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semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

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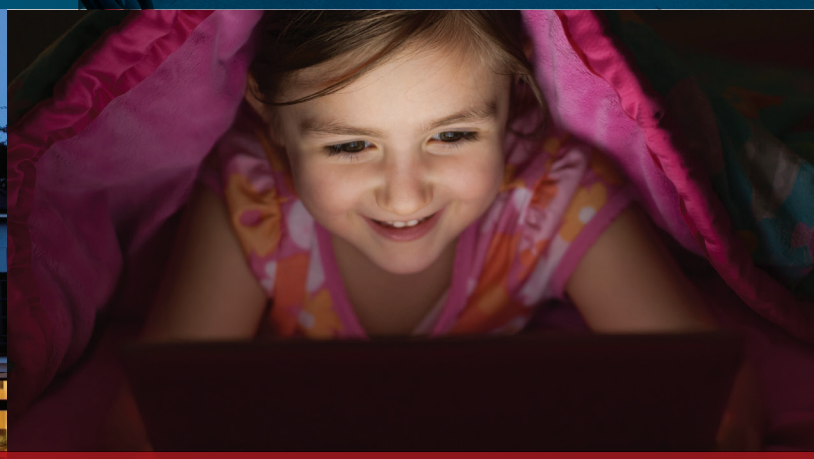
GaAs/Si tandem cell efficiency record raised

Audi & Alta Devices to develop solar cells integrated into car roof

MACOM buys Luna HSOR business • II-VI buys Kaiam's 6" UK fab

Lower Cost LEDs



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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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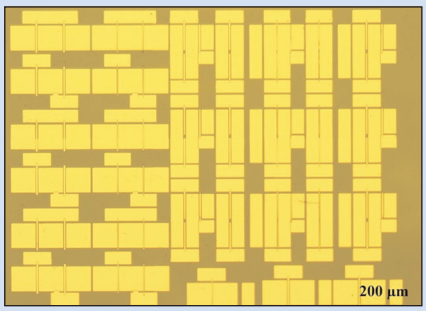
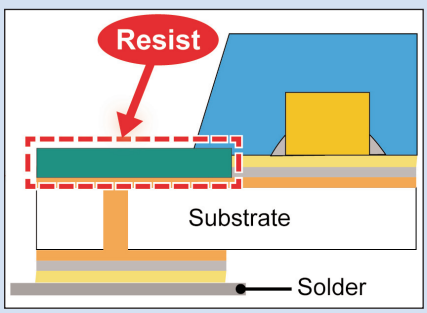
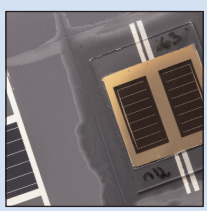


p15 Japan's National Institute for Materials Science has developed logic circuits with diamond-based MOSFETs operating in both D- and E-modes.

p34 Oxford Instruments is boosting its Asia-Pacific R&D center at Taiwan's ITRI, signing an MOU to expand cooperation to micro-LEDs & silicon photonics.



p38 ROHM has shrunk a two-color chip LED by 35% to fit the 1608-size form factor.



Cover: The USA's NREL and Switzerland's CSEM and EPFL have raised the record one-sun conversion efficiency of III–V/Si silicon-based multi-junction solar cells to 32.8% for two junctions and 35.9% for three junctions . **p61**

editorial

Integrated developments

On pages 78–83, we report on June's 2017 Symposium on VLSI Technology in Kyoto, Japan, focusing on work involving indium gallium arsenide (InGaAs), particularly integrated with silicon substrates (targeting low-cost mass production), as well as research on gallium nitride (GaN) devices for high-power switching applications.

Progress includes Singapore/MIT researchers achieving the first monolithic integration of InGaAs field-effect transistors (FETs) and GaAs/AlGaAs quantum-well laser diodes on silicon through direct epitaxial growth. Meanwhile, Lund University reported progress with increasing the on-current in vertical MOSFETs (as an alternative to traditional planar devices at the 5nm technology node). This also represents the first demonstration of a non-planar III–V MOSFET on silicon achieving off-current as low as 1nA/μm. Belgium's IMEC has demonstrated the first implant-free $In_{0.53}Ga_{0.47}As$ n-MOSFETs meeting the reliability targets of advanced technology nodes for maximum overdrive voltage (gate-threshold) of 0.6V with equivalent oxide thickness (EOT) of 1.15nm. IMEC also notes that, as the processing of the interlayer/$LaSiO_x$/HfO_2 gate stack is based on atomic layer deposition (ALD), it could be transferred to device architectures such as horizontal and vertical nanowires. IBM Research Zürich Lab reported the first demonstration of a hybrid 3D 6T-SRAM memory utilizing three-dimensional monolithic (3DM) integration of InGaAs nFETs over silicon CMOS, which promises not only dense digital circuits but also functional integration of RF-on-silicon.

Also at the VLSI Symposium, Taiwan's National Chiao Tung University, Tokyo Institute of Technology and the University of California Berkeley reported a GaN MIS-HEMT transistor (grown on silicon) with high threshold voltage (by using a $HfZrO_2$ blocking layer) for enhancement-mode operation.

The maturing of GaN transistor technology and its adoption — particularly for power switching applications — is indicated by GaN Systems enhancing its LTSpice model simulation tool for design engineers (see page 23). Meanwhile, in addition to granting State University of New York (SUNY) Polytechnic Institute $720,000 to develop more efficient GaN-based power switches as part of the PNDIODES program (page 20), the US Department of Energy's Advanced Research Projects Agency – Energy (ARPA-E) has announced $30m in funding for 21 projects as part of the CIRCUITS program, which aims to speed the deployment of efficient, lightweight and reliable power converters based on wide-bandgap (WBG) semiconductor materials including gallium nitride and silicon carbide (SiC) instead of silicon (see page 18). CIRCUITS focuses on new circuit topologies and system designs, to build on earlier programs that focused on WBG materials and devices.

The adoption of SiC in particular for power device applications such as electric vehicles is driving developments such as Pallidus launching source materials for SiC wafer growth (page 17) and Showa Denko acquiring Nippon Steel's assets for SiC wafer sublimation-recrystallization (page 15). Also, Microsemi has become a member of the PowerAmerica consortium and — as part of the $70m DoE backing over five years to promote the adoption of SiC- and GaN-based components — has been awarded a contract to develop 1.7kV and 3.3kV SiC MOSFETs and SiC Schottky diodes (see page 16).

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

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news

Photonic integrated circuit market growing at 27.5% CAGR from $539m in 2017 to $1.8bn in 2022

The global market for photonic integrated circuits (PICs) reached $426m in 2016, and is expected to rise at a compound annual growth rate (CAGR) of 27.5% from $539m in 2017 to $1.8bn in 2022, according to BCC Research's report 'Silicon Photonics: Technologies and Global Markets', which covers materials including indium phosphide (InP), gallium arsenide (GaAs), lithium niobate ($LiNbO_3$), silicon, and silica-on-silicon, and spans monolithic integration, hybrid integration and module integration.

Optical communications accounted for the largest market share of $254m in 2016, and is expected to continue to lead the market, growing at a CAGR of 26.5% from $320m in 2017 to $1.4bn in 2022. In particular, increasing demand for high-speed communication with fewer disruptions is one of the major factors fueling the demand for photonic integrated circuits.

The market for PICs in optical communication applications is led by the Asia-Pacific region, which is expected to grow 41.2% from 2017 to $426m by 2022. North America's market share is expected to grow 22.6% and surpass the market share of Europe, which will grow by 18.8% to $284m.

The optical signal processing market is expected to grow at a CAGR of 29.3% from $68m in 2017 to $246m in 2022.

Demand for the new technology is being driven by the desire for high-speed data transfer, including rapid industrialization, last-mile connectivity, and improved efficiency with real-time data availability. A newly developed laser modulator can encode optical data at the rate of 40 billion bits per second.

PIC makers leading the industry include Infinera (12.3% market share, $66.3m revenue), Huawei (9.9%, $53.4m), Broadcom (7.6%, $41m), and Intel (6.7%, $36m). California-based Infinera also offers optical networking systems based on photonic integration technology. China-based Huawei is incorporating photonic integrated circuits in its optical networking systems.

Factors impacting growth

The PIC industry is complex — there are few manufacturing hubs and manufacturers require a workforce with industry expertise. Because the life cycle of these products is short, companies only consider manufacturing if replacement technology is at least five years out. The lack of competition has created a static market, and while companies with money can enter the field, it is difficult for them to sustain their position. Also, the lack of low-cost labor in the USA is a major setback for small- and medium-size companies looking to manufacture PICs.

The report notes that, while the industry faces the challenge of high initial investment, application in various products ranging from the low frequency range to the high frequency range is increasing constantly. Prices for PICs are likely to decline in the next five years due largely to competition from India and China. At present, photonic integrated circuits are also being successfully integrated into small devices such as mobile devices and radios, and they are expected to be used in high-end RF and sensing operations in the near future.

Demand for photonic integrated circuits, particularly for use in smart gadgets, is expected to increase significantly in the coming years both in the Asia-Pacific region and in the USA, where regulatory changes will encourage small- and medium-size companies to expand.

www.bccresearch.com

Compound semiconductor market to grow at 11.24% CAGR from $40.452bn in 2017 to $68.915bn by 2022

The compound semiconductor market will rise at a CAGR of 11.24% from $40.452bn in 2017 to $68.915bn by 2022, driven by next-generation 5G technologies requiring greater speed and minimum latency, forecasts a report from Knowledge Sourcing Intelligence.

Consumer electronics accounted for the most market share in 2016 and is expected to be driven largely by the introduction of smartphones powered by gallium arsenide-based solar cells coupled with an increase in the number of smartphones and other smart devices on the market. Moreover, increasing adoption of LEDs in consumer electronics is expected to boost growth further.

Geographically, the Asia–Pacific region is expected to grow rapidly due to industrialization and urbanization, especially in emerging economies such as India, China and South Korea. Growing demand for power applications, coupled with developing wireless infrastructure, is expected to boost compound semiconductor market growth. North America is expected to grow moderately, with high demand originating from the USA.

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Qorvo's quarterly revenue down 8.3% year-on-year, but exceeding lowered guidance by $10m

Revenue to grow 27% in September quarter, driven by seasonal phone launches, recovery in China, and strength in Infrastructure & Defense Products

For fiscal first-quarter 2018 (ended 1 July 2017), Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has reported revenue of $639.9m, down slightly on $642m last quarter and down 8.3% on $697.6m a year ago, but exceeding the midpoint of the lowered $610–650m guidance by $9.9m.

Growth was driven by record revenue for Infrastructure & Defense Products (IDP) of $184m, up 9% sequentially and 22% year-on-year, due to stronger-than-expected demand for defense, Wi-Fi, and broader Internet of Things (IoT) products. "Since repositioning IDP to focus on secular high-growth markets, we've seen eight consecutive quarters of strength and the sales funnel continues to expand," notes president & CEO Bob Bruggeworth. "Our IDP product portfolio is capturing diverse, high-growth opportunities with differentiated technologies, and this is driving record bookings."

In Wi-Fi, IDP grew more than 50% year-on-year. During the quarter, IDP launched new BAW band-edge and coexistence Wi-Fi filters that enabled triple the range for smart home and enterprise applications, delivering robust coverage across the entire allocated spectrum and half the size of earlier-generation solutions. IDP also supported the transition to 802.11ax as customers implemented Qorvo's recently released portfolio of BAW filters and 2.4GHz and 5GHz front-end modules (FEMs). The firm says that these newest Wi-Fi solutions provide the high throughput and extreme thermal efficiency that are critical to high-density 802 .11ax connectivity. "Our customers are quickly filling the Wi-Fi sales funnel and we continue to expect robust growth in fiscal 2018," says Bruggeworth.

Defense & Aerospace revenue was also particularly strong, with gallium nitride (GaN) and bulk acoustic wave (BAW) both growing by more than 25% year-on-year. "We are experiencing significant growth with our ongoing multi-year defense contracts, supporting programs like F-15, F-16 and the F-35," says Bruggeworth. In particular, revenue with Qorvo's largest defense customer more than doubled year-on-year.

Mobile Products (MP) revenue was in line with expectations at $456m, reflecting growth at Samsung and a modest demand recovery in China. Excluding Huawei (about 10% of mobile revenue), about 30% of mobile revenue came from China (up from 24% last quarter).

"In Mobile Products, we've secured designs for a broad suite of new products, and we're excited about ongoing development programs for marquee platforms," says Bruggeworth. "We're building our industry's most highly integrated RF solutions, and we're targeting the most complex and most profitable opportunities," he adds.

Mobile Products also drove growth in IoT, supporting a range of applications including automotive, asset tracking, meter reading, agricultural, industrial, and even the large bicycle-sharing services in China (all with mobile M2M solutions).

In base stations, Qorvo launched what is claimed to be the first gallium nitride on silicon carbide (GaN-on-SiC) front-end module for the 39GHz frequency band in 5G infrastructure. "The module's compact design integrates two powerful GaN MMICs and uniquely addresses the complex challenges faced by telecom equipment manufacturers designing next-generation millimeter-wave systems," says Bruggeworth. "In addition, we helped advance the development of 5G with a newly launched portfolio of ultra-high-performance 28GHz solutions. These hybrid solutions draw upon Qorvo's process expertise in both GaN-on-SiC and gallium arsenide to deliver leading-edge performance in miniaturized footprints," he adds.

On a non-GAAP basis, gross margin was 47.3%, down from 48.2% a year ago but up from 46.2% last quarter and slightly above the 47% guidance.

Operating expenses were $165.5m, up from $163.1m last quarter but cut from $168.6m a year ago.

Although down on $143.1m ($1.08 per diluted share) a year ago, net income was $113.9m ($0.87 per diluted share, $0.07 over the midpoint of the $0.70–0.90 guidance), up from $111.7m ($0.85 per diluted share) last quarter.

"The Qorvo team delivered June quarter revenue and EPS at the high end of our guidance, with continued progress toward achieving our margin targets," says Bruggeworth.

Cash flow from operations was $104m, down seasonally but up 75% on a year ago. Capital expenditure (CapEx) was down sequentially to $124m and will continue to decline as Qorvo wraps up recent expansions, tool conversions and other investments to support future growth.

Overall, during the quarter, cash and cash equivalents fell from $545.5m to $512.6m, as Qorvo repurchased $32m of stock (and

intends to continue buying as part of an ongoing commitment to return capital to shareholders).

On the design front, Qorvo has been selected by the leading China-based smartphone OEM to support a marquee device ramping this fall with power amplifiers, premium filters, high-performance switches, and an envelope-tracking (ET) power management integrated circuit (PMIC). The firm has also secured design wins for a broad suite of BAW 5 products, including quadplexers for carrier aggregation (CA), Wi-Fi Sense integrated front-end modules (iFEMs) for Oppo, Xiaomi, LG, ZTE and Nokia, and a Wi-Fi coexistence filter for a marquee smartphone platform. In addition, Qorvo has helped to enable a new entrant in the Android ecosystem, winning more than $12 of RF content in a smartphone expected to ship soon.

For the open market, Qorvo has launched a broad family of premium BAW 5 filters and quadplexers that are critical for enabling the continued proliferation of carrier aggregation and high-performance Wi-Fi. It also began shipping its next-generation antenna tuners, which reduce the complex design challenges related to band proliferation, the deployment of carrier aggregation, the implementation of MIMO, and the popularity of new features like shrinking bezels and dual cameras (which require the already limited board space available for antennas).

