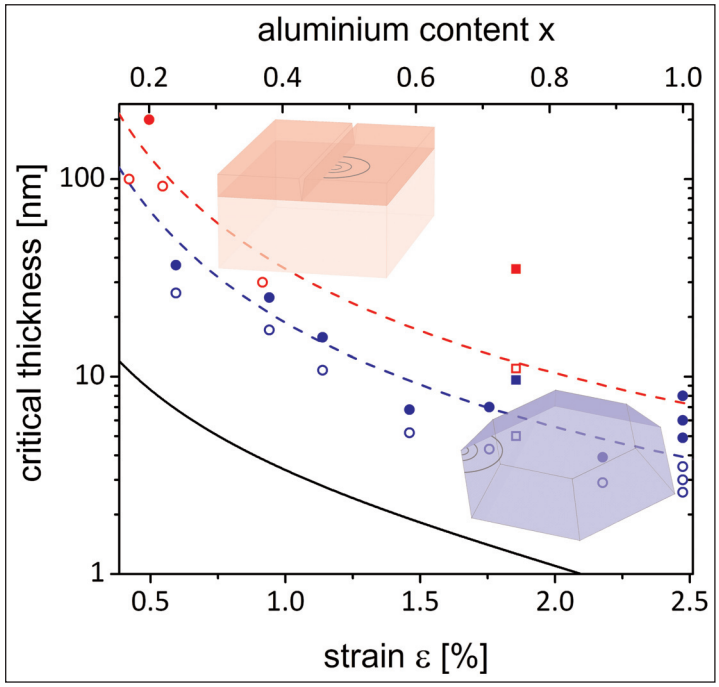

Figure 2: Critical thickness for plastic relaxation of c-plane strained wurtzite films. Dashed and solid lines correspond to calculated critical thicknesses according to the new results depending on surface morphology and old model. Symbols represent experimental data.

The work was performed in close collaboration with Osram Opto Semiconductors GmbH of Regensburg, Germany, which provided dedicated samples for the experimental study. ■

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Strain engineering higher hole density in N-polar aluminium gallium nitride

MOCVD technique overcomes high background free-electron concentration.

Jilin University in China and King Abdullah University of Science and Technology (KAUST) in Saudi Arabia have used strain engineering in graded nitrogen-polar (N-polar) p-type aluminium gallium nitride (p-AlGaN) layers to boost hole density [Long Yan et al, Appl. Phys. Lett., vol112, p182104, 2018]. The metal-organic chemical vapor deposition (MOCVD) technology enabled a significant increase in luminescence from indium gallium nitride (InGaN) multiple quantum well (MQW) light-emitting diodes.

Low hole density in p-AlGaN layers normally arises because of an activation energy that increases with aluminium concentration. By grading AlGaN composition, the researchers set up strain fields that altered the charge polarization and created fixed charges that alter the activation level of magnesium acceptor doping through field ionization. The technique has previously been developed on metal-polar and N-polar p-AlGaN grown by molecular beam epitaxy (MBE). For MOCVD, the technique has been used successfully for metal-polar structures, but N-polar layers suffer from high background electron concentrations that hinders the method's effectiveness.

The materials were grown using MOCVD on sapphire. First, a 2μm N-polar GaN template layer was deposited, followed by 75nm 1020°C magnesium-doped p-AlGaN with composition graded from 0% to 30% Al. The grading was achieved by varying the flow rates of trimethyl-Al and trimethyl-Ga precursors. The magnesium acceptors were activated with 720°C annealing in nitrogen. The AlGaN layer properties were compared with those of another sample with 100nm magnesium-doped GaN on a 2μm GaN template layer.

X-ray studies suggested the AlGaN grading was linear. Also, the x-ray measurements implied that there was no tensile strain relaxation in the AlGaN. It follows from this that the charge polarization arising from the strain should be in the same direction as that arising spontaneously from the AlGaN crystal structure. The researchers comment: "In the fully strained graded AlGaN layer, the magnitude of piezoelectric polarization

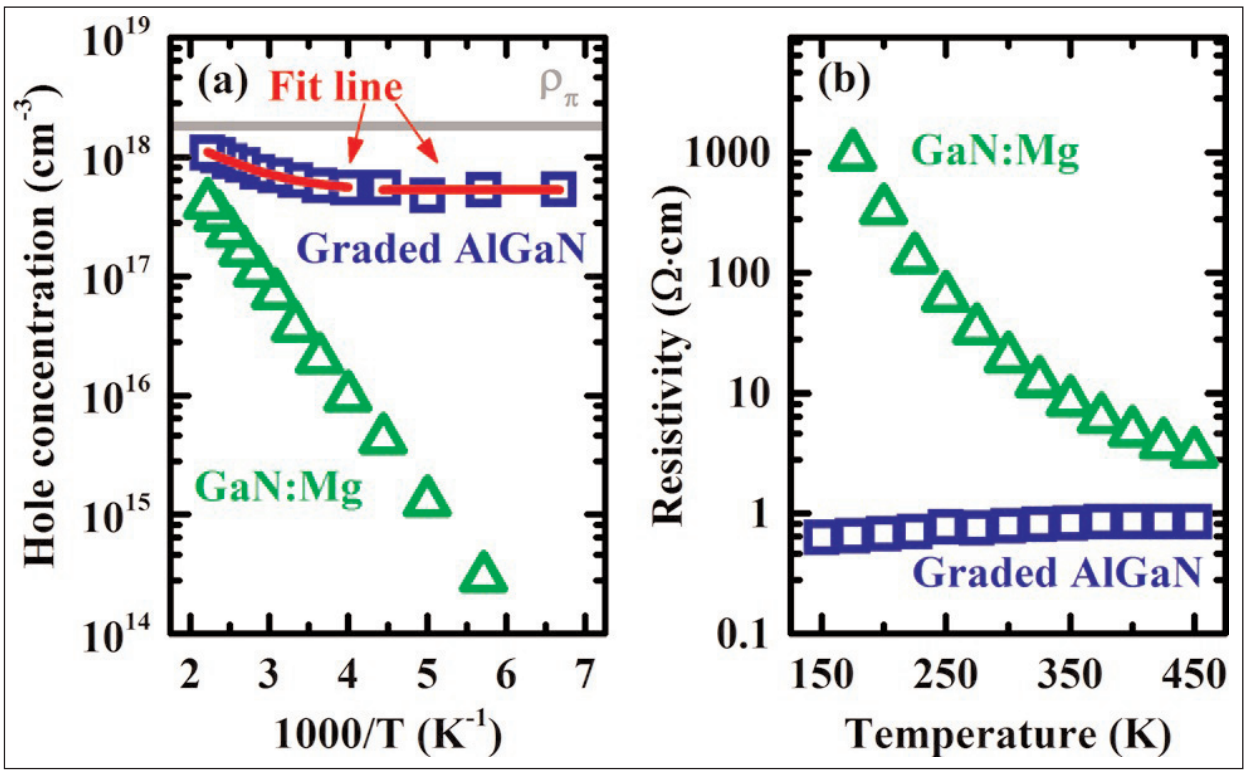

Figure 1. Temperature-dependent hole concentration (a) and resistivity (b) of graded p-AlGaN and p-GaN layers. Gray line indicates concentration of polarization-induced volume charges predicted by theory. Red line is the fit for model including effects of thermally activated and field-ionized holes.

increases with the increasing Al content, which is the same as the trend of spontaneous polarization. Therefore, the fully strained state in the graded AlGaN layer can further increase the polarization gradient."

The change (divergence) in the polarization gives rise to a polarization charge density, estimated at $2x10^{18}/cm^3$ for the p-AlGaN layer. Theoretically, the field-ionized holes from the magnesium acceptors should balance this fixed charge density.

Hall measurements actually gave a hole density in the p-AlGaN layer of $6.4x10^{17}/cm^3$. This compares with $3.7x10^{16}/cm^3$ for the p-GaN comparison sample, down a factor of 17. Furthermore, the hole density in the p-AlGaN was much less temperature-dependent over the range 150–450K (Figure 1).

The team comments: "The absence of freeze-out in the graded AlGaN layer reveals that the holes in the graded AlGaN layer are mainly created by the polarization electric field. Besides, it is worth noting that the measured hole concentration of the graded AlGaN layer is lower than the density of polarization charge (the gray solid line)."

The difference between the $6.4x10^{17}/cm^3$ hole density and the $2x10^{18}/cm^3$ polarization charge density of the p-AlGaN is speculatively attributed to "the screening effect caused by defects".

The increased hole density in the p-AlGaN was also reflected in the 300K resistivity of the layer — 0.8Ω-cm, compared with 19.6Ω-cm for the p-GaN comparison.

Inserting a silicon nitride mask into the GaN template layer increased the p-AlGaN hole density to $7.9x10^{17}/cm^3$. It has been found that silicon nitride decreases the density of oxygen donors that reduce hole density by compensation effects. Further increase in the hole density to $9.0x10^{17}/cm^3$ came with optimizing the magnesium acceptor doping.

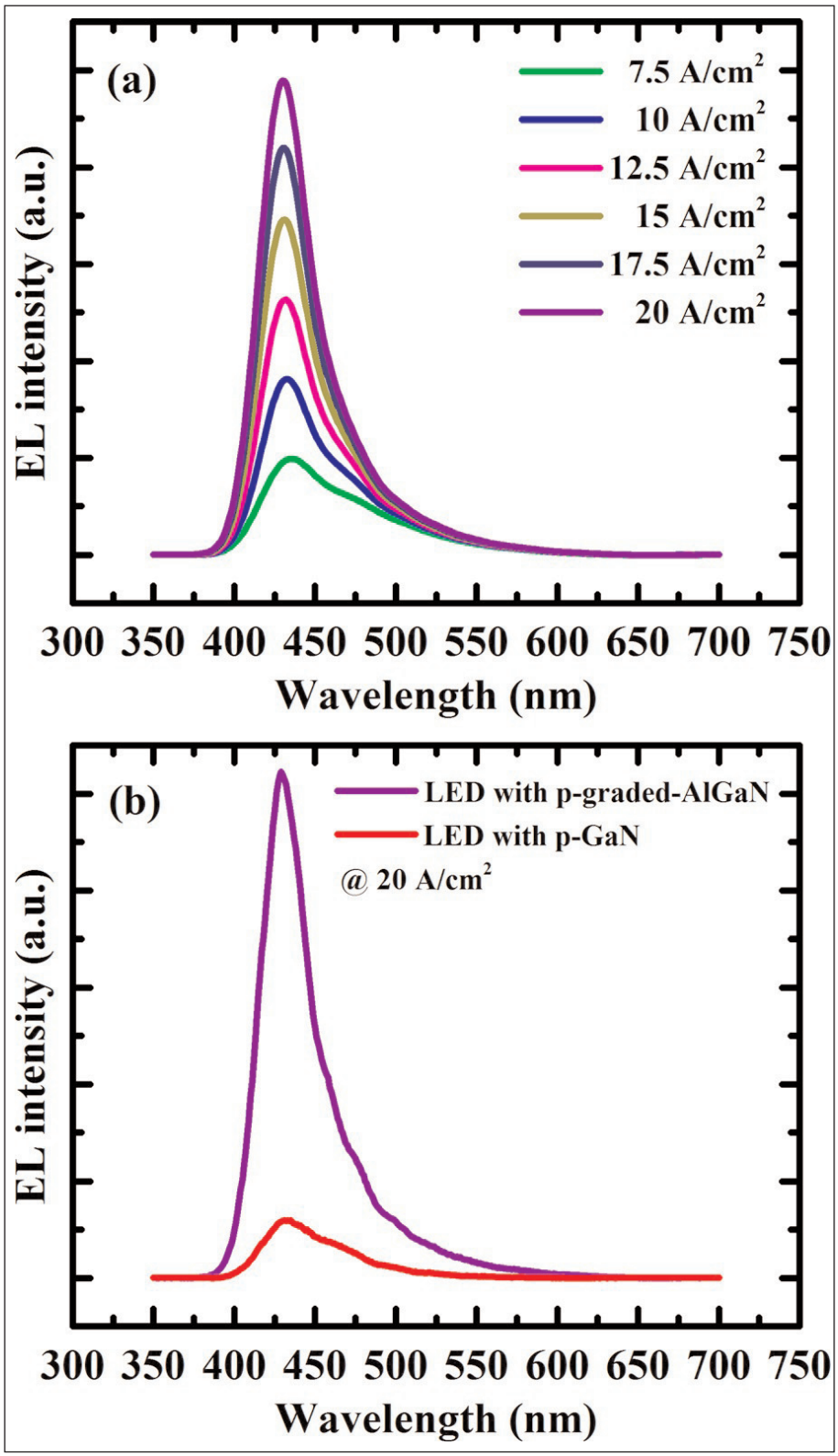

Figure 2. (a) LED spectra with graded p-AlGaN at various injection current densities. (b) LED spectra with p-GaN and graded p-AlGaN hole injectors at 20A/cm² current density.

The researchers finally used the technology to create InGaN MQW LEDs. The MQW consisted of five wells. The p-type contact layer used the optimized p-AlGaN or, for comparison, p-GaN. The p-AlGaN device had peak wavelengths of 435nm and 420nm at 7.5A/cm² and 20A/cm² injection, respectively (Figure 2). The wavelength shift was attributed to free-carrier screening of the charge polarization fields in the MQW region. The p-AlGaN LED had much higher intensity than the p-GaN comparison device, thanks to the higher hole concentration. ■

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Author: Mike Cooke

AlInN as interlayer for green-emitting multi-quantum wells

An aluminium indium nitride interlayer has boosted photoluminescence intensity from green-emitting indium gallium nitride multiple quantum wells by up to seven fold over conventional structures.