For fiscal second-quarter 2018 (to end-September 2017), Qorvo expects revenue to grow 27% sequentially to $800–820m, reflecting seasonal phone launches at the firm's largest customer, a modest China recovery, and continued strength in IDP. Gross margin should be about 47.8%, up 50 basis points. Diluted earnings per share should be $1.36–1.50. Operating expenses are forecast to remain flat sequentially as productivity improvement are offset partly by R&D related to custom product development for the firm's largest customer.

"Looking to the September quarter and beyond, we're confident in our content gains at large customers and we expect mobile revenue will track the ramp profiles of marquee devices," says Bruggeworth.

For the full fiscal year 2018, Qorvo expects revenue to strengthen from the September quarter to the December quarter followed by a slightly less-than-normal seasonal decline in March. "We project double-digit year-over-year growth in the second half, with a stronger China market, gains on new mobile platforms, and continued above-market IDP growth," says chief financial officer Mark Murphy. "In Mobile Products, we expect double-digit year-over-year growth in the second half of the fiscal year, reflecting our current view of timing of program ramps and China market dynamics," adds Bruggeworth. "In IDP, we are projecting over 15% full-year growth on strength across multiple markets." Overall, total full-year revenue is expected to grow by 4–5%.

"With our current top-line outlook and efforts to minimize inventories, utilization rates are lower than expected," says Murphy. "We still see opportunities for gross margin expansion through improving mix, yield improvements and other productivity efforts, and lower than previously projected CapEx spend and depreciation," he adds.

"Our highest-priority initiatives support our growth and margin targets, with an emphasis on BAW-based opportunities. We are converting to larger-diameter wafers and we are shrinking die sizes," notes Bruggeworth. "It's our intent to reduce BAW cost and increase asset throughput and BAW utilization as a primary driver of our gross margin performance. We've launched multiple BAW 5-based discrete and integrated solutions. And we expect the market will continue to require more BAW filters as consumers demand more mobile data and as carriers work to increase the capacity of their networks," he adds.

"In Mobile Products, we continue to be pleased with our progress on a development program with our largest customer for a module that combines multiple high-order BAW multiplexers," says Bruggeworth. "This is our single largest opportunity for driving growth and utilization."

Full-year operating expenses are forecasted to be down from fiscal 2017, to 20–21% of sales) fiscal 2018. Qorvo has reduced its projection for CapEx for the year from about $400m to less than $300m (to under 10% of sales, an over 800 basis point drop year-on-year) to take into account improvements in fab yields, successful wafer size conversions, progress on die shrink programs, and a near-term focus on improving utilization. Combined with operating cash flow, Qorvo expects this to lead to a tripling in free cash flow in fiscal 2018.

www.qorvo.com

Qorvo stockholders approve proposals at annual meeting

Qorvo says that all proposals were approved at its 2017 annual meeting of stockholders, who:

- elected 11 directors to serve a one-year term;
- approved (on an advisory basis) the compensation of the firm's named executive officers;
- reapproved the 2012 Stock Incentive Plan, for purposes of Section 162(m) of the Internal Revenue Code of 1986, as amended; and
- ratified the appointment of KPMG LLP as Qorvo's independent registered public accounting firm for the fiscal year to end-March 2018.

Peregrine's VPs of engineering & product marketing

Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has appointed two semiconductor-industry veterans as new executives. Keith Bargroff has been promoted to serve as VP of engineering, and Sumit Tomar has been hired as VP of product marketing.

Peregrine says that, since its acquisition by Japan's Murata in December 2014, it has experienced high growth in both employee headcount and new market opportunities. As the team and product portfolio expanded, the firm has created two new senior leadership positions.

"Peregrine's technology and product portfolio has increased substantially, and we are continuing to hire top-notch engineering talent worldwide to support our aggressive growth plans," says chief operating officer Dylan Kelly. "For the last two years, Keith has led Peregrine's technology platforms department, and he has the ideal background and skill set to serve as our new vice president of engineering," he adds. "Sumit's proven track record and his strong industry network in the wireless ecosystem will be a great asset for Peregrine."

An over 25-year industry veteran, Bargroff is an engineering leader and designer with a broad range of market and technology expertise including RF, analog and mixed-signal semiconductors, Internet of Things (IoT) and communications, energy management and instrumentation equipment. Prior to Peregrine, he was chief technology officer at Enverv, a fabless semiconductor company that he co-founded to develop communications system-on-chip (SoC) solutions for the energy-management and IoT markets. Bargroff was also co-founder, principal engineer and director of technical strategy for RF Magic, a fabless semiconductor company acquired by Entropic Communications in 2007. He also has experience in management at Elektradyne, Wavetek and Datron Instruments and in engineering positions with IBM and Qualcomm. Bargroff has been granted 15 patents and has over 22 pending patent applications. He earned a bachelor's degree in electronic and electrical engineering from Brunel University in London, and he completed coursework in BiCMOS analog circuit design and advanced bipolar analog integrated circuit design at Imperial College London.

Tomar is a 20-year industry veteran with a track record in marketing and product management. With a solid understanding of RF products, he has driven product execution from inception to production for hundreds of market-shaping products. From 2012 to 2016, Tomar was general manager of Qorvo's wireless infrastructure business unit. In addition, he has worked in RF product management at Texas Instruments, Sierra Monolithics and Skyworks. Product marketing experience spans 4G/5G smartphone and radio access networks, automotive semiconductor, 802.11ax access points, SDN/NFV for data centers, and machine learning and artificial intelligence for mobile edge networks. In 2016, he co-founded C-RAN Inc, a startup company that is developing a 5G RF system prototype. Tomar holds a master of science degree in electrical engineering and has completed the Stanford executive management program.

www.psemi.com

Qorvo expands online tool suite with RF matching calculator to simplify RF design

Qorvo has announced a free, downloadable calculator that supports a wide range of RF matching tasks. Qorvo MatchCalc allows RF engineers to quickly match their system designs without being connected to complex simulation programs, speeding the design process and reducing the time to get new products to market.

MatchCalc expands Qorvo's library of tools that help design engineers in mobile, infrastructure and defense markets work faster and more efficiently. University students also use the tools for their design projects. The library includes the Maximum Power Reduction tool, for designing carrier aggregation mobile devices. These tools and all of Qorvo's design resources, such as videos, blogs, white papers, e-books, block diagrams and brochures, are available at the Qorvo Design Hub.

MatchCalc is an intuitive set of basic RF design tools providing component values for matching S1P or S2P files to the desired system or reference impedance. Smith Chart, Log Mag and K-Plot matching functionality are provided with real-time tuning. MatchCalc frees RF designers to work remotely and offers capabilities not available in other downloadable tools, says Qorvo. The download, along with two instructional videos that provide an overview of the tool's functionality, can be accessed on the MatchCalc download page.

"Our goal is to ease the RF design engineer's job and help them get products to market faster," says Brandi Frye, corporate VP of marketing. "Qorvo's Design Hub offers new tools, e-books, blog posts and educational videos," she adds. "We're passionate about partnering with our customers to help them solve connectivity challenges, be it carrier aggregation, IoT or the path to 5G."

www.qorvo.com/design-hub/design-tools/matchcalc

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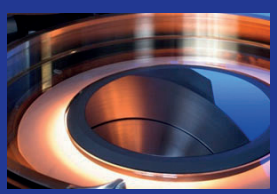

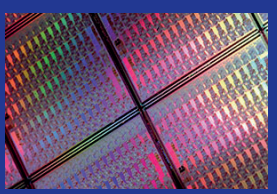

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TowerJazz offers RF and high-performance analog manufacturing processes for automotive devices

SiGe Terabit Platform targeted at ADAS and autonomous driving

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 its advanced analog specialty RF and high-performance analog (HPA) manufacturing processes, addressing the increasing demand for analog semiconductor content in the fast-growing automotive market, especially ADAS (advanced driver assistance systems) and autonomous driving. TowerJazz is serving this market through RF and HPA technology solutions developed through close partnerships and roadmap alignment with market leaders and global customer support.

RF for automotive falls into two broad categories: wireless connectivity and automotive radar, with automotive radar having the largest share of existing RF semiconductor content. Automotive radar systems have become a relatively standard feature in premium and mid-range automobiles for performing safety and driver assistance tasks such as forward collision avoidance/warning, lane departure warnings, blind spot detection, and parking assist. Wireless connectivity semiconductor content is expected to grow rapidly as well, with the number of connected cars quadrupling over the next five years.

According to a report from MarketsandMarkets, the automotive semiconductor market is expected to grow from $35bn in 2016 to over $48bn by 2022, driven by the increasing demand for automobiles coupled with the overall trend of vehicle electrification. Automotive semiconductor content remains dominated by analog with a 69% share of the total market, with RF semiconductor content expected to rise over the coming years at a double-digit compound annual growth rate (CAGR).

With increasing adoption of ADAS — and eventual migration to fully autonomous vehicles — as many as seven to 12 radar systems may be incorporated into each car. Furthermore, increasing adoption of GPS, 4G-LTE (transitioning soon to 5G) and V2X (vehicle-to-everything) communications will augment the RF semiconductor content in vehicles, further expanding the RF semiconductor market for automobiles beyond $1.8bn by 2021 with a CAGR of more than 14% (according to a 2016 MarketsandMarkets report on the ADAS market and company estimates).

Because of the high performance needed at high frequencies for automotive radar systems (24–26GHz for short-range and 76–81GHz for long range), TowerJazz says that its silicon germanium (SiGe) Terabit Platform is suited to serving this growing market. SBC18H2 through SBC18H5 SiGe technologies offer an f_T of 240–300GHz and fmax of 280–340GHz, providing latitude to optimize speed and noise requirements for specific applications. TowerJazz's SiGe Terabit Platform comes with two CMOS options: 1.8V/3.3V (180nm) and 1.2V/3.3V (130nm).

TowerJazz says that all of its SiGe technologies offer customizable metallization schemes and high-performance passives (MIM capacitors and inductors) to tailor to each customer's specific end-application. For more cost-sensitive applications, TowerJazz also offers a complete 65nm RF-CMOS technology platform in its Uozu, Japan factory. For wireless connectivity solutions, TowerJazz offers a front-end module-on-a-chip RF platform in addition to advanced RF-SOI and RF-CMOS technology with what is claimed to be best-in-class R_{on}–C_{off} for switches and noise figures for low-noise amplifiers.

"We see the proliferation of IoT devices, the advent of 5G cellular service and the promise of autonomous vehicles augmenting our RF business with additional exciting opportunities for growth, and we are investing heavily in technologies that provide our customers a strong advantage in these new areas," says Dr Marco Racanelli, senior vice president & general manager of TowerJazz's RF/High Performance Analog business group.

www.towerjazz.com

DENSO develops 24GHz-band submillimeter-wave vehicle radar sensor

Sensor detects vehicles to the rear and side of the vehicle to help reduce accident risk

DENSO Corp of Kariya, Aichi prefecture, Japan has developed a 24GHz submillimeter-wave rear and side radar sensor to help enhance vehicle safety systems. Using a monolithic microwave integrated circuit (MMIC) fabricated by specialty foundry TowerJazz, the sensor is used in the 2018 Toyota Camry launched in July.

The sensor is built into the rear bumper of the vehicle to detect other vehicles likely to enter the driver's blind spot to the rear and side, as well as vehicles approaching from the rear on the left and right when reversing. The sensor is part of a larger system that helps drivers identify and navigate around other vehicles when changing lanes or reversing out of a parking space, and controls the autonomous emergency braking function to avoid imminent collisions.

To enable accurate detection whether moving forward or reversing, a phase shifter switches the sensing direction and range of the submillimeter-wave radar sensor. Radio wave transmission and receiving, and phase shifter functions also run through separate integrated circuits to reduce the size of the sensor.

DENSO says that in 2003 it became the first company to develop and commercialize an electronically scanning in-vehicle millimeter-wave radar sensor, which utilized digital beamforming.

www.globaldenso.com
www.towerjazz.com

DENSO uses TowerJazz's 0.18µm SiGe technology to develop 24GHz rear and side radar sensor

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) says that its 0.18µm SiGe technology was used to develop a 24GHz rear and side radar sensor for Japan's DENSO Corp, a supplier of automotive technology, systems and components for major automakers. Using TowerJazz's submillimeter-wave technology, the sensor is used in the Toyota Camry that was released in North America in July and it will help enhance the vehicle safety system.

DENSO's rear and side radar sensor system offers SRR (short-range radar), enabled by TowerJazz's SiGe process, which helps to alert the driver of vehicles approaching from behind when changing lanes and when reversing. It also helps to perform automatic braking when reversing. According to Global Market Insights, the global automotive radar market is forecasted to grow from $1.4bn to more than $5bn by 2023, boosted by the advent of self-driven cars.

TowerJazz says that DENSO chose its SBC18 process as the technology combines high-performance SiGe transistors for the transmission and reception of the radar signal together with 0.18µm CMOS for the integration of digital control functions on a single chip. TowerJazz's accurate models for first time success and automotive quality certification were also factors.

"TowerJazz's leading SiGe technology enabled us to create the collision avoidance system which is our flagship offering," says Kazuma Natsume, director, Advanced Safety Engineering Division 2, DENSO. "TowerJazz's advanced process enabled the engineers to fully achieve the challenging specs required for next-generation short-range radar (SRR) for automotive applications," he adds.

"We look forward to grow the partnership and the relationship with DENSO, with this technology entering volume production and fanning out to multiple automobile models," says TowerJazz's CEO Russell Ellwanger.

www.towerjazz.com

Wolfspeed develops first 3.3 & 10kV SiC power modules to use exclusively MOSFET built-in body diode as anti-parallel rectifier

PowerAmerica funding aids manufacture and test of modules

With funding assistance from PowerAmerica, silicon carbide (SiC) device and power module manufacturer Wolfspeed has developed what are claimed to be the first SiC power modules for 3.3kV and 10kV applications to use exclusively the MOSFET built-in body diode as the anti-parallel rectifier.

Compared with an external and additional diode device, the built-in diode (or 'body diode') design maximizes the performance of SiC MOSFET modules by freeing up space in the power module, allowing for more power capability and therefore increased performance in a smaller space. It also makes assembling a power module easier, boosting long-term reliability and optimizing costs.

"Essentially, we're doubling the power and therefore increasing supply chain capability by providing another solution at higher power levels — specifically at the 3.3kV and 10kV applications," says Ty McNutt, director of business development at Wolfspeed's Fayetteville, AR location.

PowerAmerica funding helped the firm manufacture and test the modules. During testing, Wolfspeed was able to demonstrate the power improvement gained by not having the additional diodes.

Currently, the Wolfspeed power modules are being offered to PowerAmerica members and select customers.

www.wolfspeed.com/power/products
www.poweramericainstitute.org

Wolfspeed's SiC MOSFETs enable power supplies to achieve 80+ Titanium efficiency rating in telecom & data-center applications

Wolfspeed of Research Triangle Park, NC, USA — a Cree Company that makes silicon carbide (SiC) power devices (including MOSFETs, Schottky diodes, and modules) — says that its latest low-inductance SiC MOSFETs have been used to develop high-efficiency data-center power supplies — through the implementation of a totem-pole power factor correction (PFC) topology — to exceed an 80+ Titanium rating, which is critical for reducing the overall power consumption for data centers (which is estimated to be more than 70 billion kWh annually in the USA).

High-efficiency power supply designs like those employing Wolfspeed's SiC MOSFETs are vital for data-center designers as they strive to meet demanding efficiency standards without increasing costs. According to a US Department of Energy-supported study on US data center energy usage (2016 United States Data Center Energy Usage Report, Lawrence Berkeley National Laboratory, LBNL-1005775), efficiency improvements in data-center power systems have contributed to an estimated 620 billion kWh in energy savings from 2010 to 2020.

Wolfspeed recently developed a comprehensive reference design that demonstrates the implementation of a totem-pole PFC topology in a 2kW bridgeless power supply that is capable of easily exceeding the 80+ Titanium standards, with actual results of 98.7% peak efficiency at half load and 98.55% efficiency at full load — both taken at 230V redundant operation. Power supply design engineers have faced significant challenges in attaining these efficiency levels using conventional silicon switching devices due to their higher losses and the need for more complex topologies, says Wolfspeed.

"Using Wolfspeed's latest SiC MOSFETs in a totem-pole PFC design allows our server power systems to achieve an 80+ Titanium efficiency rating," comments Nash Chen, staff engineer for cloud computing at Chicony Power Technology. "Wolfspeed's MOSFETs also enabled higher-frequency operation, reduced harmonic distortion, improved thermal management, and smaller overall system size," he adds.

"Our objective was to design the simplest totem-pole PFC topology using our latest generation of 900V SiC MOSFETs, combined with low-cost silicon diodes, that could achieve 80+ Titanium system efficiency levels," says Guy Moxey, Wolfspeed's senior director of power products. "Moreover, we set the additional requirements that the design would use only established and proven commercially available wide-bandgap devices in full production, be the most practical circuit to implement and commercialize, as well as be smaller in volume than existing silicon-based systems at the lower 80+ Platinum efficiency level. And finally, the overall system bill-of-materials (BOM) cost had to be comparable or less than silicon."

The resulting reference design was presented in a webinar 'Achieving High Efficiency Power Supplies (80+Titanium) Without Increasing Complexity or Cost' by Wolfspeed engineers Dr Adam Barkley and Edgar Ayerbe.

www.wolfspeed.com/power/products

Showa Denko acquiring SiC sublimation-recrystallization assets from Nippon Steel

Quality improvement targets power device applications

Tokyo-based Showa Denko K.K. (SDK) says that, by the end of January 2018, it will acquire assets from Nippon Steel & Sumitomo Metal Corp (NSSMC) and Nippon Steel & Sumikin Materials Co Ltd (NSMAT) concerning the sublimation-recrystallization method for manufacturing silicon carbide (SiC) wafers.

SDK began R&D on SiC epitaxial wafers in 2005, and now produces and sells 3000 epitaxial wafers per month. SDK now aims to improve the quality of its products through the acquisition.

In its ongoing medium-term plan Project 2020+, SDK is positioning its business to produce and sell SiC epiwafers for power devices as an 'Advantage-establishing' business. SDK further aims to strengthen its product development and supply of SiC epiwafers, contributing to the spread of SiC-based power devices.

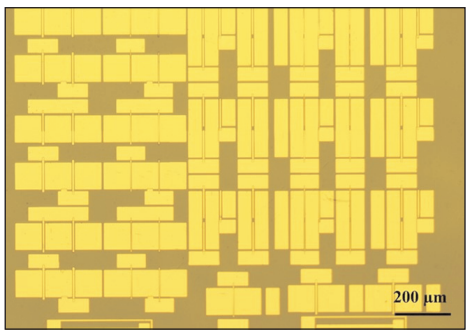
http://nsmat.nssmc.com/english/business_domain/bd05.html
www.sdk.co.jp

NIMS develops logic circuit with both D- and E-mode diamond-based MOSFETs

Step toward development of diamond ICs for extreme environments

A research group at Japan's National Institute for Materials Science (NIMS) led by Jiangwei Liu (independent scientist, Research Center for Functional Materials) and Yasuo Koide (coordinating director in the Research Network and Facility Services Division) has developed (for the first time, it is reckoned) logic circuits equipped with diamond-based metal-oxide-semiconductor field-effect-transistors (MOSFETs) at two different operation modes — a first step toward the development of diamond integrated circuits operational under extreme environments (Liu et al, 'Logic Circuits With Hydrogenated Diamond Field-Effect Transistors', IEEE Electron Device Letters vol38, issue 7, p922-925).

Since it has high carrier mobility, a high breakdown electric field and high thermal conductivity, diamond is a promising material for the development of current switches and ICs required to operate stably at high temperature, high frequency and high power. However, it had been difficult to enable diamond-based MOSFETs to control the polarity of the threshold voltage, and to fabricate MOSFETs of two different modes — depletion mode (D mode) and enhancement mode (E mode) — on the same substrate. The research group has developed



a logic circuit equipped with both D- and E-mode diamond MOSFETs after fabricating them on the same substrate using a threshold control technique developed by the group.

The researchers identified the electronic structure in the interface between various oxides and hydrogenated diamond using photoelectron spectroscopy in 2012. Then, after many difficulties, in 2013 the group then developed a diamond metal-oxide-semiconductor (MOS) capacitor with very low leakage current density and an E-mode hydrogenated diamond-based MOSFET. In 2014, the group then prototyped logic circuits by combining diamond-based MOSFETs with load resistors. Finally, in 2015, the group developed techniques to control D- and E-mode characteristics of diamond-based MOSFETs and identified the control mechanism.

The new logic circuits with diamond-based transistors are reckoned to be promising for the development of digital ICs that are required to operate stably under extreme environments, such as at high temperature as well as under exposure to radiation and cosmic rays.

The research was conducted in conjunction with the following projects: Leading Initiative for Excellent Young Researchers (Jiangwei Liu, representative), under the sponsorship of the MEXT Human Resource Development Program for Science and Technology; 'Development of new functional diamond electronic devices using a large amount of polarized charges' (with principal investigator Yasuo Koide) under the category of Grant-in-Aid for Scientific Research (A) sponsored by the MEXT Grants-in-Aid for Scientific Research; and 'Fabrication of high-current-output fin-type diamond field-effect transistors' (with principal investigator Jiangwei Liu) under the category of Grant-in-Aid for Young Scientists (B) sponsored by the MEXT Grants-in-Aid for Scientific Research. Device fabrication was supported by the NIMS Nanofabrication Platform, established under the MEXT Nanotechnology Platform Japan program.

http://dx.doi.org/10.1109/LED.2017.2702744
www.nims.go.jp/eng

Microsemi awarded contract to speed adoption of SiC technology as new member of PowerAmerica

Microsemi to develop 1.7kV and 3.3kV SiC MOSFETs and diodes as part of PowerAmerica's $70m backing from DoE over five years

Microsemi Corp of Aliso Viejo, CA, USA (which makes chips for aerospace & defense, communications, data-center and industrial markets) is now a member of PowerAmerica — a manufacturing institute consisting of public and private representatives from the semiconductor industry, the US Department of Energy (DoE), national laboratories and academia — to accelerate the commercialization and adoption of wide-bandgap semiconductors. Microsemi has also been awarded a contract as part of PowerAmerica's $70m backing from the DoE over five years, allocated to promoting the adoption of components made with silicon carbide (SiC) and gallium nitride (GaN) into a wide range of products and systems.

Microsemi's role at PowerAmerica will be specifically focused on supporting the commercialization of 1.7kV and 3.3kV SiC MOSFETs and SiC Schottky diodes as it develops next-generation devices. With key benefits including higher efficiency, high temperature/voltage operational stability, better power handling and smaller form factors, the 1.7kV and 3.3kV devices are targeted at expanding the number of applications where SiC technology can be used. Suitable for the industrial and aerospace markets, as well as the defense market where US-based suppliers are necessary, target applications include automotive electrification, railways (traction), aerospace actuation systems, power generation and distribution, solar inverters, motor drive and electromagnetic railgun.

"Our investment in this technology has been recognized by PowerAmerica's leadership," says Leon Gross, VP & business unit manager for Microsemi's Power Discretes and Modules business unit. "As one of the limited number of suppliers serving this market, Microsemi looks forward to providing cost-effective state-of-the-art 1.7kV and 3.3kV SiC devices with the ability for quick high-volume scale up via a 6-inch foundry with short lead times, ultimately leading to faster design cycles for customers," he adds.

Microsemi says that working with Power America allows it to extend its ability to offer the same high-level system integration it provides in aerospace applications with its intelligent power solutions (IPS) such as the power core module (PCM) and hybrid power drive (HPD). PowerAmerica brings the leading wide-bandgap semiconductor manufacturers, material providers and end-users together with experts from research universities and government agencies not only to reduce the cost, but also to improve the performance and reliability of wide-bandgap devices and the systems that incorporate SiC and GaN technologies. As a member of the institution, Microsemi has access to as many as 11 university research programs, three federal collaborators and over 10 startups committed to growing wide-bandgap technology.

"Microsemi's six decades of experience developing high-reliability semiconductor solutions, combined with its continuing commitment to innovate, lead and adapt to a rapidly changing landscape, will help accelerate the adoption of SiC in the power electronics industry," comments PowerAmerica's deputy executive director & chief technology officer Victor Veliadis Ph.D. "PowerAmerica is proud to join forces with Microsemi to transition its 1.7kV SiC process to high-volume ramp and develop 3.3kV devices which are critical for traction and high-voltage direct current (HVDC) grid applications."

The SiC power device market is rising at a compound annual growth rate (CAGR) of 38% from 2015 to about $1.4bn in 2021, forecasts market research firm IHS Markit Technology. With SiC MOSFETs and diodes offering superior dynamic and thermal performance over conventional silicon power devices, the benefits of SiC are influencing the development of new end-products, it adds.

Microsemi says that key features of its 1.7kV and 3.3kV SiC devices will include:

- high reliability at 175ºC;
- AEC-Q101 qualification;
- specific $R_{ds(on)}$ targeted to be less than 7mΩ.cm^2 for the 1.7kV MOSFETs (the lowest among available products on the market);
- avalanche energy rating (UIS) of over 15J/cm^2 (making the device highly rugged for industrial and automotive applications and the highest known UIS rating for any 1.7kV SiC MOSFET currently available);
- short-circuit withstand time (SCWT) of ~5μs (the longest for devices in the 1.7kV class currently), ensuring safe operation/shut-off under fault conditions.

Microsemi says that its existing portfolio of SiC products offers advantages including improved system efficiency with 25–50% power output increases for the same physical dimensions, efficiency at higher switching frequencies over insulated-gate bipolar transistors (IGBTs), reduced system size and weight, operating stability over temperature (+175ºC) and significant cooling cost savings.

www.poweramericainstitute.org
www.microsemi.com/product-directory/discretes/3613-silicon-carbide-sic

Pallidus launches silicon carbide source material

Pallidus Inc (a Melior Innovation company) of Houston, TX, USA has launched its proprietary M-SiC silicon carbide source material and technology platform, with the capability to deliver cost/performance parity against silicon devices in the $12.5bn power device market, it is claimed.

With a compound annual growth rate (CAGR) of greater than 25%, SiC power devices deliver superior performance in key segments of the power electronics market (wind energy, electric vehicles and aerospace), notes the firm. The ability to achieve cost/performance parity with silicon devices will increase market penetration by up to six times – creating a market value of >$1.bn in SiC power devices, it adds. The biggest hurdle to market expansion is the cost and availability of high-quality silicon carbide wafers, says Pallidus.

Compatible with existing manufacturing processes, M-SiC reduces the production cycle and improves both the quality and overall yield of silicon carbide wafers, says Pallidus. By reducing wafer defects, M-SiC can improve overall device yield, adds the firm. Taken together, M-SiC can deliver up to a 50% decrease in both wafer and device production costs with a significantly lower capital investment, it is claimed.

"The very high purity and form of M-SiC has allowed us to grow the highest-quality 4H-SiC 6" wafers with the lowest defect density we have ever seen," comments Andrei Maltsev, president of AGP Technologies LLC.

"M-SiC exhibits exceptional opportunity for the growth of highest-quality crystals," believes professor Peter Wellman of Germany's University of Erlangen. "In addition, the capability to produce custom-shaped 'charges' enables the never before seen opportunity to achieve ideal system performance," he adds.

"Despite its superior performance, high cost is the key obstacle for the full adoption of SiC power devices," comments Dr Hong Lin, technology & market analyst at Yole Developpement. "In particular, the SiC wafer contributes up to 60% of the final cost. Technology that can drive a major cost reduction will immediately and significantly accelerate SiC technology adoption and penetration."

www.pallidus.com

Wolfspeed extends 50V GaN HEMT family to high-efficiency 3.0GHz 250W device

Wolfspeed of Raleigh, NC, USA — a Cree Company that makes silicon carbide (SiC) power products and GaN-on-SiC high-electron-mobility transistors (HEMTs) and monolithic microwave integrated circuits (MMICs) — has extended its family of 50V unmatched GaN HEMT RF power devices by adding the 250W CGHV40200PP, which has with a frequency range up to 3.0GHz, 21dB small-signal gain at 1.8GHz, and what is claimed to be the highest efficiency of any comparably rated GaN device available (67% at P_{SAT}). This enables RF design engineers to use fewer components to design smaller and lighter linear amplifier circuits for commercial and military wireless communications and S-band radar applications.

The new 50V GaN HEMT devices provide a combination of high power and high gain with high-efficiency operation, making it possible for RF design engineers to replace several lower-power GaN HEMTs or multiple silicon LDMOS devices with a single device in their power amplifier designs. Packaged in a four-leaded metal-flanged ceramic Gemini package, the new 250W GaN HEMTs operate efficiently at full rated power, reducing the need for complex thermal management systems.

Their higher power and efficiency rating, combined with a frequency range up to 3.0GHz, makes these devices suitable for a wide range of RF linear and compressed amplifier circuits, including those for military communications systems, radar equipment (UHF, L-, S-band), electronic warfare (EW) systems, as well as RF applications in the ISM (industrial, medical & scientific) band.

"The addition of these new 250W GaN HEMT devices to our 50V product line enables Wolfspeed to deliver new levels of power and efficiency," says RF and microwave director Jim Milligan. "Now, RF engineers can simplify their power amplifier designs by replacing multiple power devices with a single part, reducing their component count and making their amplifiers smaller and lighter."

Wolfspeed says that, compared with conventional silicon (Si) and gallium arsenide (GaAs) devices, its GaN-on-SiC RF devices deliver higher breakdown voltage, higher temperature operation, higher efficiency, higher thermal conductivity, higher power density, and wider bandwidths (all critical for achieving smaller, lighter and more efficient microwave and RF products). The GaN-on-SiC RF devices enable next-generation broadband, public safety and ISM amplifiers; broadcast, satellite and tactical communications amplifiers; UAV (unmanned aerial vehicle) data links; test instrumentation; and two-way private radios.

The CGHV40200PP GaN HEMTs are now in volume production and are available immediately from distributors Digi-Key and Mouser. Wolfspeed's RF devices are supported by proprietary large-signal models at https://portal.cree.com.

www.wolfspeed.com/cghv40200pp

ARPA-E awards $30m for 21 CIRCUITS projects

DoE funding development of power converter circuit topologies and system designs building on benefits of wide-bandgap devices

The US Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) has announced $30m in funding for 21 projects as part of the CIRCUITS program ('Creating Innovative and Reliable Circuits Using Inventive Topologies and Semiconductors').

Since it is reckoned that, by 2030, 80% of all US electricity could pass through power electronics devices, CIRCUITS project teams aim to accelerate the development and deployment of power converters that save energy. Projects hence leverage efficient, lightweight and reliable power converters based on wide-bandgap (WBG) semiconductor technology, using materials such as silicon carbide (SiC) or gallium nitride (GaN) instead of the incumbent silicon.