Lehigh University in the USA has been using aluminium indium nitride (AlInN) as an interlayer (IL) to boost the photoluminescence (PL) intensity of indium gallium nitride (InGaN) multiple quantum wells (MQWs) in the green region of the visible spectrum [Wei Sun et al, Appl. Phys. Lett., vol112, p201106, 2018]. The MQWs with an AlInN interlayer achieved up to 7x the PL intensity compared with MQWs without an interlayer before the separating 10nm GaN barriers.

Green light is the most difficult to produce from semiconductor devices, compared with the red and blue components for RGB white light. Many groups have been struggling to improve heterostructures for this 'green gap' with a view to more efficient white emitters, compared with blue or ultraviolet light-emitting diodes used as an excitation source on phosphors. Also, direct RGB sourcing would allow versatile color temperature tuning.

The higher indium contents needed for green light-emitting InGaN give rise to problems such as phase separation, defects from large lattice mismatch strain, lower material quality from the low growth temperatures needed for higher indium incorporation, and built-in electric fields from varying charge polarization of the III-nitride bonds.

AlInN with high Al-content provides capping and smoothing effects for abrupt InGaN interfaces. Further, the material enables strain engineering, tuning from tensile to compressive stress by changing the In-content. The wider bandgap of AlInN should also suppress electron leakage, giving better carrier confinement in the wells. AlGaN has previously been used in research as an interlayer. While AlGaN creates tension with respect to GaN, AlInN allows strains from compression through lattice matching to tension.

Table 1. Sample MQW structures. Barriers for all structures 10nm GaN.

Sample	Well	Interlayer
A1	3.3nm $In_{0.19}Ga_{0.81}N$	1nm $Al_{0.89}In_{0.11}N$
A2	3.3nm $In_{0.15}Ga_{0.85}N$	1nm $Al_{0.83}In_{0.17}N$
A3	3.0nm $In_{0.19}Ga_{0.81}N$	1nm $Al_{0.89}In_{0.11}N$
B1	3.3nm $In_{0.20}Ga_{0.80}N$	0.4nm $Al_{0.42}Ga_{0.58}N$
B2	3.3nm $In_{0.21}Ga_{0.79}N$	1.0nm $Al_{0.42}Ga_{0.58}N$
B3	3.3nm $In_{0.21}Ga_{0.79}N$	1.7nm $Al_{0.42}Ga_{0.58}N$
C1	3.3nm $In_{0.19}Ga_{0.81}N$	None

The structures were grown using metal-organic chemical vapor deposition (MOCVD) on c-plane sapphire. Metal-organic precursors were triethylgallium (TEGa), trimethylindium (TMIn) and trimethylaluminium (TMAl), while ammonia provided the nitrogen. The GaN template consisted of an 800nm buffer grown at 1050°C and 3μm undoped material. Five-period MQW structures

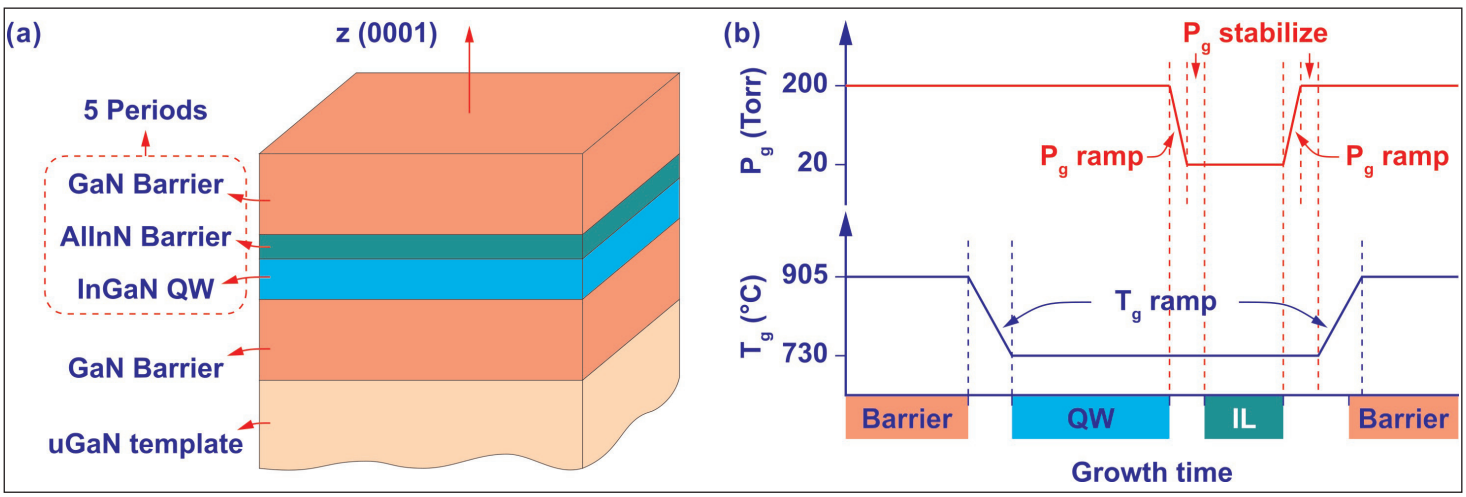

Figure 1. (a) Schematic illustration of the InGaN-based multiple quantum well (MQW) structure with an AlInN barrier layer or interlayer. (b) Profile of growth temperature (T_g) and pressure (P_g) as a function of time for one period of MQW growth. Growth times not to scale.

were grown on the template with InAlN or AlGaN interlayers (Figure 1, Table 1). During the MQW growth sequence, the pressure and temperature were varied to optimize quality. In particular, InAlN growth required a factor of 10 lower pressure than for the other layers. The changes were carefully ramped to avoid turbulence in the chamber.

X-ray diffraction (XRD) analysis suggested that the AlInN interlayer enabled improved structures with more abrupt heterointerfaces. The researchers attribute the improvement first to the interlayer capping the wells and preventing out-diffusion of indium. Second, the tensile strain of the interlayer compensates the compressive strain of the wells, allowing pseudo-morphic growth over the five periods of the MQW structure.

The sample A1 with AlInN interlayers had 5x more intense photoluminescence (PL), compared with the reference sample C1 without interlayers with excitation from a 400μm-diameter 405nm laser spot with 24W/cm^2 power density. The spectrum of the A1 sample was broader with 44nm full-width at half maximum than the spectrum from C1 (35nm). The researchers comment: "The broadening of the PL spectrum in MQW with AlInN interlayers could be attributed to the inhomogeneous growth of the MQW caused by the pressure changes and unstable growth." The peak wavelength of both structures was 530nm.

The intensity varied with pump power. The A1 sample was 4–7x more intense over the range up to almost 1.2kW/cm^2 power density, compared with C1. The intensity peaked at a lower power for A1. The team suggests that this shows "a decrease in defect or Shockley–Read–Hall recombination".

Varying the samples more widely (see Figure 2), narrower wells gave shorter wavelength, tending into the blue–green region, and higher intensity. Also, reducing the indium composition also gave shorter wavelengths and higher intensity. The AlInN interlayers gave similar performance to the more researched AlGaN structures. ■

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Author: Mike Cooke

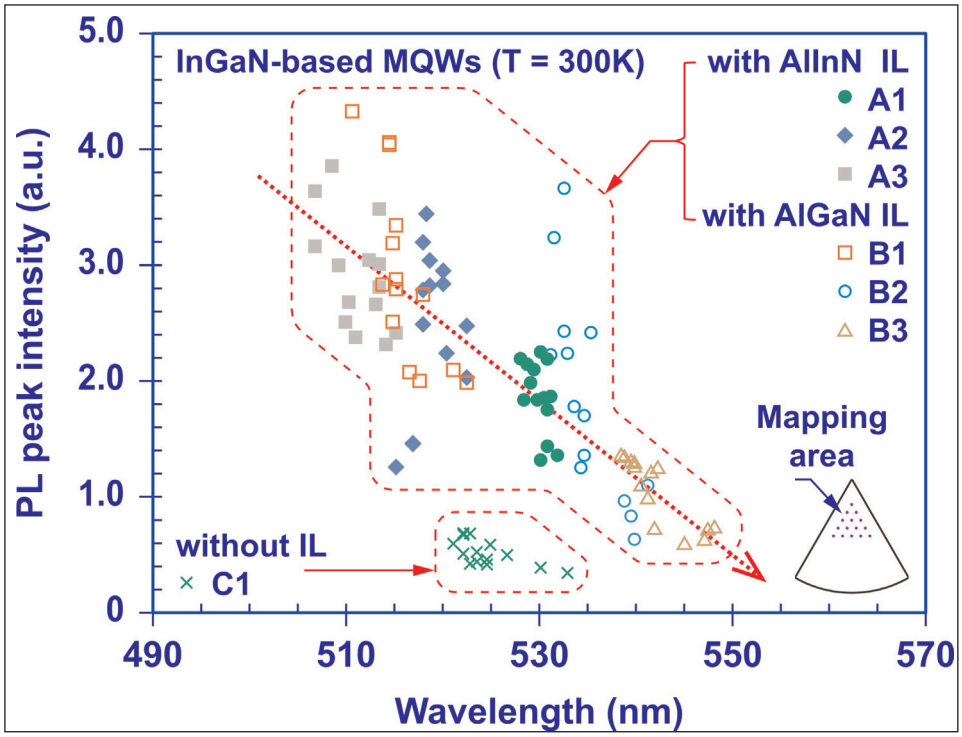


Figure 2. PL peak intensity comparison at room temperature (300K) of seven different InGaN-based MQW samples. For each MQW sample, PL spectra are mapped at 15 different spots with peak intensities plotted as function of peak wavelength.

UCLA develops defect-free boron arsenide as most efficient semiconductor material for thermal management

Better heat conduction from hotspots could boost computer chip performance and energy efficiency.

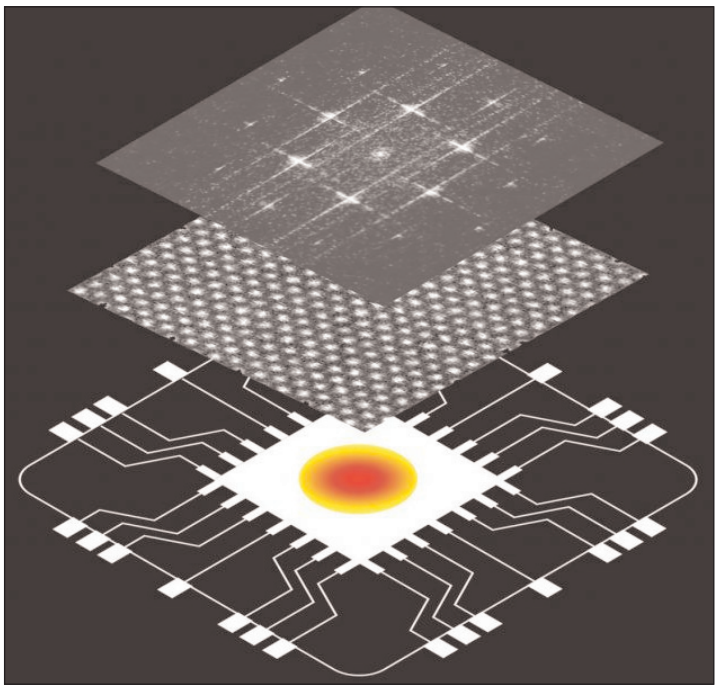
Working to address 'hotspots' in computer chips that degrade their performance, researchers at University of California, Los Angeles (UCLA) graduate students Joonsang Kang, Man Li, Huan Wu and Huuduy Nguyen in the research group of assistant professor of mechanical and aerospace engineering Yongjie Hu have developed defect-free boron arsenide as a new semiconductor material that is more effective at drawing and dissipating waste heat than any other known semiconductor or metal materials (Joon Sang Kang et al, 'Experimental observation of high thermal conductivity in boron arsenide', Science; DOI: 10.1126/science.aat5522). This could potentially revolutionize thermal management designs for computer processors and other electronic components or for light-based devices such as LEDs, it is reckoned.

Managing heat in electronics has increasingly become one of the biggest challenges in optimizing performance, for two reasons. First, as transistors shrink in size, more heat is generated within the same footprint. This slows down processor speeds, in particular at hotspots on chips where heat concentrates and temperatures soar. Second, a lot of energy is used to keep those processors cool. If CPUs did not get as hot in the first place, then they could work faster and much less energy would be needed to keep them cool.

The UCLA study was the culmination of several years of research by Hu and his students that included designing and making the materials, predictive modeling, and precision measurements of temperatures.

The defect-free boron arsenide, which was made for first time by the UCLA team, has record high thermal conductivity (more than three times faster at conducting heat than currently used materials, such as silicon carbide and copper), so that heat that would otherwise concentrate in hotspots is quickly flushed away.

"This material could help greatly improve performance and reduce energy demand in all kinds of electronics, from small devices to the most advanced computer data-center equipment," says Hu. "It has excellent potential to be integrated into current manufacturing processes because of its semiconductor properties and the demonstrated capability to scale-up this technology," he adds. "It could replace current state-of-the-art semiconductor materials for computers."



Schematic of computer chip with a hotspot (bottom); an electron microscope image of defect-free boron arsenide (middle); and image showing electron diffraction patterns in boron arsenide.

In addition to the impact for electronic and photonics devices, the study has also revealed new fundamental insights into the physics of how heat flows through a material, the researchers reckon.