"Hardware built with WBG devices has the potential to be smaller, lighter, and much more energy-efficient, with applications across valuable sectors including transportation, information technology, the grid, and consumer electronics," says ARPA-E acting director Dr Eric Rohlfing. "Developments from CIRCUITS projects could one day lead to super-fast, compact electric vehicle chargers, more efficient ship propulsion systems, and lighter, aerodynamic aircraft that can carry more passengers with less fuel," he adds.

WBG semiconductors allow devices to operate at significantly higher speeds, voltages and temperatures than conventional semiconductor materials, and do so in smaller, lighter packages. Previous efforts by ARPA-E have focused primarily on WBG material and device development. CIRCUITS focuses on new circuit topologies and system designs, ensuring that the performance benefits of WBG devices are maximized.

Examples of the 21 CIRCUITS projects that were selected include the following:

- $847,888 to Imagen Energy LLC of New Berlin, WI for '1200V SiC-Based Extremely Compact, 500kW, 2000Hz Inverter for High Speed Permanent Magnet Synchronous Machine (PMSM) Applications (Category II)' to develop a SiC-based compact motor drive system to efficiently control high-power (>500kW), high-performance permanent magnet electric motors operating at extremely high speed (>20,000rpm). Imagen Energy's design seeks to address a major roadblock in operating electric motors at high speed, namely overcoming large back electromotive forces (BEMF). The project team aims to demonstrate a motor drive capable of handling large BEMF and increase motor system efficiency over a broad range of operating speeds.
- $2,163,630 for the University of Arkansas in Fayetteville, AR for 'Reliable, High Power Density Inverters for Heavy Equipment Applications (Category II)' to develop a 2 x 250kW power inverter system for use in the electrification of heavy equipment and other higher-volume transportation applications (e.g. trucks, buses, cars). The team will leverage SiC power electronics devices to achieve high levels of efficiency while greatly increasing the volumetric and gravimetric power density of its system over existing ones. The team aims to improve power density four-fold and to reduce converter cost by 50% compared to existing technology.

www.arpa-e.energy.gov/?q=arpa-e-programs/circuits

Analog Devices introduces wideband GaN MMIC amplifier with high gain, power and efficiency in compact design

Analog Devices Inc of Norwood, MA, USA has launched a wideband gallium nitride (GaN) power amplifier that offers what is claimed to be best-in-class performance within a compact design. Covering the 300MHz–6GHz spectrum, the HMC8205 is for system designers of applications such as wireless infrastructure, radar, public mobile radio, and general-purpose amplification test equipment that require pulse or continuous wave (CW) support.

HMC8205 combines DC feed/RF bias choke, DC blocking capacitors and driver stage on a single design, while delivering 35W with up to 44% power-added efficiency (PAE) across an instantaneous bandwidth. The device also operates both pulse and continuous wave, unlike comparative designs, says the firm.

The HMC8205 GaN monolithic microwave integrated circuit (MMIC) amplifier is said to offer unmatched integration, gain, efficiency, and wide bandwidth in a small-footprint lead flange mount package that requires minimal external circuitry, reducing overall component count and board space.

www.analog.com/hmc8205
https://ez.analog.com/community/rf

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

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

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

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

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

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

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

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

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

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

www.sunypoly.edu

Power Electronics Industry Collaborative adds new executive board member

The Power Electronics Industry Collaborative (PEIC) — a national, industry-focused member-based consortium consisting of original equipment manufacturers (OEMs), material suppliers, researchers and government stakeholders in the US power electronics sector — has formally elected Nanci Vogtli of Concrete Logic to its board of directors. As founder of Concrete Logic, a technology consulting firm specializing in the cleantech hardware industry, Vogtli primarily works with startup organizations to design business models, market strategies, and tactical execution plans.

As board treasurer, Nanci will oversee the management and reporting of PEIC's finances. She will also contribute to the board's overall duties in guiding PEIC in its mission to accelerate growth of the US power electronics ecosystem and technology innovation — including a new, high-priority program to advocate for workforce development.

PEIC's new executive board member Nanci Vogtli.

"Nanci is an energetic and experienced professional with a wealth of high-technology business experience, including in the power electronics industry," comments PEIC president Keith Evans (president & CEO of Kyma Technologies Inc). "We first met Nanci at our 2015 annual member meeting hosted by PEIC member Keysight Technologies in Santa Clara, CA. Our member meetings are open to prospective members, and Nanci's firm Concrete Logic joined PEIC shortly after the meeting."

Previously general manager of Pulse Engineering's telecommunications business unit, where she directed global cross-functional design teams to address power conversion requirements in that space, Vogtli also has a more recent technical background that includes converters and inverters for renewable power, clean transportation, and energy efficiency markets. She holds a Bachelor's of Business Administration, Computer Information Systems from National University, and an Associate degree in Applied Science, Electro-Mechanical Technology from the State University of New York at Alfred.

PEIC is actively engaging its member organizations and other industry, academic institutions, and government labs to develop workforce development programs specific to power electronics engineers, with the goal of ensuring a qualified pool of engineering talent to drive the next generation of power electronics innovation.

www.peic-us.org

Qorvo launches dual-transistor GaN-on-SiC asymmetric Doherty amplifier module for macro base-stations

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has launched an asymmetric Doherty amplifier enabling ultra-high levels of power efficiency in the design of wireless base-station equipment. The gallium nitride on silicon carbide (GaN-on-SiC) amplifier features two transistors in a single package to maximize linearity, efficiency and gain, and ultimately reduce operating costs.

"GaN devices can handle more power than other high-frequency technologies like GaAs and InP, with better frequency performance characteristics than other power technologies like LDMOS," comments Eric Higham, service director at market research firm Strategy Analytics.

"Today's telecommunications infrastructure design is all about achieving power efficiencies that reduce costs," notes Roger Hall, Qorvo's general manager, High Performance Solutions. "Our customers tell us that the new GaN-on-SiC QPD2731 transistor achieves these goals as operators bring more capabilities online."

Designers are increasingly moving to GaN-on-SiC in order to realize significant improvements in performance, linearity and efficiency for wireless base stations compared with LDMOS and GaN-on-Si, which have poor thermal characteristics, says Qorvo. The QPD2731 addresses this shift with pre-matched, discrete GaN-on-SiC high-electron-mobility transistors (HEMTs). Available now for sampling in a 4-lead, earless, ceramic flange NI780 package, the new amplifier is claimed to provide the highest performance available in its operating frequency range of 2.5-2.7GHz. Doherty drain efficiency is 60% (47.5dBm), Doherty gain is 16.0dB, and peak Doherty output power is 55.0dBm (316W).

The QPD2731 can be linearized by standard, commercially available, third-party digital pre-distortion (DPD) systems.

www.qorvo.com/products/p/QPD2731
www.qorvo.com/products/discrete-

EPC launches Class 4 AirFuel-compliant wireless power demonstration kit transmitting up to 33W

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, has announced the availability of a complete Class 4 wireless power charging kit, the EPC9120, capable of transmitting up to 33W while operating at 6.78MHz — the lowest industrial, scientific & medical (ISM) band.

The purpose of the demonstration kit is to simplify the evaluation process of using eGaN FETs for highly efficient wireless power transfer. The EPC9120 utilizes the high-frequency switching capability of EPC's GaN transistors to facilitate wireless power systems with full power efficiency of 80–90% under various operating conditions.

The EPC9120 wireless power system consists of four boards:

- source board (transmitter or power amplifier) EPC9512;
- Class 4 Air Fuel-compliant source coil (transmit coil);
- Category 4 AirFuel-compliant device coil with rectifier and DC smoothing capacitor; and
- Category 3 AirFuel-compliant device coil with rectifier and DC smoothing capacitor.

The popularity of highly resonant wireless power transfer is increasing rapidly, particularly for applications targeting portable device charging, says EPC. The end applications are varied and evolving quickly, from cell-phone charging to handheld tablets and laptop computers. Delivering up to 33W supports all of these applications.

Source (amplifier) board

The source 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 operating to the AirFuel Class 4 standard over a wide load range.

This amplifier board is available separately as EPC9512 for evaluation in existing customer systems.

Source (transmit) and device (receiving) coils

The source coil, as well as the device coil, are AirFuel compliant and have been pre-tuned to operate at 6.78MHz. The source coil is Class 4- and the device coils are Category 3- and Category 4-compliant.

EPC9120 wireless power transfer demonstration systems are priced at $907.20 each. The EPC9512 amplifier board can also be purchased separately and is priced at $390 each. Both are available for immediate delivery from Digi-Key.

http://epc-co.com/epc/Products/DemoBoards/EPC9120.aspx
http://epc-co.com/epc/Products/

EPC introduces 60W Class-E amplifier development board with 200V eGaN FET, boosting efficiency up to 15MHz for wireless power & LiDAR

Providing an easy-to-use way for power systems designers to evaluate the performance of gallium nitride transistors and get their products into volume production quickly, Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – has announced the EPC9083, a high-efficiency, flexible, GaN-based differential mode development board that can operate up to 15MHz, including 6.78MHz (popular for wireless power applications).

The development board is designed for class-E applications, such as wireless power, but can be used for any application where a low-side switch is utilized. Examples include (but are not limited to) push-pull converters, current-mode class-D amplifiers, common-source bi-directional switches, and high-voltage narrow pulse width applications such as LiDAR.

The EPC9083 features the EPC2046, EPC's latest-generation 200V, 25m_ eGaN FET, which allows even less switching loss than the previous generation of eGaN FETs, in an even smaller size, while keeping the same drain-source on-resistance. The amplifiers are set to operate in differential mode and can be re-configured to operate in single-ended mode and include the gate driver and logic supply regulator.

The EPC9083 is priced at $158.13 each and is available for immediate delivery from Digi-Key. A Quick Start Guide (containing set-up procedures, schematic, and bill of material for the boards) is provided on-line.

http://epc-co.com/epc/Products/DemoBoards.aspx
www.digikey.com/Suppliers/us/Efficient-Power-Conversion.page?lang=en

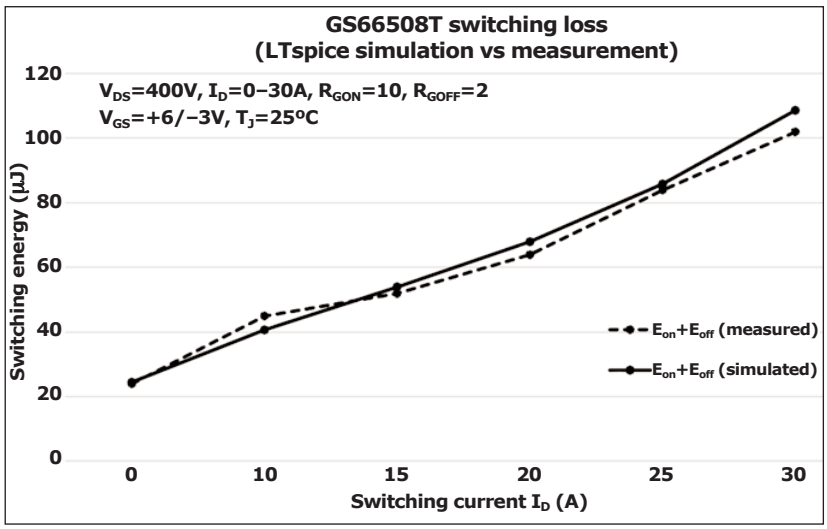
GaN Systems' enhanced LTSpice model simulation tool simplifies GaN design

GaN Systems Inc of Ottawa, Ontario, Canada — a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control — says that its new set of LTSpice models enables power system design engineers to be fast, accurate and confident with their simulated designs prior to building hardware.

Increasing efficiency and power density requires proper layout and understanding of the characteristics of these fast transistors. GaN Systems provides a full-featured set of LTSpice simulation files (available for download) that allow for a variety of inputs and simulations options — select the product of interest and then select the LTSpice button. LTSpice application notes GN007 and GN008 are also available on GaN Systems' website.

The LTSpice model user guide helps engineers to model systems at three levels, ranging from an initial overview of circuit performance to detailed analysis and fine tuning of the design:

- Level 1: basic adjustment and analysis of switching speeds, optimized for quick simulation;
- Level 2: includes (in additional to Level 1 features) thermal inputs and Cauer thermal RC network transient models for simulating the device junction temperature and self-heating effect; and
- Level 3: includes (in addition to Level 2 features) parasitic losses, providing the most accurate model with the longest simulation times.



To confirm the accuracy of the LTSpice model, laboratory measurements of GaN E-HEMT switching losses were recorded using a half-bridge, double-pulse test circuit. The measured switching losses were then compared with the LTSpice model simulations. The comparison demonstrates a strong correlation between the simulated results and real-time circuit measurements. With a 400V, 0–30A switching current setup using a 650V, 50mΩ GS65008T device, the difference between actual measurement and the simulated model is less than 5% — a very good number for E_{on}/E_{off} accuracy. The outcome is a simulation tool that provides a convenient and accurate way to understand GaN switching characteristics, evaluate GaN switching performance under different electrical conditions, and build overall confidence in a new product design.

"By developing and making available for download this full-featured LTSpice simulation tool, GaN Systems has made it easier for power system designers to leverage all the benefits of GaN transistors and to optimize their system performance," says GaN Systems' VP of sales & marketing Larry Spaziani. "Rarely do designers use spice simulation to estimate E_{on}/E_{off}; with our models they can," he adds. "This tool will help designers more fully understand GaN technology and accelerate their design completion."

www.gansystems.com/transistors.php
www.gansystems.com/whitepapers

Comtech wins $7.5m order for solid-state power amplifiers for in-flight connectivity

Comtech Telecommunications Corp of Melville, NY, USA says that during fiscal fourth-quarter 2017, its subsidiary Comtech Xicom Technology Inc of Santa Clara, CA — a part of Comtech´s Commercial Solutions segment that makes tube-based and solid-state power amplifiers (SSPAs) for military and commercial satellite communication (SATCOM) uplink applications — has received a $7.5m order for solid-state power amplifiers (SSPAs) for airborne in-flight connectivity applications.

To be shipped in fiscal 2018, the gallium nitride (GaN)-based SSPAs will enable high-speed satellite connectivity for both airlines and travelers around the world.

Comtech Xicom Technology's product range encompasses power levels from 8W to 3kW, with frequency coverage in sub-bands within the 2–45GHz spectrum. Amplifiers are available for fixed and ground-based, ship-board and airborne mobile applications.

www.xicomtech.com
www.comtechtel.com

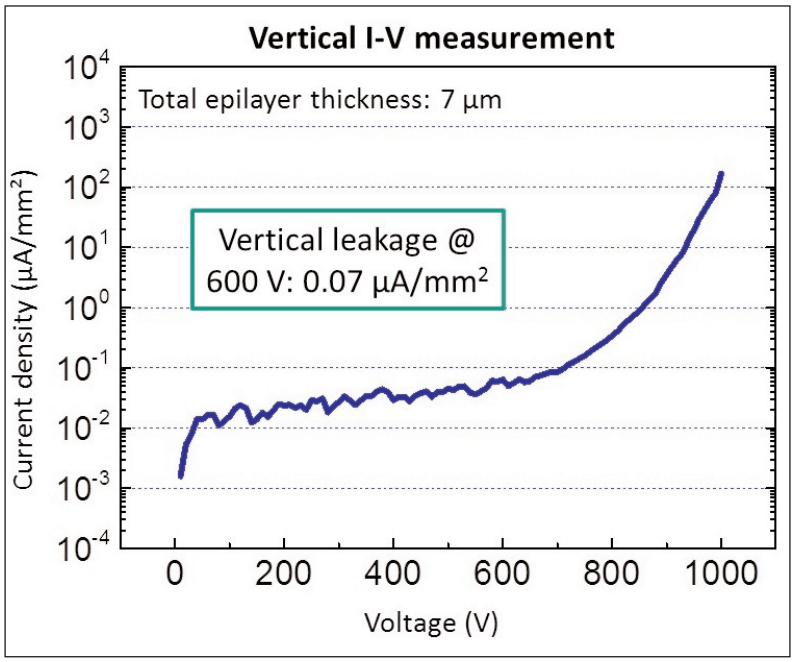
ALLOS challenges conventional beliefs of GaN-on-Si

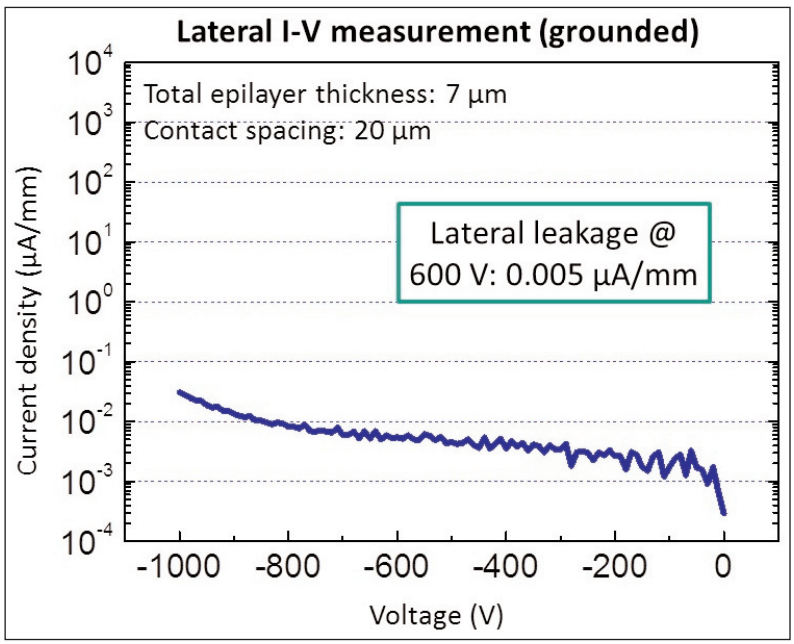
Carbon-doping not needed for high isolation, buffer interlayers not a source of leakage, and choice of reactor not decisive

In the presentation 'Low vertical leakage current of 0.07µm/mm^2 at 600V without intentional doping for 7µm-thick GaN-on-Si' at the 12th International Conference on Nitride Semiconductors (ICNS-12) in Strasbourg, France (24–28 July), Dr Atsushi Nishikawa, co-founder & chief technology officer of technology engineering & licensing firm ALLOS Semiconductors GmbH of Dresden, Germany, discussed three common beliefs about gallium nitride on silicon (GaN-on-Si): first, that the usage of intentional carbon doping would be inevitable, second that using interlayers in the buffer would be a source of leakage, and third that the choice of the right reactor hardware would be decisive for achieving good results. However, with the experimental evidence presented, Nishikawa is challenging the validity of these three widespread beliefs.

● Developers of GaN-on-Si epiwafers are suffering from the fact that crystal impurities from the growth process cause the isolation of GaN to be far below its theoretically possible values. To overcome these deficiencies, GaN-on-Si epiwafer makers usually apply carbon doping to achieve the required isolation. Unfortunately, conventional methods of carbon and other doping have negative side-effects. In contrast, says Nishikawa, ALLOS' results prove that, by focusing on superior crystal quality and thick GaN layers, the required low leakage currents can be achieved without any intentional carbon or other doping. This not only avoids the negative side-effects of doping but also widens the process window for further optimization of numerous manufacturing and electrical properties, he adds.

● Nishikawa also presented experimental evidence that, rather than that interlayers being a source of leakage, in fact the opposite is true:





Carefully controlled interlayer growth conditions and positioning of the interlayers can improve isolation by more than one order of magnitude, says Nishikawa. In combination, these techniques allow ALLOS to achieve very low vertical and lateral leakage currents of only 0.07µA/mm^2 and 0.005µA/mm, respectively, at 600V. This is based on 7µm-thick GaN with very high crystal quality of 316 arcsec for (002) and 413 arcsec for (002) XRD (x-ray diffraction). Available on epiwafers of both 150mm and 200mm diameter with SEMI-standard thicknesses, ALLOS says that its technology is designed for manufacturability, is suitable for standard silicon lines, and has a controlled minimum bow and no cracks.

● Regarding the belief that the choice of the right reactor hardware is decisive, Nishikawa acknowledges that, of course, good hardware matters but it is far from the dominant factor. ALLOS says that it can apply its structure and growth methods on several hardware platforms, as demonstrated by a comparison of results from two leading models of multi-wafer metal-organic chemical vapor deposition (MOCVD) reactor. On both reactors, similar material and electrical properties have been achieved, Nishikawa notes.

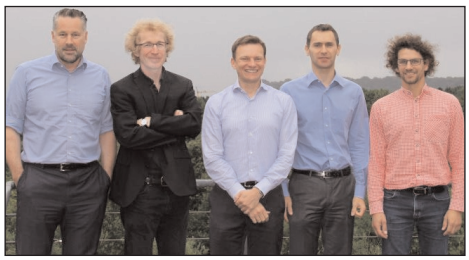
www.allos-semiconductors.com

RWTH Aachen University and AMO launch joint Aachen Graphene & 2D-Materials Center

Members of EU-funded Graphene Flagship project aim to bridge gap between science and applications in electronics and photonics

RWTH Aachen University and AMO GmbH in Germany have launched a new joint research center with a focus on efficiently bridging the gap between fundamental science and applications within graphene and related materials-based electronics and photonics.

Sharing the vision of bringing graphene and related materials research from the lab into applications, the five founding principal investigators of the Aachen Graphene & 2D-Materials Center (who are also all members of the EU-funded 'Graphene Flagship' project) are professor Christoph Stampfer (of RWTH, and spokesman for the center), professor Max Lemme (of AMO and RWTH), professor Markus Morgenstern (of RWTH), professor Renato Negra (of RWTH) and Dr Daniel Neumaier (of AMO).



Founding members of the Aachen Graphene & 2D-Materials Center at the kick-off meeting.

"The center will help to turn the exciting properties of graphene and 2D [two-dimensional] materials into true functions, making these materials not only fascinating for scientists but also serving society," said Christoph Stampfer following the center's kick-off meeting on 24 July. "With the Aachen Graphene & 2D-Material Center, we aim at increasing the visibility of Aachen as an excellent place to undertake graphene and 2D material research with both a fundamental and applied focus."

The center enables the integration of the already ongoing work from RWTH Aachen University and AMO under a legal framework that allows for full collaboration between the groups. In particular, the center will focus on addressing the challenges of future technology including high-frequency electronics, flexible electronics, energy-efficient sensing, photonics as well as spintronics and valleytronics with graphene and related materials and their heterostructures.

www.graphene-center-aachen.de

Ferrotec introduces FerroVac vacuum controller to automate legacy manual-control deposition systems

The Ferrotec (USA) Corp subsidiary of materials, component and precision system supplier Ferrotec Holdings Corp of Santa Clara, CA, USA (whose Temescal division of Livermore, CA, USA makes electron-beam evaporative coating systems) has unveiled the FerroVac vacuum controller, an integrated solution to manage vacuum system processes.

FerroVac integrates automated vacuum control with gauge reading functionality. When combined with the Temescal EBC Electron Beam Controller and a Temescal power supply, the FerroVac enables legacy manual-controlled systems to be updated with full system-level, automated control of the vacuum pump and e-beam functions.

Since many precision technologies (both experimental and production manufacturing) start inside a vacuum chamber, managing the chamber environment requires control of the pump and vents as well as the vacuum gauges used to measure the status of the chamber and create a feedback loop. The FerroVac controller integrates this functionality into a modern, programmable device that's managed through a touch-screen interface.

"For decades, vacuum system operators like our Temescal E-beam system customers have depended upon manual toggle/push buttons to operate valves and classic devices like our Versavac 2/5," says Imran Amirani, director of sales for Ferrotec's Temescal division. "With the FerroVac vacuum controller, this classically unsophisticated portion of a vacuum system has been streamlined and automated," he adds. "When it's combined with a Temescal EBC Electron Beam Controller and a Temescal power supply, it enables legacy manual-controlled vacuum systems to be automated — it's like adding an auto-pilot to your vacuum processes."

The FerroVac was developed on decades of experience with Temescal electron-beam evaporation systems. While the FerroVac controller is suitable for e-beam deposition systems, it's core utility makes it an effective solution for controlling virtually any vacuum system, regardless of the processes taking place inside the vacuum chamber, says Ferrotec. As well as streamlining processes and integrating discrete control processes, FerroVac simplifies system wiring and connectivity, making the physical system hardware easier to manage and maintain.

www.temescal.net

AXT's revenue rises 14.6% in Q2

Growth across portfolio led by record InP revenue

For second-quarter 2017, AXT Inc of Fremont, CA, USA — which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials — has reported revenue of $23.6m, up 14.6% on $20.6m last quarter and $20.5m a year ago (and above the guidance of 9% growth to $22–23m).

Revenue from substrates was $19.1m (80.9% of sales), up 15% on $16.6m (80.6% of sales) last quarter. Revenue from raw material joint ventures was $4.4m, up 10% on $4m last quarter (while falling from 19.4% to 18.6% of total sales).

Of total revenue, Asia-Pacific comprised 68% (rebounding from 63% last quarter), while North America comprised 7% (down from 10%) and Europe 25% (down from 27%). Two customers generated more than 10% of revenue, while the top five customers generated about 37% of revenue (up from 35% last quarter), again reflecting the continuing diversification of both products and customers.

"While much attention lately has been placed on certain applications for compound semiconductor substrates, we are seeing an expanding universe of emerging applications and technologies across our portfolio that are driving growth in every one of our substrate product categories," notes CEO Morris Young. "As a result, we achieved record revenue in indium phosphide substrates in Q2 [comprising about 30% of total revenue], and posted solid growth in semi-insulating gallium arsenide, semiconducting gallium arsenide, and germanium substrates."

Gross margin has risen further, from 29.4% a year ago and 30.5% last quarter to 30.8%. Substrate gross margin was higher than overall company gross margin. However, this was offset by lower gross margin on raw materials, reducing total gross margin by almost 1 percentage point due to an inventory write-down of raw gallium at one of AXT's joint ventures in China (since the raw material market continues to struggle with overcapacity, particularly in raw gallium).

Operating expenses were $4.961m, up by just $44,000 from $4.917m last quarter, as OpEx continues to run relatively flat quarter-to-quarter.

Net profit was $1.93m ($0.05 per diluted share), up from $0.665m ($0.02 per diluted share) last quarter and $1.15m ($0.03 per diluted share) a year ago.

Depreciation & amortization was steady at $1.1m, while capital expenditure (CapEx) has been raised from $0.7m last quarter to $1.9m. Overall, during the quarter, cash, cash equivalents and investments hence rose by $767,000, from $86.8m to $87.5m.

"Q3 is shaping up nicely, reflecting an increase in each of our substrate categories," comments chief financial officer Gary Fischer. For third-quarter 2017, AXT expects revenue to rise by about 14% to $26.5–27.5m.

"We're seeing a meaningful positive impact by increased volume because our manufacturing overhead costs are spreading over more units," says Fischer. This is expected to boost gross margin by 1–2% over Q2. "We work diligently with one of our three consolidated joint venture companies to increase the utilization of a very important raw material that they supply for our manufacturing process," he adds. The cost savings are hence expected to provide an additional 1–2% benefit to gross margin. "This illustrates the tangible benefit derived from our supply chain strategy," notes Fischer. AXT hence expects earnings per diluted share to rise to $0.08–0.10.

Regarding the relocation of AXT's GaAs substrate production line from Beijing (which is being accelerated to take advantage of the market opportunity in 3D sensing), Young says that the firm has identified a new site (in a different city in China with lower labor rates, but reasonably close to its existing current location) and that it expects to finalize the agreement in the near future. It has 140,000ft^2 of manufacturing space already built plus an additional building that can be used as dormitory and offices. "Existing buildings will ease the logistic requirements for technicians [one of the reasons for choosing the site]," says Young. The first stage (doing some of the crystal growth) should be completed in 3–4 months. Wafer polishing will continue in the Beijing facility until build-out of the cleanroom is completed, after which samples from wafer processing at the new site are expected by the end of first-quarter 2018. The two facilities should operate concurrently for maybe a year to a year and a half, reckons Young (after which the Beijing facility should be monetized).

● AXT has appointed Wilson Lin Ph.D. as chief operating officer, responsible for global operations and reporting to CEO Morris Young.

Before AXT, Lin was director & CEO of General Photonics Corp (a manufacturer of optical polarization modules and instruments). Previously, at Newport Corp, from December 2006 he was director, global supply chain management. Lin was made general manager of China Operations in February 2010 and VP, Asia Pacific in January 2013.

"Wilson has a solid track record of demonstrating expanding responsibility and achievement," comments Young. "His business skills and broad experience in China, as well as his deep understanding of single-crystal growth technology, will combine to bring a very positive contribution to AXT," he adds.

www.axt.com

Veeco's Q2 revenue up 21% year-on-year organically

Targets increased for revenue synergies from $10m to $15m and cost reductions from $10m to $23m, following Ultratech acquisition

For second-quarter 2017, epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue of $115.1m, up 22% on $94.4m last quarter and up 53% on $75.3m a year ago.

However, this includes $24m from about one month of business from Ultratech Inc of San Jose, CA, USA (which designs and makes lithography, laser-processing and inspection systems for the advanced packaging, front-end semiconductor and LED markets), which was acquired on 26 May. Ultratech's main businesses address the advanced packaging lithography and semiconductor laser annealing markets, both of which are highly complementary to Veeco.

Excluding Ultratech, revenue was $91m, down 3.6% on $94.4m last quarter but up 21% on $75.3m a year ago, driven primarily by strong sales of metal-organic chemical vapor deposition (MOCVD) and Precision Surface Processing (PSP) systems into lighting, display and power electronics markets as well as greater demand for data storage solutions from the scientific and industrial market.

The Lighting, Display & Power Electronics segment contributed $56.2m (49% of overall revenue) driven by the continued shipment of systems to China, Southeast Asia and Europe.

The Advanced Packaging, MEMS & RF segment almost doubled from $11.6m last quarter to $21.4m (19% of overall revenue), driven by Ultratech sales in advanced packaging and PSP sales for MEMS applications.

The Scientific & Industrial segment was steady at $27m (23% of overall revenue), supported by shipments of AVE systems for optical and data storage application as well as shipments of molecular beam epitaxy (MBE) systems.

Formerly part of the Scientific & Industrial segment (before the Ultratech acquisition), the Front-end Semiconductor segment contributed $10.4m (9% of overall revenue), driven by the shipment of laser annealing systems.

Geographically, the concentration on China fell back to 23% of total revenue (after a surge to 43% last quarter driven by MOCVD demand from LED makers) and Europe, the Middle-East & Africa (EMEA) fell to 16% while the USA was unchanged at 18%, as the rest of the world rose to 43%.

On a non-GAAP basis, gross margin was 40.6%, up from 37% last quarter, driven largely by better performance in the MOCVD and MBE product lines. Excluding Ultratech, gross margin was 40.1% (just exceeding the expected 38–40%), down from 42.4% a year ago.

Operating expenditure (OpEx) was $37.2m, up $6.7m sequentially, reflecting the additional expenses from Ultratech's partial quarter. Excluding Ultratech, OpEx was $32.1m, cut from $38m a year ago.