"This success exemplifies the power of combining experiments and theory in new materials discovery, and I believe this approach will continue to push the scientific frontiers in many areas, including energy, electronics, and photonics applications," Hu says. ■

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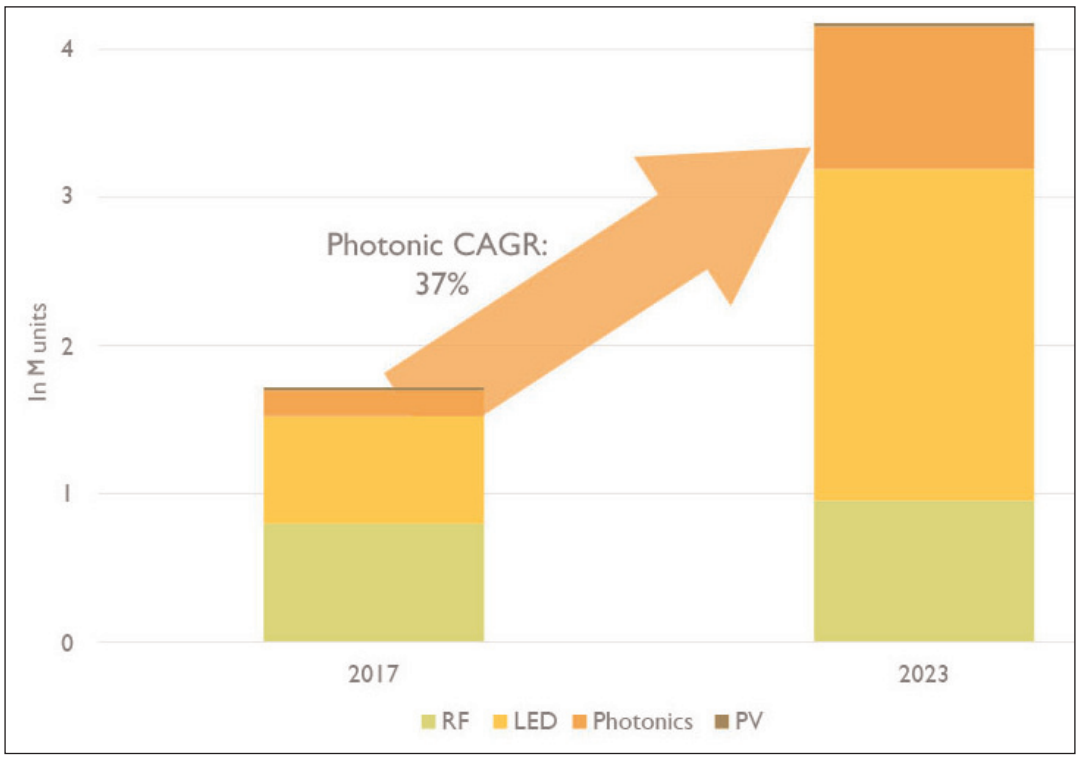
GaAs wafer market growing at 15% CAGR to 2023, driven by photonics applications growing at 37%

RF still comprises over half of the GaAs wafer market, but Apple is driving the adoption for VCSELs while LEDs are growing at a CAGR of 21% to over half of the GaAs wafer market by 2023.

After a quiet period due to the saturation of the mobile handset industry, the gallium arsenide (GaAs) wafer market is rising at a compound annual growth rate (CAGR) of 15% (by volume) between 2017 and 2023, including 37% for photonics applications in particular, according to the report 'GaAs Wafer & Epi-wafer Market: RF, Photonics, LED and PV applications' from Yole Développement.

As one of the most mature compound semiconductors, GaAs has been ubiquitous as the building block of power amplifiers in every mobile handset. In 2018, GaAs radio frequency (RF) business represents more than 50% of the GaAs wafer market. However, in the past couple of years growth has slowed due to the handset market's gradual saturation and shrinking die size. "With the transition from 4G to 5G, we expect GaAs to remain the mainstream technology for sub-6GHz instead of CMOS, owing to GaAs' high-power and linearity performance as required by carrier aggregation and MIMO technology," says technology and market analyst Dr Hong Ling.

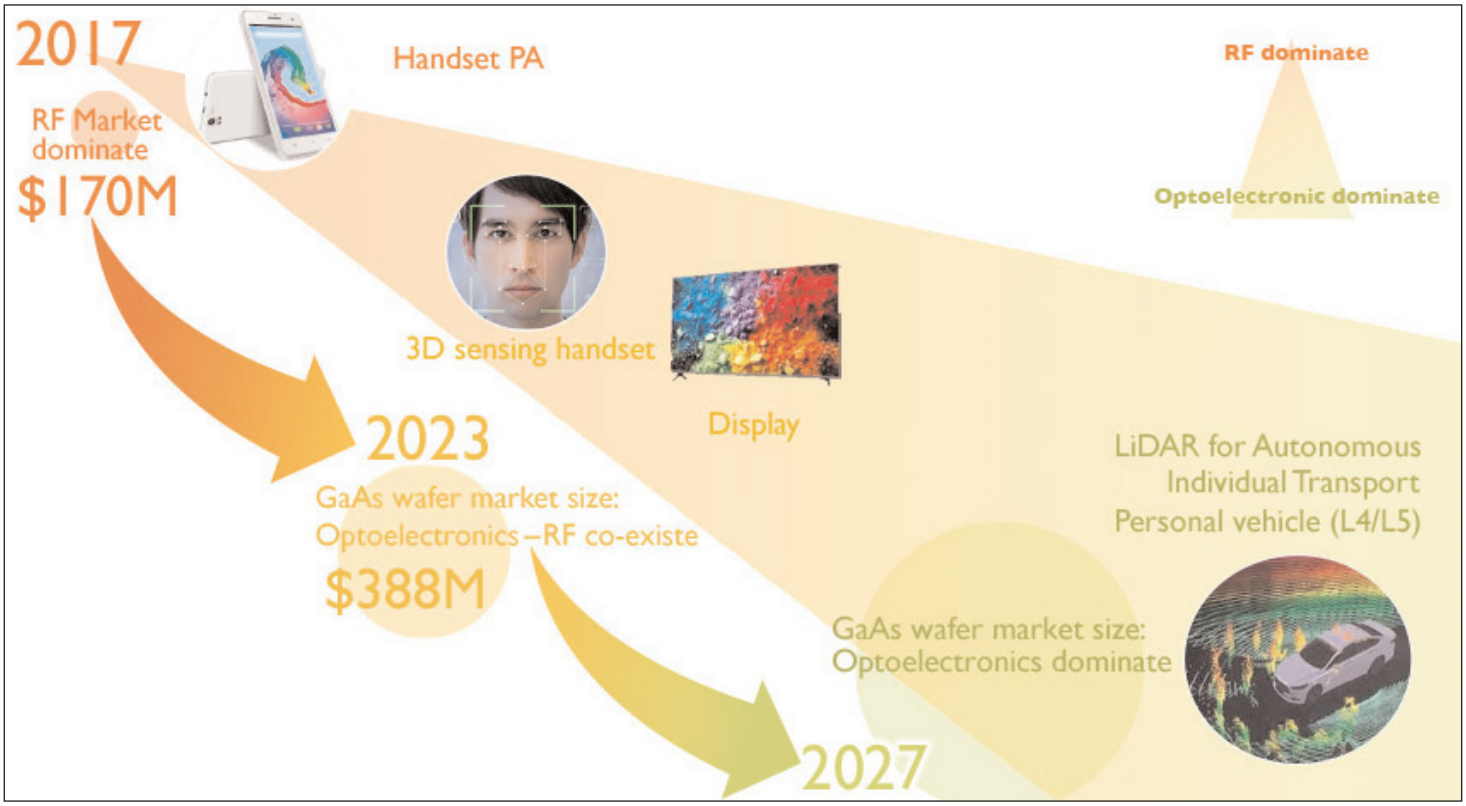


GaAs substrate volume (6-inch equivalent) from 2017 to 2023.

Since 2017, GaAs wafers have been particularly notable in photonics applications. When Apple introduced its new iPhoneX with a 3D sensing function using GaAs-based vertical-cavity surface-emitting lasers (VCSELs), it paved the way for a significant boost in the GaAs wafer market segment for photonics applications, which should grow at a CAGR of 37% to about $150m by 2023.

"GaAs-based ROY [red-orange-yellow] and infrared light-emitting diode applications have also caught our attention," says technology and market analyst Dr Ezgi Dogmus. For the total GaAs LED market, Yole forecasts a 21% CAGR, surpassing more than half of GaAs wafer volume by 2023.

In terms of wafer and epiwafer business, each application needs a different size and quality when determining prices. As a new entrant, photonics applications will impose new specification requirements compared with the well-established RF and LED wafers and epiwafers, creating significant diversity in average selling price (ASP).



Evolution of the GaAs industry, from 2017 to 2027, by market segment.

GaAs photonics: smartphones today, automotive tomorrow?

The GaAs wafer and epiwafer markets are now entering a new era, with optoelectronics taking the limelight from RF applications. Not too long ago, GaAs photonics was a relatively tiny market whose principal application was data centers. But ever since the introduction of a 3D sensing function using GaAs-based VCSELs in Apple's iPhone X, GaAs VCSELs have attracted huge attention. Indeed, three sensor modules based on GaAs VCSELs are used in the iPhone X for facial recognition:
(1) a proximity sensor for activity/human detection;
(2) a flood illuminator for face and eye detection in daytime or night; and
(3) a dot projector for facial recognition.
With potential adoption of this technology by Android platforms, Yole expects this GaAs wafer market segment for VCSELs to grow at a remarkable 58% CAGR over 2017–2023.

Moreover, the GaAs photonics market is not limited to VCSEL applications. Light detection and ranging (LiDAR) is a key technology allowing the creation of a 3D map of surroundings for autonomous vehicles and robotics. This emerging application uses high-power and large-size GaAs-based edge-emitting laser (EEL) devices, which will represent an incredible boost for the GaAs photonics wafer market, says Yole.

Along with the GaAs photonics wafer market's remarkable growth, ROY and infrared LEDs on GaAs substrates are expected to show strong growth potential. Large-display, automotive and horticultural lighting applications are the main drivers for red LEDs, posting a CAGR of 21% over 2017-2023 for the ROY GaAs wafer market. Similarly, GaAs-based IR-LEDs used in medical sensors for blood pressure and blood sugar, as well as proximity sensors for gesture recognition in smartphones and automotive, are also growth segments of the market.

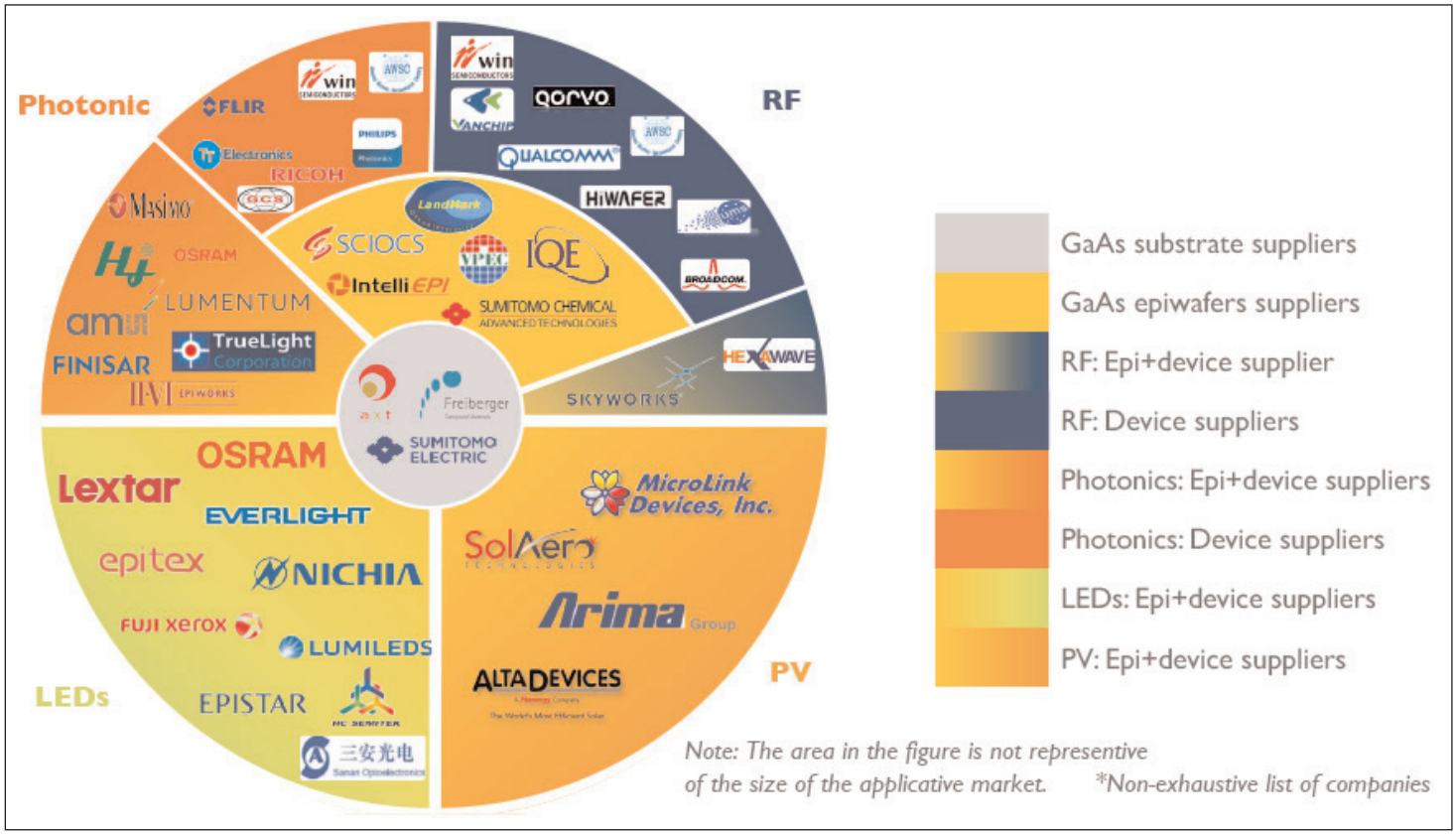
Industrial players embracing the new era

From the point of view of the value chain, the GaAs photonics market's remarkable growth potential will offer plenty of opportunities for wafer and epiwafer suppliers as well as metal-organic chemical vapor deposition (MOCVD) equipment suppliers, and investors.