Operating income was $9.6m, versus a loss of $6.2m a year ago. Net income was $6.4m ($0.15 per share, above the $0.09 upper limit of the guidance range), improving from $3.6m ($0.09 per diluted share) last quarter and a loss of $7.6m ($0.19 per share) a year ago.

Adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) was $12.8m (above the expected $4–10m), improving on $7.3m last quarter and a loss of $2.8m a year ago.

During the quarter, cash and short-term investments fell by $379m from $682m to $303m, reflecting $378m of net cash used in the Ultratech acquisition.

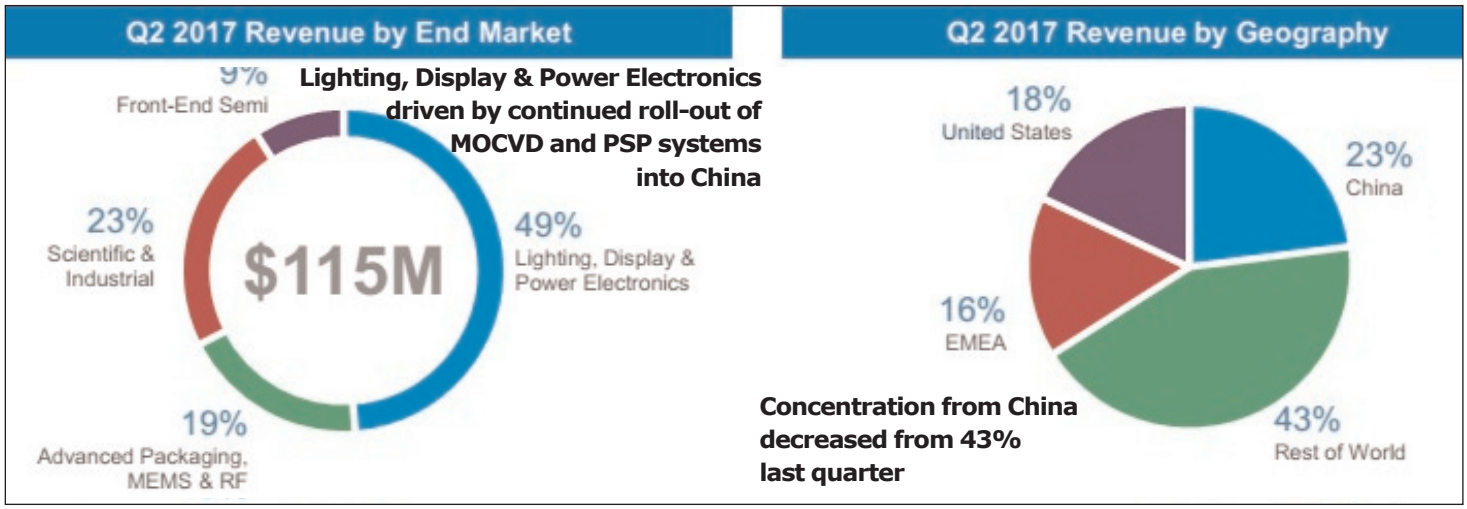
Order bookings were $123m or, excluding Ultratech, $110m (up on $107m last quarter), with continued positive momentum across many of the firm's businesses. The Lighting, Display & Power Electronics segment received multiple systems orders from Chinese and European LED makers. The Advanced Packaging, MEMS & RF segment won repeat PSP orders from a European sensor manufacturer and repeat advanced packaging lithography orders in support of customers' wafer-level packaging and copper pillar applications. Scientific & Industrial segment orders were up, driven by Ultratech's ALD systems and technology buys from data storage customers.

During the quarter, order backlog rose from $221m to $270m, up by $48m ($30m of which is due to Ultratech).

For third-quarter 2017, Veeco expects revenue of $125–145m, lower than previously expected due to two main causes.

- Not included are shipments in Q3 to multiple customer of several systems of the firm's soon-to-be-launched high-productivity EPIK MOCVD system (which doubles the capacity of the existing EPIK 700 by doubling the number of reactor modules to four), for which $20–25m will only be recognized as deferred revenue after the tools are installed and the customers place them into production (expected in early 2018).
- Veeco has seen a temporary pause in the advanced packaging market over the last few months that has resulted in several Ultratech lithography tool shipments being pushed out of Q3, reducing revenue by about $15m.

Gross margin should be 39–41%. Operating expenses are expected to be $49–51m. In Q3, Veeco is already realizing $2m of early OpEx synergies from Ultratech (offset by elevated spending levels to drive integration efforts). Operating income is expected to be $0–9m. Net income should range between



a loss of $4m ($0.09 per share) and a profit of $5m ($0.09 per share).

"LED industry conditions continue to improve, and we believe we can achieve a stronger second half of 2017," says chairman & CEO John R. Peeler. "In addition, the integration of Ultratech is proceeding well and we are very optimistic about the potential synergies in both revenue and costs," he adds.

Veeco has now increased its targets for revenue synergies from $10m to $15m (to be realized by end-December 2018) and for cost reductions from $10m to $23m. All of this is expected to generate $30m in annualized operating income synergies by the end of calendar 2018. Over the next 12–18 months, the firm expects to reduce OpEx by $15m through rationalization of field infrastructure, ERP (enterprise resource planning) conversion, material cost reductions, and focused R&D projects. On top of the $30m in operating income synergies, Veeco believes that there is an additional $10m of annual synergies in stock-based compensation compared with the historical levels of Ultratech.

www.veeco.com

Aixtron's first-half revenue doubles year-on-year

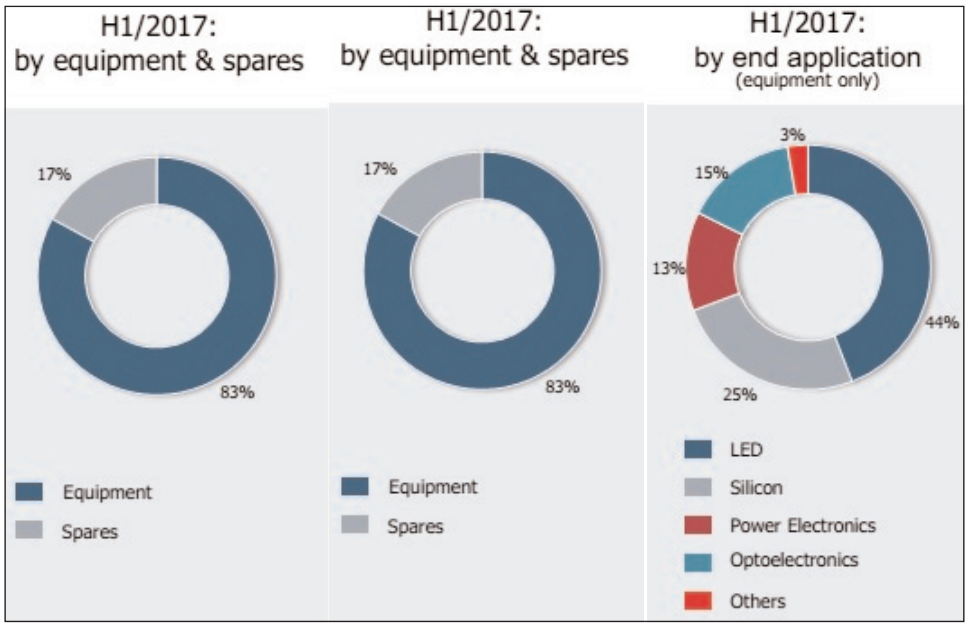
Full-year 2017 revenue and order guidance raised from €180–210m to €210–230m

For first-half 2017, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €114.1m, more than doubling from first-half 2016's €55.5m.

Specifically, equipment sales of €94.4m comprised 83% of total revenue (up from 66%, or €36.6m, in first-half 2016). Sales of spare parts and services comprised the remaining €19.7m or 17% of total revenue.

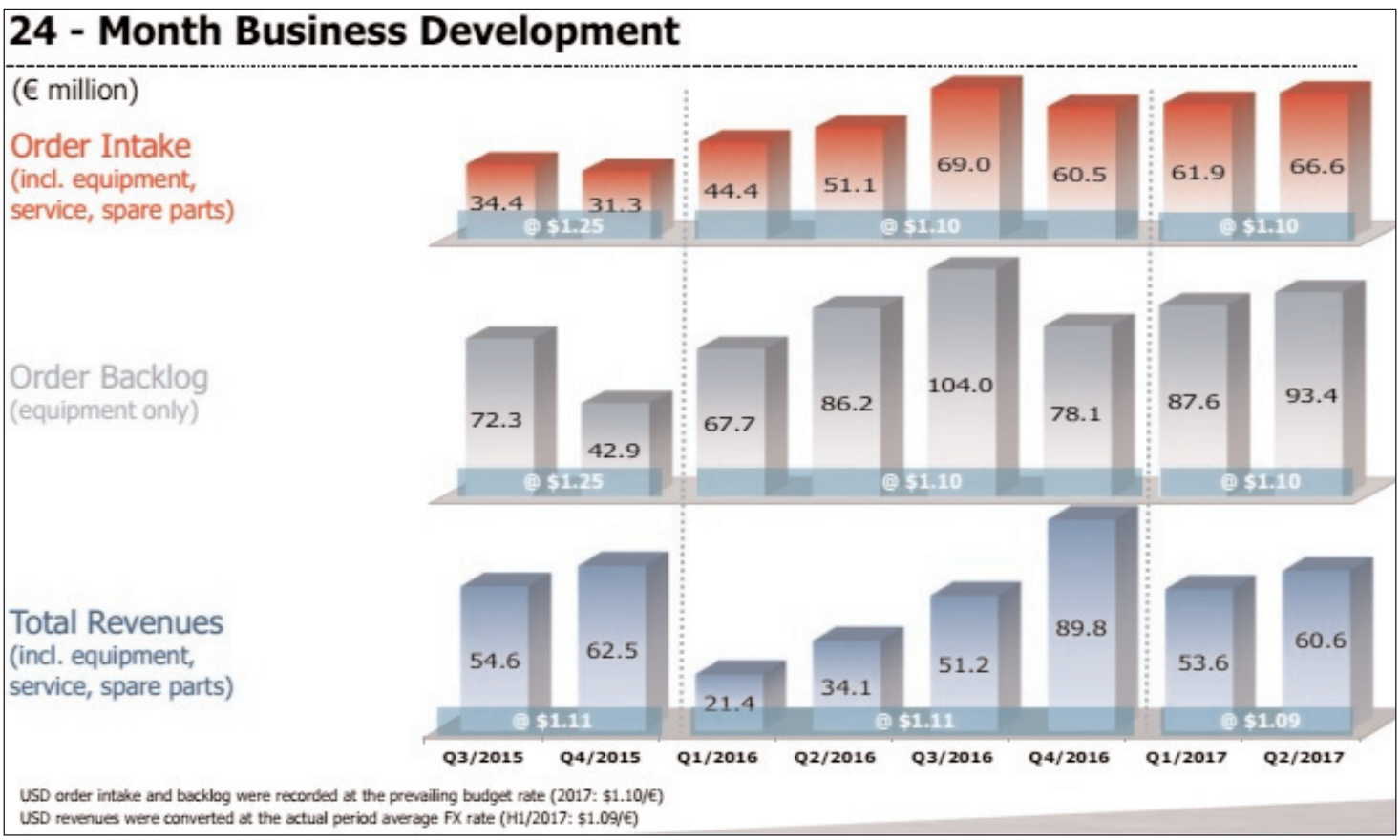
On a regional basis, 82% of revenue came from Asia (continuing to rebound, after dipping to just 55% in first-half 2016), 8% came from Europe, and 10% came from the US.

For Q2/2017, revenue was €60.6m, up 13% on €53.6m last quarter and up 78% on €34.1m a year ago. Equipment sales of €50.9m comprised 84% of total revenue (up from 81% or €43.5m in Q1 and 72% or just €24.7m a year ago).



First-half 2017 revenue growth was driven mainly by improved demand for metal-organic chemical vapor deposition (MOCVD) systems for manufacturing vertical-cavity surface-emitting lasers (VCSELs), red-orange-yellow (ROY) and specialty LEDs as well as power electronics, and chemical vapor deposition (CVD) systems for manufacturing flash memory.

Gross margin has improved from 18% in first-half 2016 to 25% in first-half 2017, or 27% after adjust-



ing for restructuring costs of €2.3m (with Q2's 26% down slightly from Q1's 27%, impacted as expected by low-margin shipments from inventory of the remaining AIX R6 MOCVD systems for GaN LEDs).

Operating expenses rose from €35.9m in first-half 2016 to €40.2m in first-half 2017 (while being cut from €20.6m in Q1 to €19.6m in Q2).

Earnings before interest, tax, depreciation and amortization (EBITDA) have improved from –€20m in first-half 2016 to –€10.2m in second-half 2017, or –€4m after adjusting for €6.2m of restructuring costs (improving from –€2.7m in Q1 to –€1.3m in Q2).

The net result improved from –€26.6m in first-half 2016 to €24.9m in second-half 2017, or –€10.4m after adjusting for €14.5m of restructuring costs.

Operating cash flow has improved from –€39.3m in first-half 2016 to €43.3m in first-half 2017, while capital expenditure (CapEx) for property, plant & equipment has been halved from €5.9m to just €3m. Free cash flow has hence improved by €81.3m from –€41m to €40.3m (€33.3m in Q1 and €7m in Q2), due mainly to the collection of receivables as well as advanced payments received from customers.

Cash and cash equivalents at the end of June were €197.1m, up from €193.6m at the end of March but up by €37m from €160.1m at the end of December.

Total order intake (including spares and service) has risen by 34% from first-half 2016's €95.5m to €128.5m in first-half 2017 (with Q2's €66.6m up 8% on Q1's €61.9m and up 30% on €51.1m a year ago, driven mainly by increased demand from LED and optoelectronic as well as memory applications).

Equipment order backlog at the end of June was €93.4m, up 7% on €87.6m at the end of March. Most of the backlog is due for shipment in 2017.

"In H1/2017, the positive development in order intake has continued and will result in improved revenues," notes CEO Kim Schindelhauer. Aixtron has therefore raised its full-year 2017 guidance for both order intake and revenue from €180–210m to €210–230m (consisting of H1/2017's revenue of €114.1m supplemented by 2017-shippable order backlog of at least €70m joined by a forecasted €5–25m of further 2017-shippable equipment order intake, plus a forecasted €20m of spares & service revenue).

In addition, in first-half 2017 Aixtron stepped forward in focusing on its core business:

- In Q1 Aixtron froze product development for III-V on silicon (TFOS) materials for next-generation logic chips (resulting in a one-time write down of €6.6m) and in Q2 the firm froze thin-film encapsulation (TFE) activities (involving write downs of €6.4m).
- As it continues to transform the company to align R&D expenses with revenue (targeting a return to profitability in 2018), on 25 May Aixtron agreed to sell the assets of its ALD & CVD memory product line (based mainly at US subsidiary Aixtron Inc in Sunnyvale, CA) to Eugene Technologies Inc, a US subsidiary of South Korea-based Eugene Technology Co Ltd that makes single-wafer ALD, CVD and plasma deposition and surface treatment systems.
- To support the ongoing establishment of a joint venture to spin-off its organic light-emitting diode (OLED) deposition technology, Aixtron has founded the subsidiary APEVA SE (with all related staff transferring to the new JV by 1 October).

Dr Felix Grawert will join Aixtron as member of the executive board by 14 August, which means that in first-half 2017 Aixtron completed the majority of tasks concerning the firm's realignment.

Aixtron says that it continues to transform the firm to align R&D expenses with revenues in order to return to profitability in 2018. As the execution of this strategy may have a substantial influence on profit, management is not guiding on EBITDA, EBIT and net result for full-year 2017. Nevertheless, Aixtron expects to achieve positive free cash flow in 2017 and a positive EBIT for 2018.

San'an Optoelectronic first to qualify new Aixtron Showerhead 19x2"-wafer MOCVD reactor for DUV LEDs production

San'an Optoelectronic Co Ltd (China's largest LED maker) has completed qualification of Aixtron's Close Coupled Showerhead (CCS) process chamber, designed for the production of deep ultraviolet LEDs.

Based on CCS technology, the new process chamber is said to be the first commercially available MOVD reactor that offers the extremely high process temperatures needed for the production of DUV LEDs. The enhanced chamber performance facilitates cost-efficient high-volume manufacturing of DUV LEDs, as used for water and air purification. The 19x2" wafer configuration represents the largest capacity currently available on the market for this high-end MOCVD application, claims Aixtron.

"The new Aixtron CCS reactor design is a key enabling factor for San'an producing next-generation DUV LED products with higher quantum efficiencies and significantly higher output powers," comments Dr Ryan Chuo, VP of San'an's Technology Center. "Already being one of the largest suppliers for LEDs, Aixtron's newly designed process chamber perfectly supports our strategic targets in the area of DUV LEDs," he adds. "We are very pleased to be the first company to qualify and utilize Aixtron's new reactor kit."

www.sanan-e.com/en
www.aixtron.com

AES showcases SEMI-GAS fully automatic valve manifold box for dichlorosilane

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 service) — is showcasing its new SEMI-GAS Nanoturion Valve Manifold Box for Dichlorosilane (DCS) to support semiconductor process equipment manufacturing and related applications.

The Fully Automatic system includes manifold heat tracing and a standalone wall-mounted heater controller to enable multi-zone heat capabilities for stabilizing the high flow rates and delivery pressures required for vaporizing and delivering DCS. The inlet header and various stick zones are independently controlled to support separate process, tool or experiment gas supplies.

The specialized Nanoturion valve manifold box is equipped with a GigaGuard GSM Fully Automatic Controller, which includes a color touchscreen interface for intuitive operator control and the ability to automate sequences for streamlined operations and maintenance. The controller features Ethernet communications, exhaust pressure monitoring, and user-configured set limits, warnings, and alarms.

Additional design highlights include:

- ultra-high-purity 316L SS components orbitally welded and assembled in a Class 100 cleanroom;
- a SEMI S2-certified design and helium leak testing system validation to 1.0 x 10^{-9}atm-cm^3/sec;
- a fully loaded stick design in an 8-line configuration with 8 process gas sticks populated;
- fully automatic purge capability via automated sequences set from the GSM controller; and
- multiple safety features to support toxic gas delivery requirements, including a UV/IR pyrophoric gas detector, an EMO (emergency off) button for manual shutdown, and optional Z-Purge kit for Class I, Division II applications.

"We realized that, given the proliferation of dichlorosilane as one of the most widely-used specialty gases in semiconductor fabs, a system tailored specifically to DCS handling requirements was needed," says AES general manager Jim Murphy. "This Nanoturion Fully Automatic Valve Manifold Box is tailored to uphold the highest standards of safety while also giving operators programmable and independent control to supply DCS to different processes — enabling the flexibility that supports rapid innovation," he adds.

www.appliedenergysystems.com

Plasma-Therm to distribute Trymax's resist ashing products in North America

Trymax Semiconductor Equipment BV of Nijmegen, The Netherlands has granted plasma process equipment maker Plasma-Therm LLC of St Petersburg, FL, USA exclusive rights to distribute all of its NEO products for ashing applications in North America.

Plasma-Therm and Trymax can now address all ashing, polymer removal and dry cleaning applications in the served markets, for all wafer sizes including 12 inches. The alliance provides a full set of stripping technologies to customers in North America, from low temperature at 50°C to high strip rate at higher temperature.

"Partnering with Trymax allows Plasma-Therm to offer resist strip and ashing products which complement well our existing high-density radical flux (HDRF) technology, which targets polymer removal and low-damage surface treatment," says Plasma-Therm's business development manager Yannick Pilloux.

"The agreement with Plasma-Therm is a critical component to our North American expansion strategy," says Trymax's executive VP Ludo Vandenberk. "By combining forces with Plasma-Therm, we are able to better serve US front-end, MEMS and back-end manufacturers with solutions that span the ashing and non-critical etch process steps. We are eager to get started serving our customers with the competitive advantages that our technologies can offer."

Trymax's NEO products for ashing/etching and descum accommodate 150mm, 200mm and 300mm substrates. The bridge tools are fully flexible for processing multiple different substrate types, such as silicon, gallium arsenide (GaAs), silicon carbide (SiC), LiN, LiT, eWLB (embedded wafer-level ball grid array) and Taiko wafers from R&D to high-volume markets.

www.plasmatherm.com
www.trymax-semiconductor.com

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Oxford Instruments boosting Asia-Pacific R&D center at Taiwan's ITRI

MOU signed to expand cooperation to micro-LEDs & silicon photonics

Oxford Instruments plc plans to increase personnel at its R&D base at Taiwan's Industrial Technology Research Institute (ITRI), and to leverage ITRI's R&D capacities to strengthen their cooperative relationship in technology development.

Y. Tim Tsai (advisor at the Department of Industrial Technology under the Ministry of Economic Affairs) and Catherine Nettleton (representative of the British Office Taipei) jointly witnessed the formal signing of the memorandum of understanding (MOU) by ITRI vice president Dr Jia-Ruey Duann and Adam Jaufurally, finance director of Oxford Instruments Plasma Technology (OIPT). Cooperation will be expanded to MEMS, micro-LEDs, silicon photonics, and the development of other optoelectronic components and equipment technology.

ITRI's research in semiconductors and optoelectronics span upstream, midstream and downstream industrial supply chains, underpinning the development of related industries in Taiwan, noted Duann. ITRI and Oxford Instruments first signed an MOU on cooperation in 2006, after which ITRI's MEMS Center and Oxford Instruments engaged in close cooperation and developed HB-LED-related technology. The expanding research capacities

under the latest agreement aim to not only aid the future development of traditional LED-related technology but also to focus on cooperation in emerging technologies and applications in micro-LEDs and silicon photonics. It is hoped that the collaborative efforts will promote semiconductor technology applications and expedite economic growth in Asian emerging markets, adds Duann.

Oxford Instruments is attracted to Taiwan due to the technology and comprehensive industrial supply chain in its semiconductor industry, comments Jaufurally. As ITRI plays a key role in R&D, Oxford Instruments is interested in expanding its collaboration with both ITRI and Taiwan industry. The firm will jointly hold precision testing/analysis training courses with ITRI, making ITRI an important base for Oxford Instruments in the Asia-Pacific in training engineering R&D personnel, he adds.

Nettleton said that, since the British government looks favorably on Oxford Instruments' expanded cooperation with ITRI (along with bilateral interaction in technology and innovation), the UK will actively assist British enterprises and startups in engaging in R&D cooperation in Taiwan. The UK this year has set out five priority areas for technology cooperation with Taiwan — life sciences, advanced manufacturing, digital economy, space science, and clean energy — which correspond to the '5+2' Industrial Innovation Plan being promoted by the Taiwan government. Nettleton expects these efforts to further strengthen innovative cooperation in these fields.

www.oxford-instruments.com

OIPT announces Woowon as Korea representative

UK-based equipment maker Oxford Instruments Plasma Technology has signed an agent agreement for Woowon Technology Co Ltd to represent its complete range of etch, deposition and growth solutions in South Korea.

Established in 1990, Woowon offers experience to customers engaged in the development and manufacture of semiconductor, LED, solar energy and MEMS devices.

"Demand for Oxford Instruments' process solutions has increased significantly across Asia, therefore joining with local business partners to acquire applications and support expertise complementary to our own can be invaluable both to our customers and Oxford Instruments", says OIPT's global sales director Paul Davies. "Oxford Instruments looks forward to a long and beneficial relationship with Woowon Technology, offering our customers efficient and effective local sales and service support in Korea," he adds.

"We are delighted to be offering their flexible, configurable process tools and leading-edge processes for the engineering of micro- and nano-structures," comments Woowon's founder & president Dr Hwan Oh about OIPT.

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MRSI launches high-speed die bonder for photonics high-volume manufacturing

MRSI Systems of North Billerica, MA, USA, which manufactures fully automated, high-precision die bonding and epoxy dispensing systems, has launched the MRSI-HVM3 high-speed die bonder to support high-volume manufacturing requirements for photonics applications. The MRSI-HVM3 is in full production and shipping to customers worldwide.

Users need to scale up manufacturing to unprecedented levels for advanced applications such as data centers, telecom upgrades to 100G+, 5G wireless, the Internet of Things (IoT), and advanced optical sensors. High-volume manufacturing of photonic, sensor, and semiconductor devices now demands a die bonding system that can deliver high speed without sacrificing precision and flexibility, says the firm. The MRSI-HVM3 high-speed, flexible 3µm die bonder has been built to address this challenge. The new system leverages a well-defined set of MRSI's core competences, built up over 30 years, in system design, software development, machine vision, motion control, industrial automation, and process solutions.

"The new MRSI-HVM3 incorporates the latest hardware and software innovations," notes Dr Yi Qian, VP of product management. "Equipped with ultrafast-ramp eutectic stations, it deploys multiple levels of parallel processing utilizing dual gantries, dual heads, dual bonding stages, and 'on-the-fly' tool changes," he adds. "Used across all products, MRSI's platform software makes it easy for users to change process settings on their own for new parts, new processes, and new products. These features provide our customers with best-in-class throughput for capacity expansion; high accuracy for high-density packaging; and unmatched flexibility for multi-chip multi-process production in one machine," Qian claims. The MRSI-HVM3 high-speed die bonder supports applications including chip-on-carrier (CoC), chip-on-submount (CoS), and chip-on-baseplate or board (CoB).

At the 19th China International Optoelectronic Exposition (CIOE 2017) in Shenzhen (6–9 September), MRSI is exhibiting with its Chinese representative CYCAD Century Science and Technology (in booth #1C66), including private demonstrations of the MRSI-HVM3 performing CoC eutectic and epoxy bonding.

www.cioe.cn/en
www.mrsisystems.com

BluGlass' BLG-300 upgrade installation and commissioning completed; industry evaluations to restart within weeks

BluGlass Ltd of Silverwater, Australia — which was spun off from the III-nitride department of Macquarie University in 2005 to develop a proprietary low-temperature process using remote-plasma chemical vapor deposition (RPCVD) to grow materials including gallium nitride (GaN) and indium gallium nitride (InGaN) on glass substrates — says that its upgraded, larger BLG-300 remote-plasma chemical vapor deposition (RPCVD) platform has been successfully installed and commissioned.

The upgraded platform is already demonstrating good progress towards the uniformity and electrical properties required for BluGlass' industry evaluations. The technology team will continue to test and adjust the new installation over the coming weeks to optimize its performance. The BLG-300 is expected to return to industry evaluation work in the coming weeks.

The upgrade has produced good results from the first run, says chief technology & operations manager Dr Ian Mann, with early results showing good progress on uniformity. "This demonstration of the scalability using the new modular RPCVD design will be replicable in the future and help enable even larger-deposition RPCVD platforms," he believes.

While the BLG-300 installation has slowed some of the industry evaluation progression, BluGlass and LED maker Lumileds of San Jose, CA, USA agree that the Phase II collaboration is making steady progress. This and the IQE collaboration will again be expedited with the upgraded BLG-300 starting industry work in September.

"The opportunity for RPCVD that we are exploring with Lumileds is very compelling, as demonstrated by the high level of commitment from both parties," comments managing director Giles Bourne. "Both Lumileds and BluGlass are encouraged with the strong progress being made on the Phase II collaboration."

www.bluglass.com.au
www.iqep.com
www.lumileds.com

ROHM shrinks two-color chip LED by 35% into 1608-size

ROHM Semiconductor of Kyoto, Japan has launched what it claims is the industry's smallest class (1608 size) of two-color chip LEDs. The SML-D22MUW also features a special design that is said to improve reliability along with a backside electrode configuration that supports high-resolution displays.

In recent years, chip LEDs have increasingly been used for numerical displays in industrial equipment and consumer devices. Conventional numerical displays use a single color to indicate numbers, but there is a growing need to change the color to make it easier to recognize abnormalities. However, this typically entails using two separate LEDs (doubling the mounting area, along with development costs) or opting for a standard two-color LED (which also increases board size).

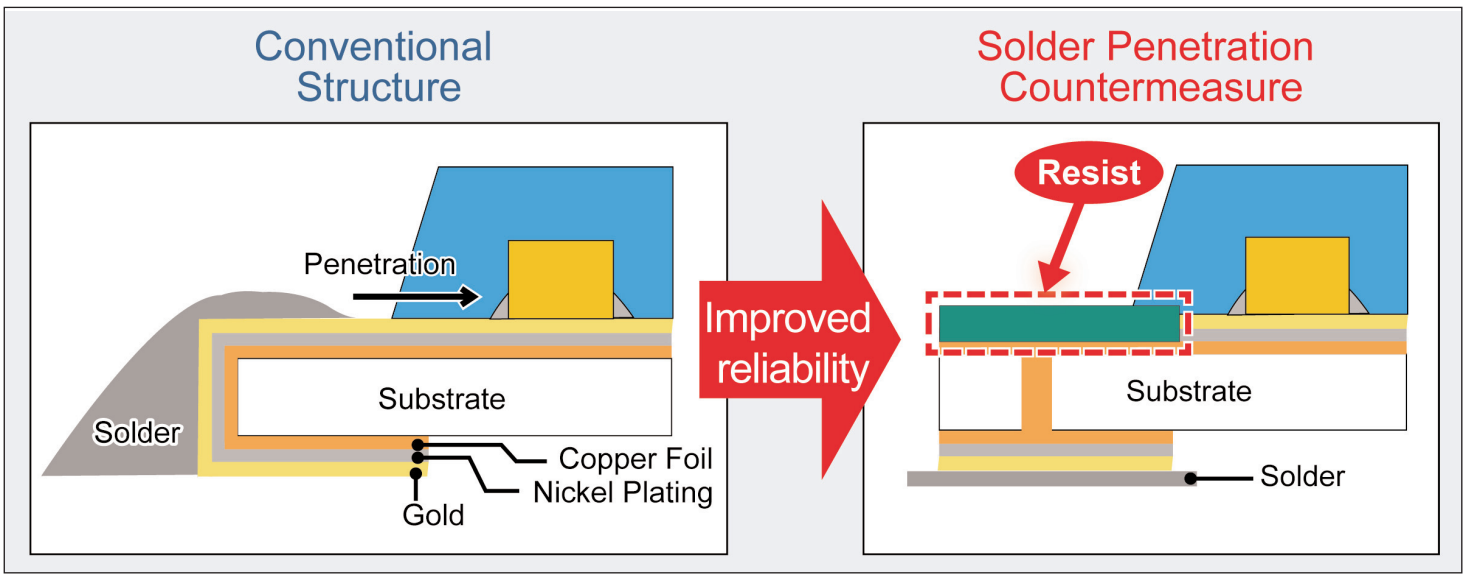
In contrast, ROHM says that, in addition to chip miniaturization, the SML-D22MUW leverages proprietary PicoLED mounting and wire bonding technologies and processes to integrate the two chips (red and green) in a compact 1.6mm x 0.8mm package — the same size as conventional single-color LEDs. This makes it possible to emit multiple colors in a smaller footprint. Board space is reduced by 35% over standard 1.5mm x 1.3mm two-color LEDs, contributing to thinner displays.