In terms of GaAs wafer supply, Sumitomo Electric, Freiberger Compound Materials and AXT lead the market, with a collective market share of about 95%. Also, since new laser applications have very high-specification requirements for GaAs wafers that are constantly evolving, Yole expects the top players to maintain their technical advantage for at least another 3–5 years.

Meanwhile, Chinese GaAs wafer suppliers like Vital Materials, which have captured part of the LED market from the leading suppliers, are expected to increase their share thanks to LED markets.

Regarding GaAs epiwafer production, Yole identifies different business models. The GaAs LED market is principally vertically integrated, with very well-established integrated device manufacturers (IDMs) like Osram, San'an, Epistar and Changelight. In parallel, GaAs RF businesses outsource significantly from well-



Overview of the gallium arsenide industry (in 2017).

established epi houses.

Over the last few years, the GaAs RF epi sector has gone through much consolidation, resulting in four main players: IQE, VPEC, Sumitomo Chemicals (including Sumitomo Chemical Advanced Technologies and SCIOCS), and IntelliEPI.

Regarding the GaAs photonics sector, the epi business is still application-dependent. The GaAs datacom segment is mostly epi-integrated, with dominant IDMs like Finisar, Avago and II-VI. For 3D sensing in smartphones, epi outsourcing is significant.

In 2017, Apple's supplier Lumentum used IQE as its VCSEL epi supplier. This resulted in an almost 10x increase in IQE's stock price. Other leading GaAs epi houses are in qualification or ramping up. Yole concludes that it expects the photonic epiwafer market to behave similarly to the GaAs RF epiwafer market. ■

www.i-micronews.com/compound-semi-report/product/gaas-wafer-and-epiwafer-market-rf-photonics-led-and-pv-applications.html

NTT and Tokyo Institute of Technology develop IC allowing 100Gbps wireless transmission in 300GHz band

Future development using multiple carrier wavelengths aims to open up terahertz frequencies.

Tokyo-based Nippon Telegraph and Telephone Corp (NTT) and Tokyo Institute of Technology have jointly developed an ultra-high-speed IC for wireless front-ends that operates at terahertz frequencies, and in the 300GHz band they have achieved what is claimed to be the world's fastest wireless transmission data rate, at 100Gbps — presented at the IEEE MTT-S International Microwave Symposium (IMS 2018) in Philadelphia, PA, USA (10–15 June).

With the spread of broadband networks, high-capacity wireless transmission technology for 100Gbps has attracted global attention (Figure 1). There are three ways of further increasing the capacity of wireless transmission - expanding the transmission bandwidth, increasing the modulation multi-level number, and increasing the spatial multiplexing number. To realize

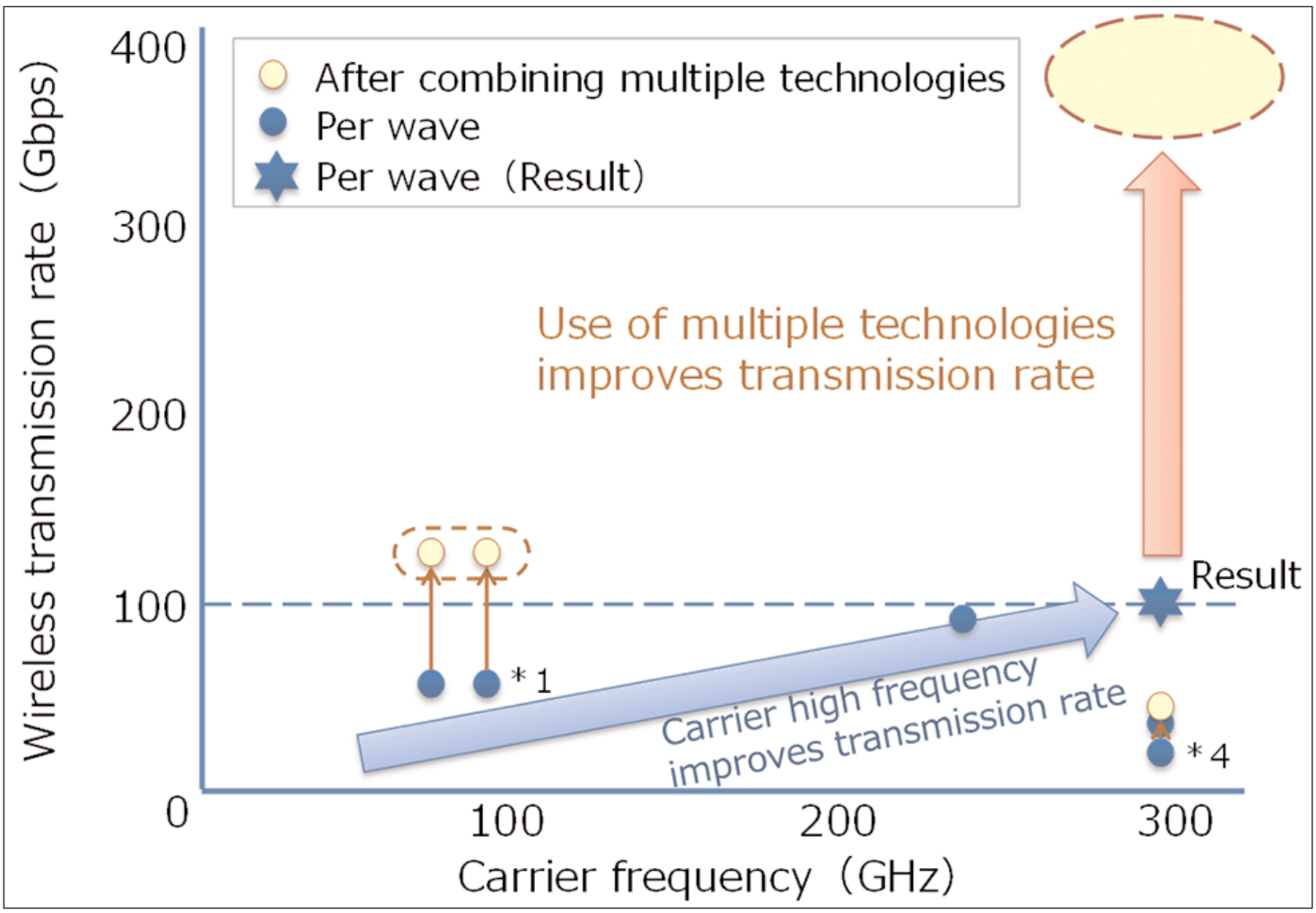


Figure 1. Development of large-capacity wireless transmission technology.

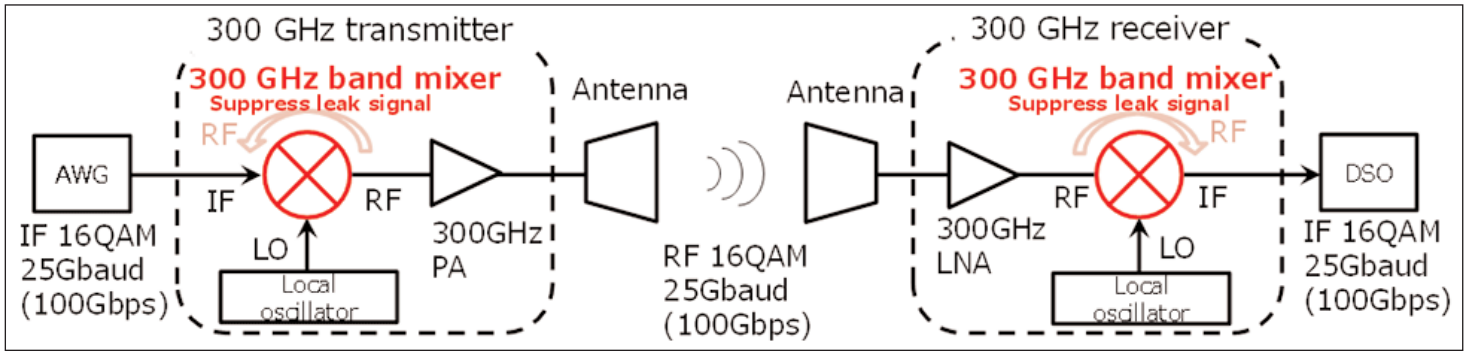


Figure 2. Configuration of 300GHz wireless front end.

future high-capacity wireless transmission technology from 400Gbps to 1 terabit per second (Tbps), it is necessary in one wave (one carrier) to expand both the transmission bandwidth and the modulation multi-level number simultaneously and to increase the number of spatial multiplexing transmissions by superposing them multiple times.

With carrier frequencies from 28GHz to 110GHz that are currently being developed, the transmission bandwidth is limited. So, researchers are studying the use of frequencies that make it easier to expand the transmission band area, from the 300GHz band to the terahertz-wave frequency band. The 300GHz band has a frequency at least 10 higher than the 28GHz band for 5G next-generation mobile communication technology. With the 300GHz band, it will be easier to secure a wide transmission bandwidth from employing as-yet unused terahertz-wave frequencies. On the other hand, with such a high frequency, there tends to be leakage of unnecessary signals between the ports inside the IC and mounting, and so far it has been impossible to achieve a sufficiently high signal-to-noise ratio (SNR). Hence, even if a 300GHz band is used, it is impossible to obtain both a wide transmission bandwidth and a high modulation multi-level value at the same time. So, wireless transmission up to now has remained at a rate of several tens of Gigabits per second (Gbps).

The researchers have now devised a proprietary high-isolation design and applied this technology to a mixer circuit (Figure 2), which is a key component responsible for frequency conversion in the 300GHz-band wireless front end. They also developed an IC using indium phosphide high-electron-mobility transistors (InP-HEMTs).

A mixer circuit has three ports: a local oscillation frequency port (LO), a radio frequency port (RF), and an intermediate frequency port (IF). When operating with

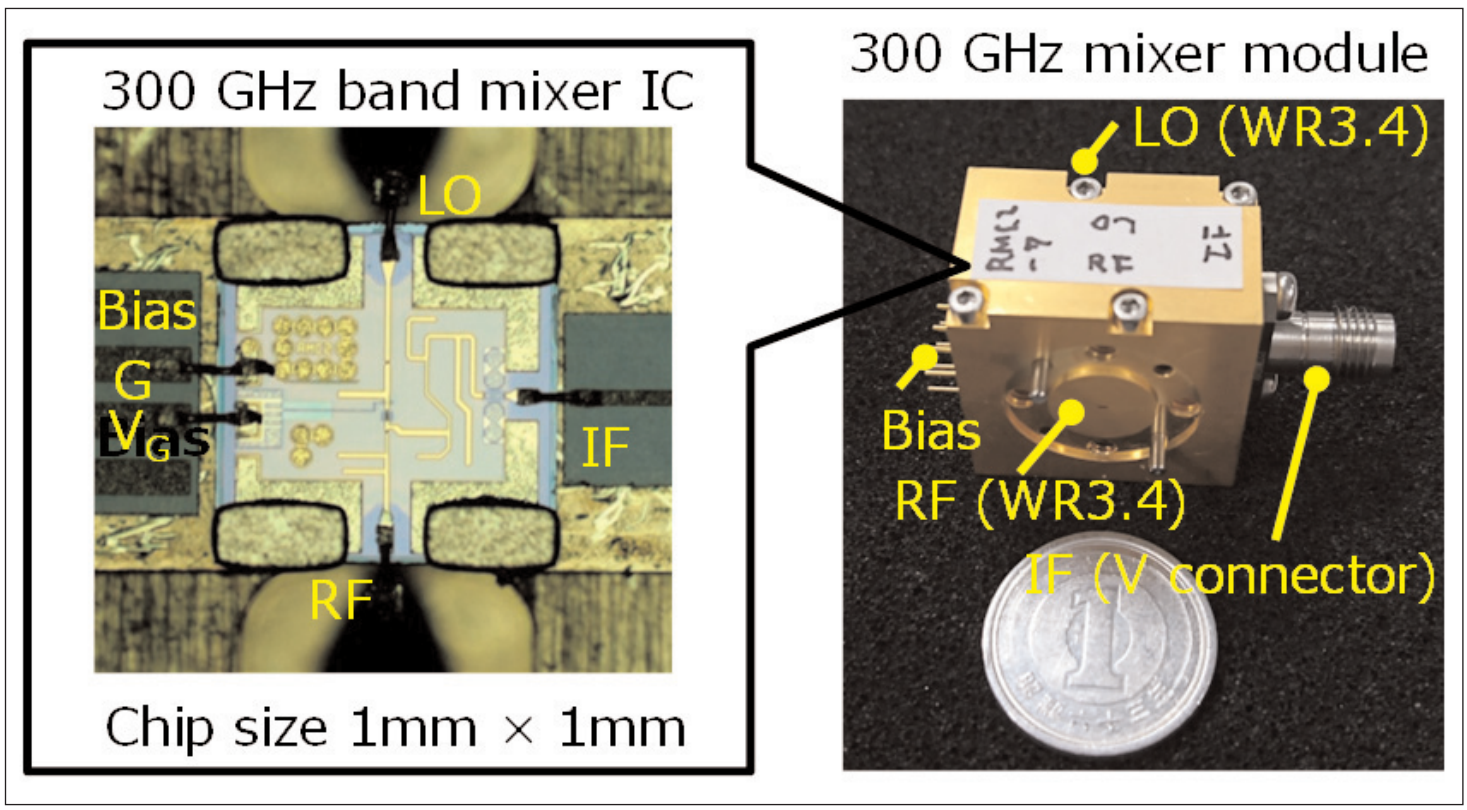


Figure 3. Mixer IC and module.

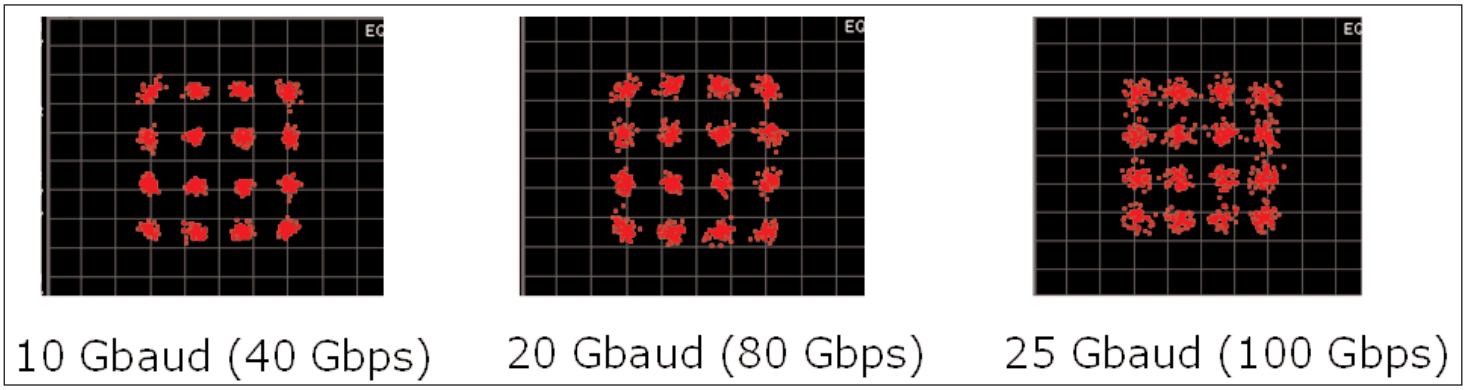


Figure 4. Reception constellation by back-to-back transmission.

the very high-frequency signals of terahertz waves, unnecessary signals leak easily between ports in the IC as the result of a small parasitic capacitance on the mixer circuit and external mounting. By adding a quarter-wave line and series capacitance, a unique design was created that dramatically improved isolation between ports. The high-isolation characteristics realized in this way can suppress the leakage of unnecessary signals, contributing not only to improved SNR but also to preventing the deterioration of frequency characteristics when the mixer IC is mounted on a module. As a result, the researchers achieved both broadband characteristics and high-SNR characteristics for a wireless front-end module.

By using these technologies, the researchers hence realized a 300GHz-band wireless front-end module (Figure 3), and confirmed the reception of a good 16QAM signal in back-to-back transmission (Figure 4). In a 300GHz band, they also confirmed transmission at a speed of 100Gbps, the first time this speed has been attained (Figure 5).

Since 100Gbps wireless transmission was achieved using just one carrier wave, in the future this can be extended to multiple carriers by making use of the wide frequency range of the 300GHz band, as well as using spatial multiplexing technology such as MIMO and OAM. With this combination, it is expected that ultra-high-speed IC technology will enable high-capacity wireless transmission at over 400Gbps, i.e. about 400 times the data rate for existing LTE and Wi-Fi mobile communication technology and 40 times that for next-generation 5G technology. The technology is also expected to open up utilization of the unused terahertz wave frequency band in both communications and non-communication fields, such as imaging and sensing.

NTT says that, through collaboration with partners, it aims to create new services and industries using ultra-high-speed ICs, as well as further developing the technology.

The work was supported in part by the R&D program on multi-tens gigabit wireless communication technology at subterahertz frequencies of Japan's Ministry of Internal Affairs and Communications. ■

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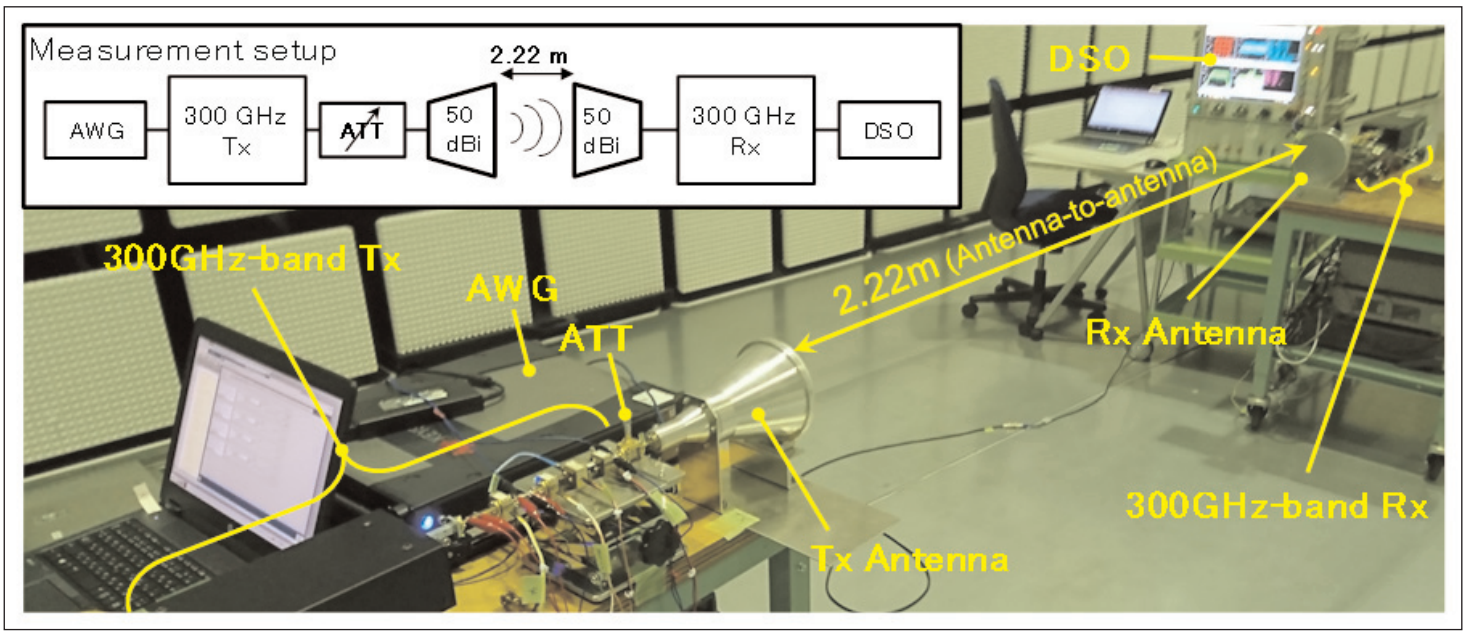

Figure 5. Transmission experiment.

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Expanding the potential of hydride vapor phase epitaxy

Researchers see the growth technique as offering lower silicon doping for vertical gallium nitride power device applications. Mike Cooke reports.

Japan's SCIOCS Co Ltd has been developing its hydride vapor phase epitaxy (HVPE) technology and has recently reported with Hosei University its use as an alternative to metal-organic chemical vapor deposition (MOCVD) for creating very lightly doped n-type gallium nitride (GaN) drift layers in vertical power devices. SCIOCS' researchers believe that device-quality smooth as-grown surfaces with good thickness uniformity can be achieved using HVPE that are comparable with the results of MOCVD. Traditionally, HVPE has been seen as a means to grow thick layers relatively quickly, but with a lower structural quality.

In addition, the firm's researchers have used HVPE to create 6mm-thick free-standing GaN crystals with diameters up to 6 inches. This followed on from the company's claim in 2017 of the first controlled growth of thick GaN layers by an HVPE method with sufficiently low carrier concentrations for drift layers in power-device applications.

The name SCIOCS means 'I know compound semiconductors' (Latin 'scio' + 'CS'). "The name SCIOCS represents our company's philosophy that SCIOCS has the deepest understanding of compound semiconductors, and provides the highest-quality compound semiconductor materials," president Masahiko Kobayashi explains on the firm's website.

SCIOCS was founded in 2015 as part of the Sumitomo Chemical Group, bringing in compound semiconductor activities of Hitachi Cable Ltd, dating back to 1971. Indeed, the firm is located in Hitachi city (-shi), Ibaraki prefecture (-ken). In 2017, Sumitomo Chemical's own compound semiconductor activities were merged with those of SCIOCS.

The company produces GaN substrates and epitaxial wafers, using HVPE and MOCVD, that can be used in microwave equipment (cell phones, base stations, radars and wireless LANs) and in optical equipment (laser diodes for Blu-ray/DVD/CD drives, LEDs for general lighting and LCD backlights). Under development are HVPE aluminium nitride (AlN) templates on sapphire for ultraviolet light-emitting diode application, and potassium sodium niobate (KNN, $(K,Na)NbO_3$) as a lead-free alternative to lead zirconate titanate (PZT, $Pb(Zi,Ti)O_3$) for piezoelectric thin films in micro-electro-mechanical systems (MEMS). SCIOCS used to produce gallium arsenide (GaAs) substrates, but this production line and business has been discontinued.

The use of HVPE technology for vertical GaN-on-GaN growth has been another recent development drive at SCIOCS, creating devices aimed at power conversion using the high frequency and high critical field capability of the material.

Vertical diode

Drift layers in vertical power devices extend the distance over which a potential drops, reducing the electric field and hence increasing breakdown voltages. Epitaxial material for the vertical diode developed with Hosei University was grown on 2-inch free-standing silicon-doped n-GaN substrates [Hajime Fujikura et al, Appl. Phys. Express, vol11, p045502, 2018]. The free-standing substrates were prepared using a void-assisted separation method developed by the researchers during 2003–2017 (see below). The threading dislocation density was uniform in the range $(1–3)x10^6/cm^2$.

The new structure combined epitaxial growth by HVPE and MOCVD methods (Figure 1), and was compared with the results of an MOCVD-only process. The MOCVD-only method required a rather complex n-type drift layer structure (Figure 2). The MOCVD re-growth on HVPE material was prepared with a hydrofluoric cleaning process.

The fabrication of the vertical pn diode (PND) involved mesa etching for isolation and deposition of electrodes consisting of palladium/titanium/gold (Pd/Ti/Au) and indium tin oxide (ITO) for the p- and n-contacts, respectively.

The researchers used an HVPE chamber without quartz parts, as developed by SCIOCS last year [see e.g. Hajime Fujikura et al, Jpn. J. Appl. Phys., vol56, p085503, 2017]. Quartz consists of silicon dioxide. Silicon (Si) and oxygen (O) are donor impurities in GaN. The use of HVPE also avoids carbon (C) incorporation, which is a problem with the metal-organic precursors of MOCVD.

In a quartz-based HVPE system unintended silicon impurity concentration can be of the order of $1x10^{17}/cm^3$, while oxygen incorporation is of the order $8x10^{15}/cm^3$. In their 2017 research, the SCIOCS team found that, by removing quartz from high-temperature areas of the reaction chamber, oxygen and carbon contents were reduced below the detection limit (mid-$10^{15}/cm^3$) of the secondary-ion mass spectroscopy (SIMS) system used to measure impurity concentrations. Process optimization enabled the researchers to reduce the silicon concentration to below the SIMS detection limit of $5x10^{14}/cm^3$. "To the best of our knowledge, this is the purest GaN layer ever reported to date," the researchers commented at the time.

Low-silicon-impurity GaN layers from quartz-free HVPE also have high resistivity of more than $1x10^9\Omega$-cm. Such high resistivity could be the base for devices built using ion implantation of silicon and magnesium impurity doping, as in mainstream silicon electronics. The mobility of n-GaN layers with $1x10^{15}/cm^3$ electron concentration was $1150cm^2/V$-s.

For the more recent research on vertical diodes, the use of quartz-free HVPE was found to reduce non-uniform conductivity due to carbon incorporation and uncontrolled silicon impurity concentration in the drift layer. Non-uniformity was detected by studying electroluminescence variations under a microscope.

Carbon incorporation and the resulting compensation effects in MOCVD material is non-uniform due to the presence of macro-steps of the scale of several tens of microns on the growth surface. The absence of carbon in the HVPE drift layer was confirmed by SIMS.

The team comments: "The absence of carbon compensation and in-plane carrier concentration modulation will make it easy to grow power device structures as they are designed, and hence enable the design of devices with performance reaching the material limitations. Additionally, the absence of off-angle-dependent carrier concentration changes will improve the uniformity and reproducibility of device performance, leading to improved yield in mass production of GaN-based power devices, even if off-angle differences exist within given wafers and/or between wafers."

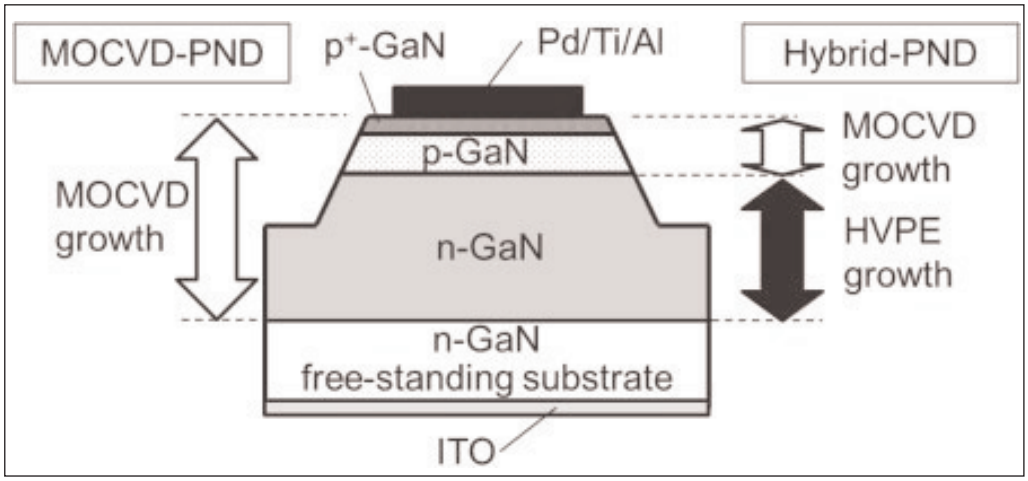

Figure 1. Schematic structure of PN-junction diode.

Off-angle variations arise due to wafer bowing.

A hybrid MOCVD/HVPE diode with 200μm diameter achieved a high breakdown of ~2kV and relatively low on-resistance of $2m\Omega$-cm^2 (Figure 3). The device did not have a field-plate structure to avoid field concentration effects at electrode edges. There was some leakage at low forward bias and the ideality was around 2 rather than the ~1 ideality achieved in the comparison MOCVD-only structure.

The researchers comment: "This deterioration could be attributed to dominance of the recombination current through defect and/or impurity levels within the bandgap due to the presence of accumulated silicon at the re-grown interface. However, all of these observed characteristics of the present hybrid pn diode were superior to those recently reported for a similar pn diode having an MOCVD-grown drift layer and a p-GaN layer re-grown by molecular beam epitaxy." ►

MOCVD	p-GaN	$2x10^{20}/cm^3$ Mg	20nm
MOCVD	p-GaN	$1x10^{19}/cm^2$ Mg	100nm
HVPE drift	n-GaN	$2x10^{15}/cm^2$ Si	33μm
Substrate	Freestanding n-GaN		

MOCVD	p-GaN	$2x10^{20}/cm^3$ Mg	30nm
MOCVD	p-GaN	$1x10^{19}/cm^2$ Mg	500nm
MOCVD drift	n-GaN	$1x10^{15}/cm^3$ Si	2μm
MOCVD drift	n-GaN	$8x10^{15}/cm^3$ Si	15μm
MOCVD drift	n-GaN	$2x10^{18}/cm^3$ Si	2μm
Substrate	Freestanding n-GaN		

Figure 2. (Top) HVPE/MOCVD epitaxial structure. (Bottom) MOCVD-only structure.

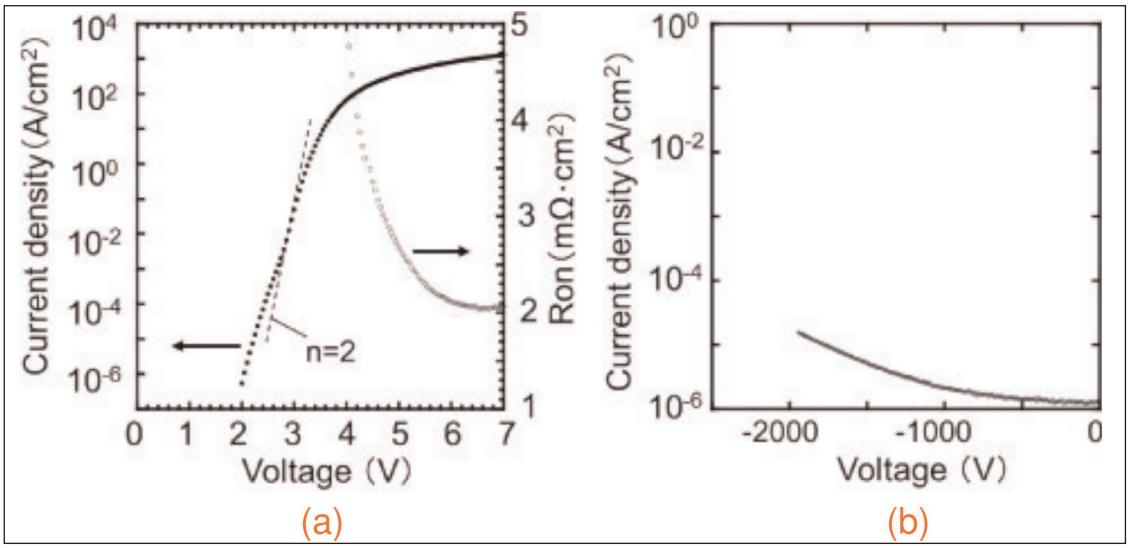

Figure 3. (a) Forward and (b) reverse I–V characteristics of hybrid PN diode made by MOCVD re-growth on HVPE-grown GaN drift layer.

Substrate

SCOICS researchers also used their void-assisted separation method to create 6mm-thick GaN crystals with diameters up to 4 inches [Hajime Fujikura et al, Jpn. J. Appl. Phys., vol57, p065502, 2018]. The team reports that a 6-inch wafer is being processed, but has not yet been characterized: "However, with the availability of similar thick 6-inch bulk crystals as for the 2- and 4-inch crystals, we expect the fabrication of high-quality, macro-defect-free 6-inch GaN wafers from this bulk crystal in the near future."

Void-assisted separation consists mainly of HVPE growth on sapphire (Figure 4). First MOCVD is used to create a thin GaN seed layer with many nanometer-size voids. The HVPE GaN first forms islands on the MOCVD material, which then coalesce and bow the wafer. As the growth proceeds, the bowing becomes less extreme.

The material tends to be less prone to macro-defects, compared with epitaxial layer over-growth methods, since the GaN from the small islands of the seed layer more quickly coalesces. Macro-defects include pits, high-threading-dislocation-density (TDD) regions, inversion domains (IDs), through-holes and cracks.

As the bowing reduces, there are a number of sources of the stress that can lead to cracking. Some stress arises from the bowing reduction. Stress also arises at the edge of the wafer due to increased impurity incorporation compared with the bulk. The edge stress can be reduced by slicing and polishing the final free-standing GaN substrate.

The HVPE process used GaCl as the metal-hydride source. The GaCl was created by flowing hydrogen chloride (HCl) gas over gallium at 800ºC. The nitrogen component of GaN came from ammonia (NH_3). The HVPE growth temperature was typically 1050ºC.

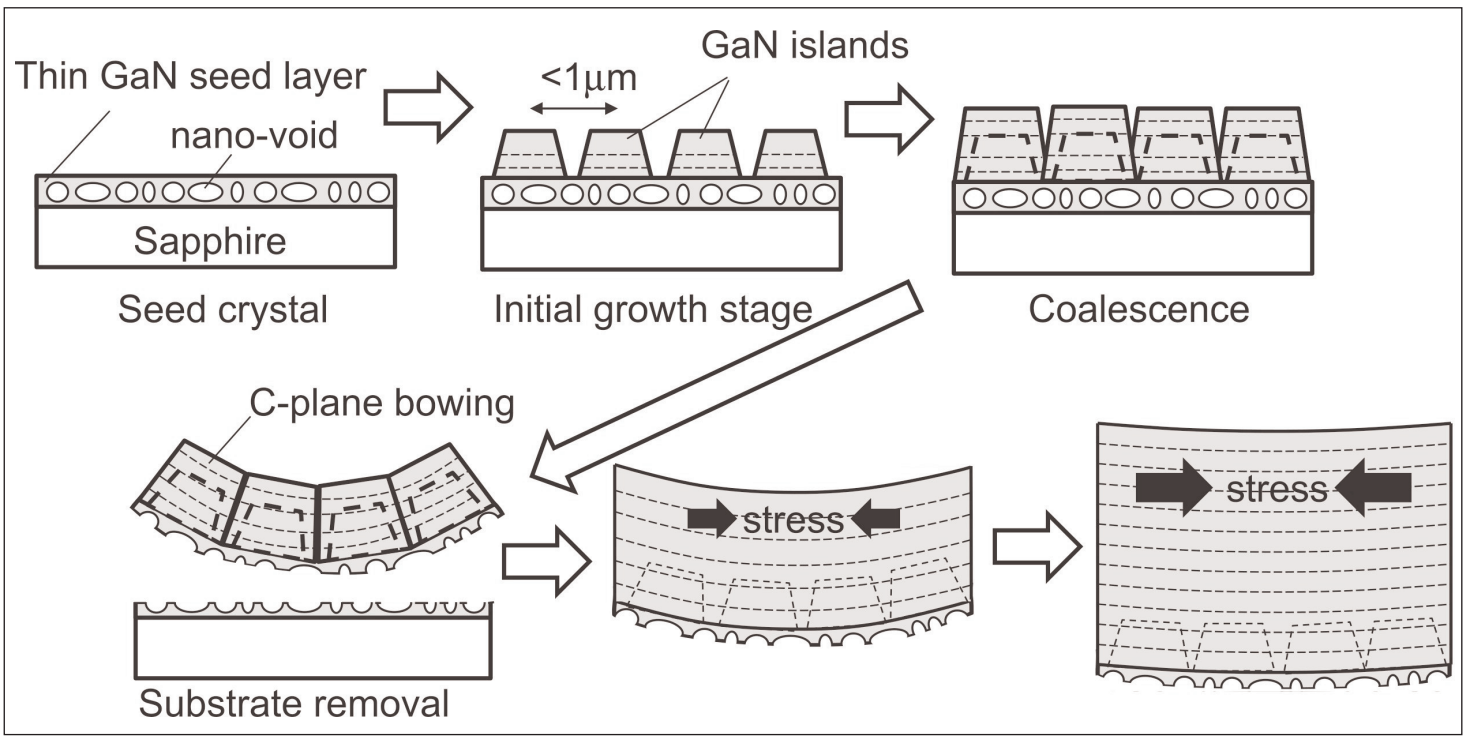

Figure 4. Sequence of void-assisted separation method.

The resulting GaN substrates ranged in thickness from 100μm (0.1mm) to more than 6mm.

The researchers found that the presence of macro-defects allowed the growth of thick GaN substrates without stress-induced cracking or breakage. Macro-defects reduce internal stress since crystal imperfection gives additional freedom for crystal deformation. However, macro-defects make it difficult to produce practical devices with high yield.

The team has therefore studied ways to use increased hardness to overcome the tradeoff by increasing the critical stress allowed in the GaN crystal. The hardness increase was achieved by controlling the HVPE growth conditions to reduce potential for plastic deformation. In previous work, the hardness of GaN substrates was increased from 19.7GPa to 20.1GPa and even 20.7GPa (samples A–C, respectively). The higher hardness value allowed the team to reduce threading dislocation densities even below $1x10^6/cm^2$, compared with $5x10^6/cm^2$ for the 19.7GPa initial sample. The 20.7GPa hardness process enabled GaN thicknesses up to 2mm without cracking.

Building on this work, the researchers achieved 22GPa hardness, allowing GaN thickness to reach 6mm without macro-defects in a 55mm-diameter substrate (2.17 inches). The sample (D) also showed much reduced TDD to the mid $10^5/cm^2$ range (Figure 5). Sample D did not show any tendency for the reduction of TDD with as-grown thickness to saturate. The new growth process for sample D also eliminated basal plane dislocations, allowing for increased thickness. The off-angle variation was less than 0.1º.

The researchers used their technology to realize 4-inch and 6-inch free-standing macro-defect-free GaN wafers with thicknesses of more than 3mm. Off-angle variation was 0.2º for the 4-inch substrate, and the TDD was in the $10^5/cm^2$ range. ■

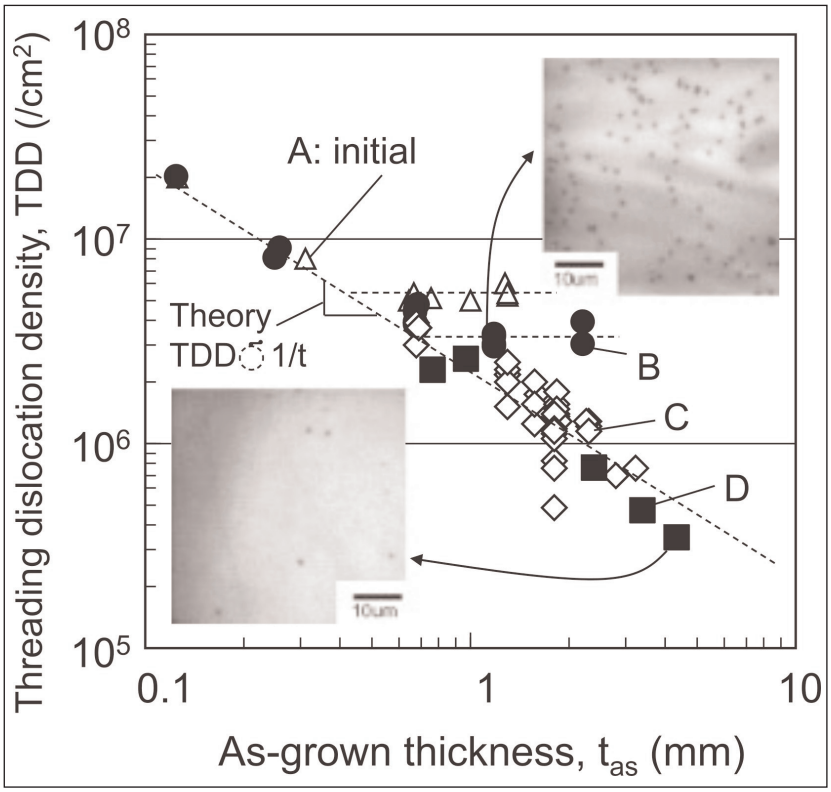

Figure 5. Relationships between as-grown thickness (t_{as}) and TDD for macro-defect-free GaN substrates grown by VAS method using conditions A–D. Insets: cathodoluminescence (CL) images for GaN substrates grown using conditions B and D.

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

Schottky diodes integrated in vertical GaN transistors on silicon

Researchers seek lower costs for vertical power devices using much less expensive substrate.

École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland claims the first monolithic integration of vertical gallium nitride (GaN) metal-oxide-semiconductor field-effect transistors (MOSFETs) with freewheeling Schottky barrier diodes (SBD) grown on 6-inch silicon substrates by metal-organic chemical vapor deposition [Chao Liu et al, IEEE Electron Device Letters, vol39, issue 7, p1034]. This builds on prior work [www.semiconductor-today.com/news_items/2018/jan/epfl_160118.shtml].

The researchers hope to find a lower-cost route to vertical GaN power devices than the very expensive processes based on high-price bulk or free-standing GaN substrates that are presently used in research. GaN substrates are used to avoid defects that reduce the critical electric field for breakdown. Vertical power devices should be able to handle higher voltages and currents than lateral architectures. The use of large-diameter silicon substrates should reduce costs, but growth of GaN on silicon tends to introduce many performance-killing defects.

Freewheeling diodes are used in power conversion applications to allow the flow of reverse-bias current in the off state, releasing energy stored in inductive elements. While the in-built body p-i-n diode of the EPFL structure does allow some current flow, the turn-on voltage is high, increasing losses during switching. SBDs have a much lower turn-on voltage, along with faster switching and lower resistance.

Using external discrete SBDs would increase parasitic inductance with the consequent risks of ringing and

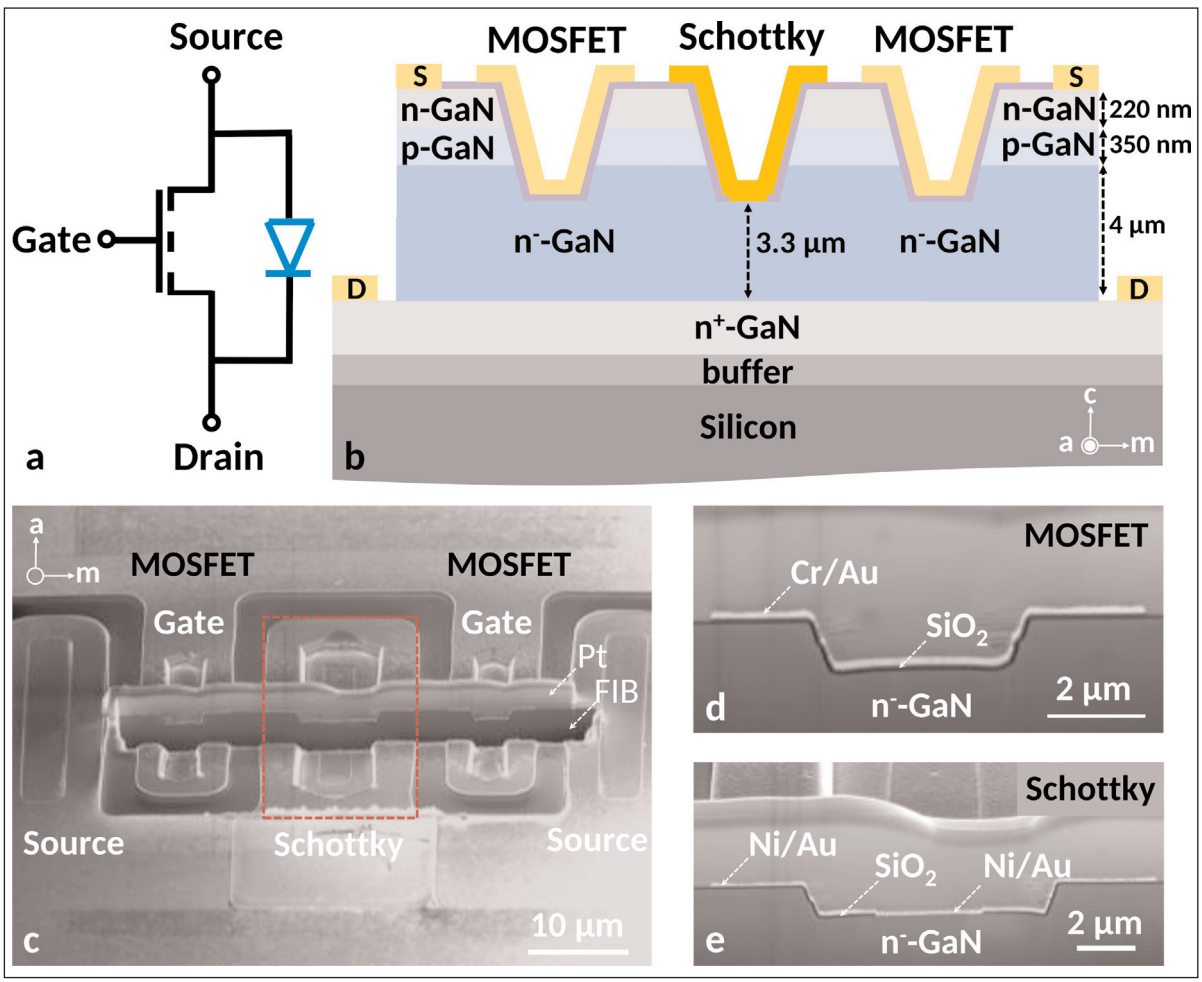

Figure 1. (a) Equivalent circuit. (b) Schematic of integrated vertical MOSFET-Schottky barrier diode (SBD). Scanning electron microscope images of (c) integrated vertical MOSFET-SBD, and (d) cross-sections of integrated vertical MOSFET, and (e) integrated vertical SBD.

other system instabilities. Monolithic integration should reduce parasitic inductance and offer reduced footprints and simpler packaging.

The EPFL device was fabricated from an npn GaN structure on 6-inch (111)-oriented silicon (Figure 1). Plasma etching down to the n^--GaN drift layer was used for 1.3μm trench structures. The surfaces of the trenches were smoothed to 0.42nm root-mean-square roughness with tetra-methyl ammonium hydroxide (TMAH) solution treatment at 85°C for 90 minutes. The SBD metal contact consisted of nickel/gold (Ni/Au). The MOSFET gate stacks used silicon dioxide (SiO_2) insulation with chromium/gold (Cr/Au) metal.

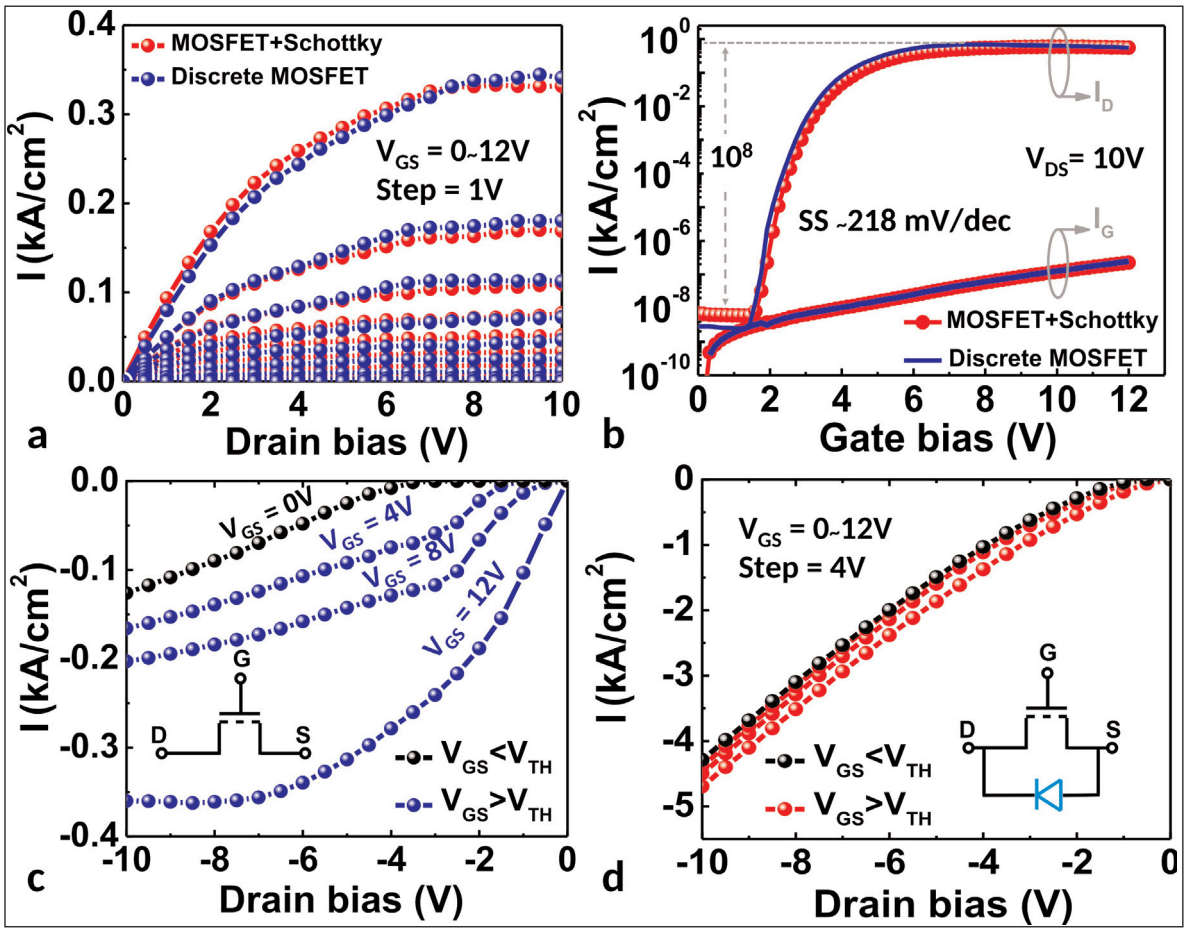

Figure 2. (a) Output and (b) transfer characteristics of vertical MOSFET with/without integrated freewheeling SBD. Reverse-bias characteristics of (c) discrete vertical MOSFET and (d) integrated vertical MOSFET-SBD.

The MOSFET–SBD structure was compared with reference discrete GaN MOSFETs: the saturation current densities were ~0.35kA/cm^2 for both, with respective specific on-resistances of 10.1mΩ-cm^2 and 12.6mΩ-cm^2 (Figure 2). The resistance difference was within the on-wafer variation for devices of the same kind.

With 10V drain bias, the threshold voltages were ~+3.9V for both devices, giving enhancement-mode, normally-on behavior. Under the same conditions, the on/off current ratio was more than 10^8, and the subthreshold swing was ~218mV/decade. The MOSFET–SBD structure did have a slightly higher off-state leakage, but still less than 10^{-8}kA/cm^2. An increase in gate leakage from $6x10^{-10}$kA/cm^2 to $2x10^{-7}$kA/cm^2 as the gate potential was increased from 0V to 12V could be eliminated by a higher-quality, more conformal gate dielectric, according to the researchers.

With a reverse bias on the drain, the turn-on voltage is –3.7V for the body p-i-n diode. By contrast, the SBD allows current to flow even with the gate potential below threshold, and going above threshold only slightly increases the current flow.

The SBD on-voltage for a 20A/cm^2 current density was 0.76V, described as "among the lowest values reported in vertical GaN diodes so far". The specific on-resistance ($R_{ON,SP}$) at 8.7V forward bias was 1.6mΩ-cm^2. The ideality factor at 0.4V was about 1.5. The reverse current was in the picoamp range. The team comments: "A combination of such low $R_{ON,SP}$ and good ideality factor is a result of the excellent drift-layer quality with low defect density, high electron mobility, as well as excellent Schottky contact formed on the smooth n^--GaN surface subject to TMAH treatment."

The breakdown voltages of the discrete and SBD–MOSFETs were 542V and 254V, respectively. Although the SDB-MOSFET had reduced breakdown, the team points out that the SBD had "state-of-the-art performance compared to vertical GaN-on-Si SBDs".

Apart from using low-defect-density GaN substrates, improved breakdown performance could come from increasing the drift layer thickness and reducing background carrier concentrations, along with deploying field-plate, edge-termination and guard-ring technologies. Benefit could also be extracted from alternative architectures such as trench or junction SBDs. ■

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Author: Mike Cooke

SiC power semiconductor market growing at 29% CAGR to $1.4bn in 2023, aided by automotive adoption

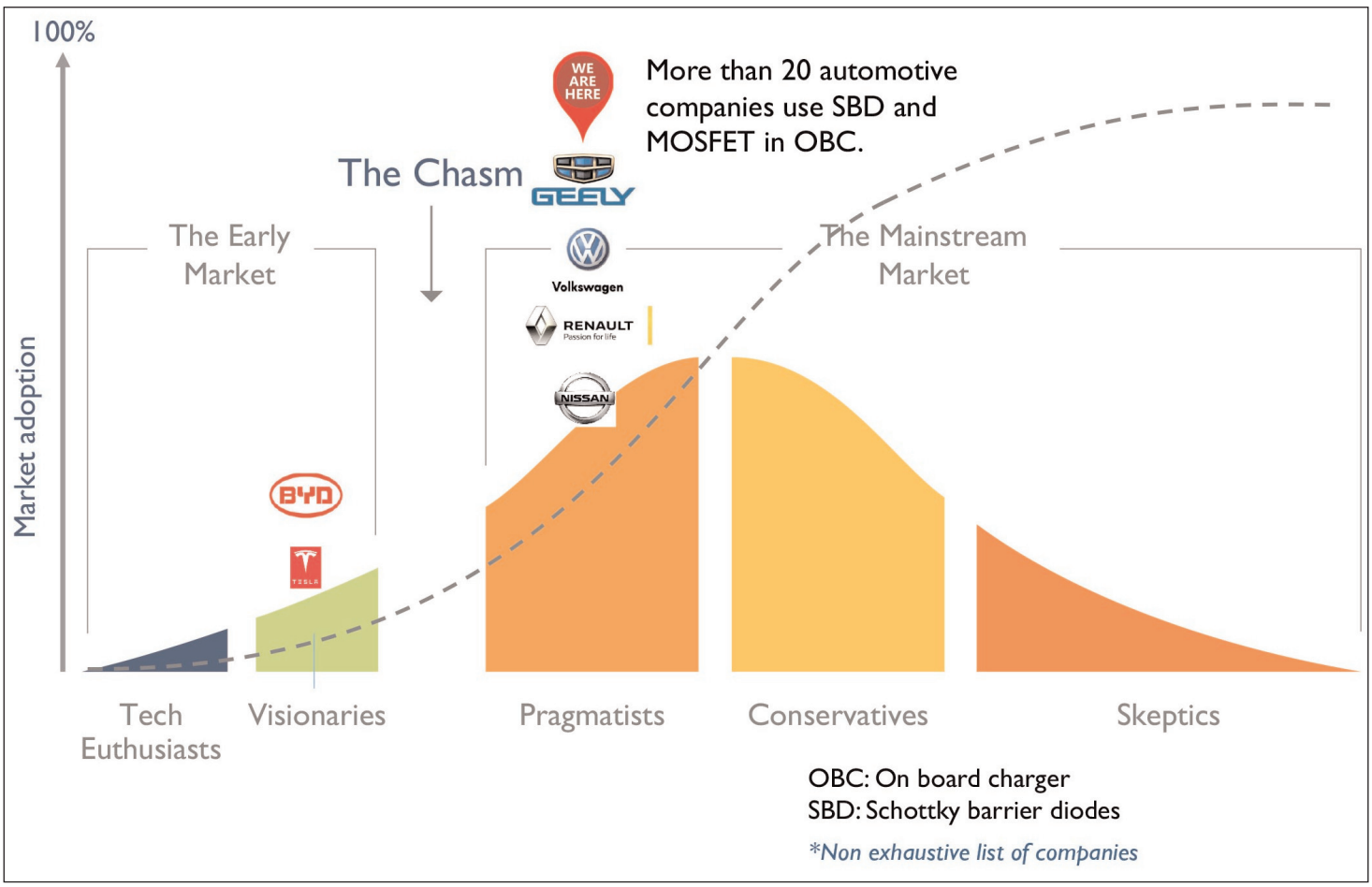
The silicon carbide power semiconductor market is driven by diodes for power factor correction and photovoltaic applications, but transistors are rising at a compound annual growth rate of 50% to be the main driver in 2023.

The silicon carbide (SiC) power semiconductor market is increasing at a compound annual growth rate (CAGR) of 29% from 2017 to $1.4bn in 2023, according to the report 'Power SiC 2018: Materials, Devices and Applications' by the Power & Wireless team at market research and strategy consulting company Yole Développement.

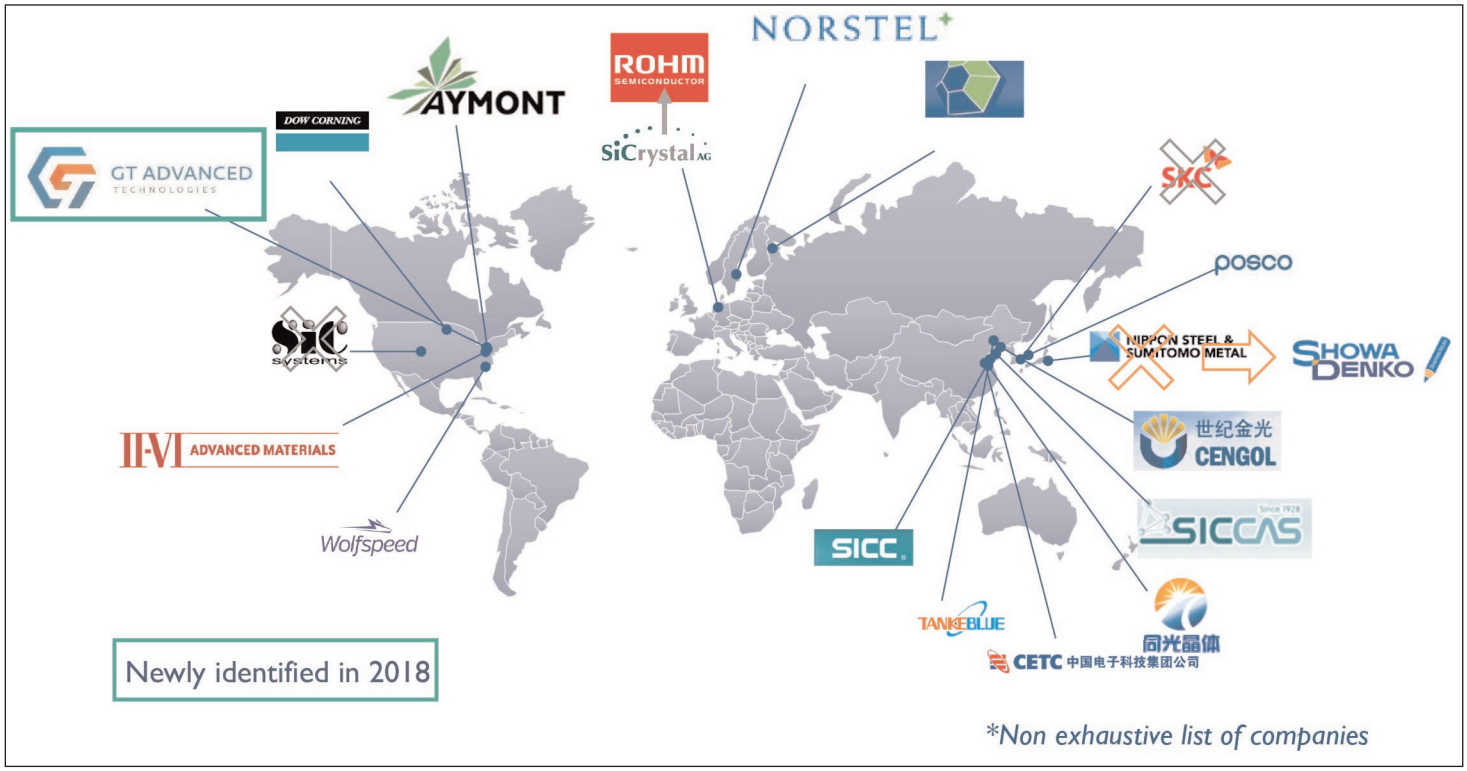
The SiC market is still being driven by diodes used in power factor correction (PFC) and photovoltaic (PV) applications. However, Yole expects that in five years the main SiC device market driver will be transistors, with a 50% CAGR over 2017–2023.

Adoption is partially due to the improvement in transistor performance and reliability compared with the first generation of products, giving confidence to customers regarding implementation.

Yole says that atopic that has been discussed in all its exchanges with industrial players is SiC adoption for



Do SiC technologies cross the chasm?



SiC wafer market — competitive landscape, including R&D players (July 2018).

automotive applications over the next 5–10 years. "Its implementation rate differs depending on where SiC is being used," comments Dr Hong Lin, technology and market analyst, Compound Semiconductors at Yole. "That could be in the main inverter, in the on-board charger (OBC) or in the DC/DC converter," he adds. "More than 20 automotive companies are already using SiC Schottky barrier diodes (SBDs) or SiC metal-oxide semiconductor field-effect transistors (MOSFETs) for the OBC, which will lead to a 44% CAGR through to 2023."

Yole anticipates SiC adoption in the main inverter by some pioneers, at a 108% CAGR during 2017–2023, since nearly all carmakers have projects to implement SiC in the main inverter over coming years. Chinese automotive players in particular are strongly considering the adoption of SiC.

An example of early adoption is the recent SiC module developed by STMicroelectronics for Tesla and its Model 3 car. The SiC-based inverter, analyzed by Yole's sister company System Plus Consulting, consists of 24 1-in-1 power modules. Each contains two SiC MOSFETs with an innovative die attach solution and connected directly on the terminals with copper clips and thermally dissipated by copper baseplates. The thermal dissipation of the modules is enabled by a specially designed pin-fin heatsink.

"The SiC MOSFET is manufactured with the latest STMicroelectronics technology design," notes Dr Elena Barbarini, head of Department Devices at System Plus Consulting. "This technical choice allows a reduction of conduction losses and switching losses," she adds.

STMicroelectronics is strongly involved in the development of SiC-based modules for the automotive industry. During its recent Capital Markets Day, the leading player detailed its activities in this field (Source: Automotive & Discrete Group presentation — May). STMicroelectronics is also committed to the development of innovative packaging solutions.

PV has also caught the attention of Yole's analysts during recent months. China claimed almost the half of the world's installations in the last year. This segment therefore could have helped grow the SiC device market. However, due to new governmental regulations, Yole foresees a slowdown in the PV market in the short term and has hence lowered its expectation of SiC penetration for the segment.

In general, system manufacturers are interested in implementing cost-effective systems that are reliable, regardless of whether the power devices are silicon or SiC based. "Today, even if it's certified that SiC performs better than silicon, system manufacturers still get questions about long-term reliability and the total cost of the SiC inverter," comments Ana Villamor, technology & market analyst, Power Electronics & Compound Semiconductors at Yole.

Silicon carbide adoption accelerating, but is the supply chain ready?

The market is growing in 2018. The question now is how big it will be in five years. Another question is whether the supply chain is ready to embrace the market acceleration? One of the bottlenecks as of 2018 is SiC wafer supply.

The shortage has existed since late 2016. Yole says that last year it heard complaints. Some expected the situation to be resolved in second-half 2017, but as of mid-2018 the issue remains, due to two main reasons:
(1) the transition from 4" to 6" wafers is much faster than suppliers expected;
(2) the increase in wafer demand has been faster than expected.

Some say that the shortage is temporary and typical when shifting to larger wafer sizes. Others consider the situation to be critical. It is a good problem for wafer suppliers, as constrained supply allows them to maintain high wafer prices. But they are also investing heavily to satisfy demand from numerous clients. Yole estimates that, in the coming years, several hundred million dollars will be invested, as leading SiC wafer suppliers Cree-Wolfspeed, II-VI Inc and Dow are all planning to expand capacity.

At the epiwafer level, the market has struggled to take off for several years, but the situation is evolving quickly. For example, Yole has seen Showa Denko expand its capacity consecutively in 2015, 2016 and 2018 as the technology becomes more mature and the outsourcing ratio increases.

Cree pivots, while STMicroelectronics steps up with Tesla

At its investor day in February, Cree announced a turnaround in its strategy following the abortive sale of its Wolfspeed business to Infineon. It decided to instead focus on Wolfspeed which, despite being Cree's smallest business, in 2017 was the market leader in both the SiC wafer and SiC power device markets. This strategy pivot will allow Cree to invest more into its SiC activities (expanding wafer, epiwafer and device capacity) and prepare for market growth. On the other side of the abortive acquisition, Infineon has also developed its SiC power business. The firm signed a long-term SiC wafer supply agreement with Cree and began to actively promote its CoolSiC MOSFETs at different power electronic tradeshows and conferences in 2018.

A foundry model is clearly forming that enables fabless and fab-lite companies to launch SiC products and make the technology more accessible. However, there was also a short supply of foundry services in 2017. The new 6" wafer foundry Clas-SiC Wafer Fab Ltd was founded in 2017 comprising the entire SiC team from Raytheon, which has ceased its SiC activities. Taiwanese foundry Episil is also now active.

Yole and System Plus Consulting teams will attend the SEMICON Europa 2018 tradeshow in Munich, Germany (13–16 November), where Dr Milan Rosina, senior technology & market analyst, Power Electronics & Batteries at Yole, will give a presentation on wide-bandgap semiconductors at 2:30pm on 15 November. SiC and GaN devices have demonstrated their large potential for power electronic applications. During the presentation 'GaN and SiC power device: market overview' in the Power Electronics Session, Rosina will give an overview of the market, technology and the industrial supply chain. ■

www.systemplus.fr

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5 Deposition materials

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8 Wafer processing equipment

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http://spie.org/Optics_Photonics

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CIOE 2018: 20th China International Optoelectronic Exposition
Shenzhen Convention and Exhibition Center, China
E-mail: derek.deng@cioe.cn
www.cioe.cn/en

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

23–27 September 2018
ECOC 2018: 44th European Conference on Optical Communications
Nuova Fiera di Roma, Rome, Italy
E-mail: registration@ecoc2018.org
www.ecoc2018.org

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

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Opera House Bregenz, Austria
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www.led-professional-symposium.com

30 September – 4 October 2018
31st Annual Conference of the IEEE Photonics Society (IPC 2018)
Reston, VA, USA
E-mail: c.c.scott@ieee.org
https://ieee-ipc.org

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Photonex EUROPE LIVE!
Ricoh Arena Coventry, UK
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www.photonex.org

17–19 October 2018
6th International Workshop on Power Supply-on-Chip (PwrSoC18)
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E-mail: trifon@wlmtech.com
http://pwrsocevents.com

23 October 2018
POP2-2018: 2nd International Conference on Photonics and Opto Packaging
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E-mail: office@imaps.org.uk
www.imaps.org.uk/events/pop2-2018-the-2nd-international-conference-on-photonics-and-opto-packaging

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

31 October – 2 November 2018
6th IEEE Workshop on Wide Bandgap Power Devices and Applications (WiPDA 2018)
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www.wipda.org

4–7 November 2018
2nd IEEE International Power Electronics and Application Conference and Exhibition (PEAC 2018)
Shenzhen, China
E-mail: peac@cpss.org.cn
www.peac-conf.org

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

2–6 February 2019
IEEE International Solid- State Circuits Conference (ISSCC 2019)
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E-mail: Issccinfo@yesevents.com
www.isscc.org

2–7 February 2019
SPIE Photonics West 2019, including OPTO 2019 – Optoelectronic Materials, Devices, and Applications
Moscone Centre, San Francisco, CA, USA
E-mail: customerservice@spie.org
www.spie.org/SPIE_PHOTONICS_WEST_Conference
www.spie.org/SPIE_OPTO_conference

17–21 March 2019
APEC 2019: IEEE Applied Power Electronics Conference and Exposition
Anaheim Convention Center, CA, USA
E-mail: apec@apec-conf.org
www.apec-conf.org

7–9 May 2019
PCIM Europe (Power conversion and Intelligent Motion) 2019
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E-mail: daniela.kaeser@mesago.com
www.mesago.de/en/PCIM/main.htm

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Intersolar Europe 2019
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E-mail: info@intersolar.de
www.intersolar.de

27–31 May 2019
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