In addition, the extremely close configuration of color elements results in color mixing properties that make it possible to produce not only red and green colors but a number of intermediate colors as well.

Also, after taking into consideration usage conditions during reflow, countermeasures were adopted. Incorporating a stopper resist before the gold plating process blocks the gold pattern (that features good wettability). This prevents solder penetration into the resin, eliminating failures due to short circuits and contributing to greater reliability.

Finally, adopting a backside electrode design allows mounting in narrow spaces, enabling high-definition display in dot matrix and other applications.

www.rohm.com



AquiSense achieves ISO 9001 certification

AquiSense Technologies LLC of Erlanger, KY, USA (which designs and manufactures water, air and surface disinfection systems based on UV-C LEDs) has been awarded ISO 9001:2015 certification by the International Organization for Standardization.

The ISO 9001 standard places heavy emphasis on quality management system performance and ensures that a company's quality management system is strictly aligned with customer expectations.

"Since the formation of AquiSense, we have focused on establishing ourselves as a market leader by engineering innovative UV-C LED based systems and certifying these systems to the world's most demanding quality and performance standards," says CEO Oliver Lawal. "Our receipt of ISO 9001 reaffirms this strategy," he adds.

"This quality standard is a key requirement for many of our global OEM customers, which include many large multinational corporations," says VP of operations Mike Hymas.

In addition, AquiSense's PearlAqua water disinfection platform has been microbiologically tested in accordance with the US Environmental Protection Agency (EPA) drinking water guidelines and has received certification in 2016 to NSF/ANSI 61 & 372 for materials safety. AquiSense also complies with CE and RoHS standards for all its products.

www.aquisense.com

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Seoul Semiconductor's Q2 revenue up 14.9% year-on-year, driven by general lighting applications

Growth maintained despite intensified competition from China

For second-quarter 2017, South Korean LED maker Seoul Semiconductor Co Ltd has reported revenue of KRW267bn (US$238m), up 14.9% on a year ago (and towards the top of the guidance range of KRW250-270bn) due to strong sales in general lighting and strengths across all divisions of the company, with growth in automotive lighting sales proving particularly profitable.

Seoul Semiconductor reckons that it is only Korean firm to maintain revenue growth despite intensifying competition from Chinese LED makers.

For the lighting division, while differentiated products such as Wicop and Acrich rose as a proportion of sales, automotive exterior lamps (e.g. daytime running lights and headlights) continued their rapid growth. The automotive lighting sector has a high barrier to entry due to high technology requirements and intellectual property. Seoul expects to gain further market share with its differentiated Wicop technology.

For the IT division, sales growth was driven mainly by existing customers expanding their product line-ups, supplemented by new customers.

To improve share price stability and increase shareholder value, Seoul has announced plans to almost double its future dividends, based on the fact that its current level of pay-out is half the industry average and an increase to the industry average is necessary. In addition, the firm has sufficient cash generation capabilities, since it has booked above 20% gains in EBITDA, leaving sufficient funds available for future investments (as part of last quarter's announcement to execute a KRW10bn share buyback program).

For Q2/2017, Seoul Semiconductor expects revenue of KRW260–280bn. It plans to further strengthen its sales and marketing activities for its proprietary technologies including Acrich and Wicop and to focus on acquiring more new customers in order to boost earnings.

Chief financial officer Sangbum Lee notes that SunLike (a new LED technology unveiled in in June that produces light closely matching the spectrum of natural sunlight) has received great interest from customers worldwide, and the firm plans to launch additional new products during the rest of the year and to focus on protecting its intellectual properties.

www.SeoulSemicon.com

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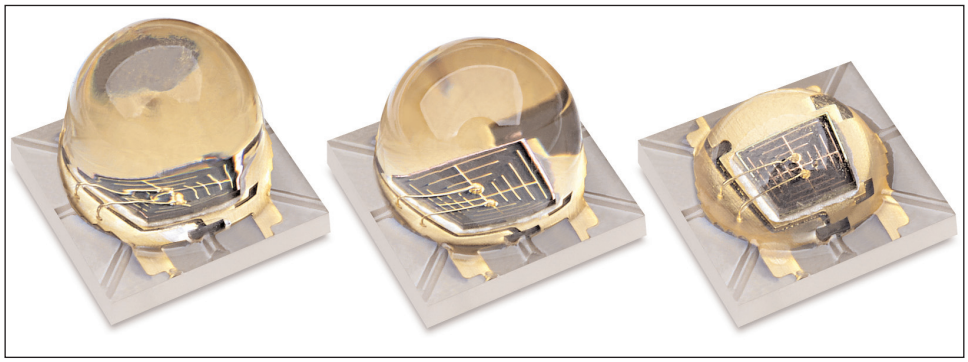
Lumileds launches LUXEON IR Family of high-radiant-intensity emitters for imaging applications

LED maker Lumileds of San Jose, CA, USA has launched a family of high-power infrared (IR) emitters designed to address the vast array of rapidly growing IR applications, ranging from facial recognition/iris and gesture scanning to wearable health monitors, machine vision, night-vision cameras and other industrial/biotech applications. The LUXEON IR Family combines high-radiant-intensity imaging with what is claimed to be the industry's lowest thermal resistance, resulting in optimal solutions for compact system designs.

All emitters are available in wavelengths above the visible spectrum at 850nm and 940nm, each of which has advantages depending on the use. The 850nm emitter is the workhorse for most cameras (including CCTV) because of its high system efficiency. However, a known drawback for all 850nm emitters in the industry is its susceptibility to interference from sunlight and its reddish glow. To address these issues, the Lumileds IR Family also includes a 940nm-wavelength emitter, which is almost invisible and is less sensitive to sunlight interference, making this wavelength suitable for use with ambient light and 'stealth mode' systems.



The LUXEON IR Family is built on two platforms: the LUXEON IR Compact Line (which enables IR transmission with very high radiant power density up to 1150mW at 940nm) and the LUXEON IR Domed Line (which uses various beam angles and achieves radiant power up to 1400mW at 940nm for high-punch, long-range applications).

"The LUXEON IR Compact Line addresses markets that require high power density in a small footprint," says Thierry De Smet, director of product management. The LUXEON IR Compact Line is 1.37mm x 1.90mm and delivers 400mW/mm^2, outperforming all competing products, it is claimed.

The LUXEON IR Domed Line is also offered at 850nm and 940nm, but in beam angles of 60º, 90º and 150º in an industry-standard 3.7mm x 3.7mm package. This design enables drop-in upgrades in applications that require high punch, long range and high uniformity, including positioning and depth measurement, biometric identification and industrial automation. Delivering what is claimed to be the industry's lowest thermal resistance (2.5K/W), the package efficiently transfers heat away from the emitter for greater system reliability and performance. To ease system design, the LUXEON IR Dome line is compatible with an ecosystem of off-the-shelf lenses.

The LUXEON IR Family is rated as Risk Free for eye safety according to the IEC Photobiological Test (IEC/EN 62471 standard). Initial L70 reliability testing has indicated lumen maintenance of over 30,000 hours.

www.lumileds.com/LUXEONIR

Lumileds launches 1700lm single-die LED

Lumileds has unveilled its highest-flux-density LED. Packaged in a compact 4.0mm x 4.0mm footprint, LUXEON V can be driven harder than other LEDs in its class, it is reckoned, due to new die and packaging technologies. Luminous flux is more than 1700lm at a correlated color temperature (CCT) of 5700K and a color rendering index (CRI) of 70 (4.8A) — 50% higher output than competing LEDs, the firm claims.

"LUXEON V enables fixture designs that were previously unattainable for stadium and area lighting, torch and other portables because of the unique combination of high efficacy at high drive current with extremely low thermal resistance and optimized radiation pattern," says Kathleen Hartnett, senior director, product marketing.

LUXEON V LEDs leverage Lumileds' next-generation patterned sapphire substrate (PSS) chip-scale packaging (CSP) technology, enabling high efficacy at high drive currents, higher maximum drive current and higher lm/mm^2. The nominal drive current is 1.4A and the LEDs may be driven at up to 4.8A — 60% higher than competing emitters, it is reckoned. With the industry's lowest thermal resistance of 0.8K/W, designers can use smaller heat sinks for more compact fixtures.

Offered in a range of CCTs including 3000–6500K, LUXEON V LEDs feature a standard 3-stripe footprint for ease of design and assembly.

www.lumileds.com/LUXEONV

Bridgelux files patent infringement lawsuit countering Everlight's claims

Bridgelux Inc of Fremont, CA, USA (a vertically integrated manufacturer of solid-state light sources for lighting applications) has filed a counter claim against Taiwan-based Everlight Electronics Co Ltd in the US District Court for the Northern District of California seeking past and current damages, and an injunction preventing further sale of certain products in the USA. Bridgelux asserts that many Everlight products including that firm's 2835 and chip-on-board (COB) product lines infringe on Bridgelux's United States patent numbers 6,869,812, 8,567,988, 8,256,929 and 8,092,051.

This is in response to Everlight previously (on 10 June) filing a lawsuit alleging that Bridgelux was infringing US Patent 6,335,548 and 7,253,448 (which concern essential and fundamental structures in LEDs) by manufacturing and selling LED products including, for example, the 2835 series packaged surface-mount device (SMD) LEDs. The patented technology is broadly used in high-, mid- or low-power LED products.

Bridgelux says that it has invested heavily in research and product development of fundamental LED technologies, which are the intellectual property of Bridgelux and protected through its patent portfolio. These include light extraction processes, thermal management, and packaging used throughout the solid-state lighting industry across die, surface-mount, array and modular systems.

"Bridgelux is not an imitator. We develop our own technology, and are therefore confident in the strength of our claims, the quality of our intellectual property, and the ability of the US judicial system to reach the appropriate outcome," comments CEO Tim Lester.

With over 1000 patents owned or licensed, Bridgelux says that it respects the intellectual property process and the intellectual property of others, and will continue to defend itself. It has therefore engaged intellectual property firm Arent Fox LLP to represent it.

www.everlight.com
www.bridgelux.com

Cree and Emson settle dispute and agree supply deal

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has reached a confidential settlement in its patent infringement lawsuit with E. Mishan and Sons Inc (Emson).

Cree filed a complaint last November with the US District Court for the District of Massachusetts alleging infringement of its patented LED technology in the flashlights (e.g. the Bell + Howell Taclight) of Emson. Cree sought an award of enhanced damages, attorneys' fees and an injunction to prevent Emson from offering for sale and selling any products using 'knock-off' LEDs.

Emson has now agreed to an exclusive supply agreement to purchase Cree high-power LEDs for its high performance tactical flashlights.

"Cree will continue to diligently protect consumers and vendors from the perils of unauthorized LEDs across multiple applications and markets," says Dave Emerson, Cree LEDs senior VP & general manager. "We look forward to working together with Emson to provide superior products that include genuine, high-quality LED chips and components from Cree."

Cree says that it has developed an extensive LED patent portfolio after many years of intensive R&D, with numerous patents still pending. Emson joins other leading flashlight manufacturers in using Cree's patented high-power LEDs.

www.cree.com

Cree grants royalty-bearing, non-exclusive patent license to Light Polymers

Cree Inc of Durham, NC, USA (which makes lighting-class LEDs, LED lighting and power semiconductors) has granted a royalty-bearing, non-exclusive patent license on certain Cree patents for certain LED luminaires to Light Polymers Inc of San Francisco, CA, USA.

The agreement will allow Light Polymers to apply their proprietary nanochemistry to affordably manufacture luminaires with photonic films that are said to enhance the efficiency and effectiveness of LED lighting products.

"This patent licensing agreement with Cree is a big step in helping Light Polymers deliver the next generation of LED optics that enable more comfortable, safer and higher-quality, well-distributed lighting for homes and businesses," says Light Polymers' CEO Marc McConnaughey.

Light Polymers recently introduced its Crystallin Downlight product line using lyotropic materials that deliver a color rendering index (CRI) as high as 98. The firm's proprietary lyotropic materials can improve LED optics, yielding well-distributed lighting with much higher CRI and at affordable prices, it is claimed.

www.lightpolymers.com

Cree's quarterly revenue down 8% year-on-year

Wolfspeed expansion accelerated to overcome capacity constraints

For full-year fiscal 2017 (ended 25 June), Cree Inc of Durham, NC, USA reported revenue of $1.47bn, down 9% on fiscal 2016's $1.62bn.

Specifically, Lighting Products (mainly LED lighting systems and lamps) fell by 21% from $889.1m (55% of total revenue) to $701.5m (48% of total revenue) due mainly to fiscal Q2 commercial product holds and lower consumer bulb sales. LED Products (chips and components) were roughly flat at $550.3m (rising from 34% to 37% of total revenue) as higher product sales offset lower license revenue. The Wolfspeed business (Power & RF devices and silicon carbide materials) grew strongly by 25% from $176.3m (11% of total revenue) to $221.2m (15% of total revenue).

Fiscal fourth-quarter 2017 revenue was $358.9m, down 8% on $388.4m a year ago but up 5% on $341.5m last quarter (and towards the top of the $340–360m guidance range).

Wolfspeed contributed an above-expected $60.8m (17% of revenue), up 8% on $56.1m (16% of revenue) last quarter and up 30% on $46.7m (12% of revenue) a year ago. "While our current Wolfspeed capacity is constrained, we did achieve additional throughput in Q4 due to productivity improvements," notes chief financial officer Mike McDevitt.

LED Product contributed $143.4m (40% of revenue), at the high end of the target range, up 9% on $131.3m (39% of revenue) last quarter due to strong demand, and up slightly on $143.3m (37% of revenue) a year ago.

Lighting Product contributed $154.7m (43% of revenue), down 22% on $198.4m (51% of revenue) a year ago but up slightly on $154m (45% of revenue) last quarter, led by a solid recovery in US commercial and industrial (C&I) business, offsetting lower sales in the contractor value segment of the business, as well as seasonally lower consumer sales.

"While the US lighting market has been slower than forecast over the last two quarters, our internal fundamentals continued to improve in Q4, specifically in North American C&I business, driven by an improvement in service levels," notes Danny Castillo, executive VP & head of the Lighting Business.

On a non-GAAP basis, full-year gross margin has fallen from 31.1% for fiscal 2016 to 30.2% for fiscal 2017. Lighting Product gross margin has risen from 27.2% to 28%, due mainly to patent license revenue received during fiscal Q2/2017 related to the settlement with Feit Electric Company Inc. However, LED Product gross margin fell from 31.5% to 27.6%, due to lower license revenue and costs associated with the new LED chip ramp-up. Wolfspeed gross margin fell from 53.7% to 46.8%, due mainly to costs associated with new product ramp-ups and changes in product mix.

For fiscal Q4, company gross margin was 28%, below the expected 29% and down on 30.8% a year ago but up on 25.9% last quarter. Specifically, Lighting Product gross margin was 23.8%, down from 25.8% a year ago but up from 23% last quarter, due mainly to a higher mix of commercial sales plus better factory utilization and lower warranty costs. LED Product gross margin was 25.9%, down from 32.2% a year ago but up from 24.7% last quarter, due mainly to product mix. In contrast, Wolfspeed gross margin fell further, from 50.6% a year ago and 47% last quarter to 45.5%, due mainly to product mix.

Operating expenses have risen from $94m last quarter to $97m in fiscal Q4, due mainly to non-recurring costs associated with right-sizing the Lighting Products business plus start-up costs for the new joint venture Cree Venture LED Company Ltd with San'an Optoelectronics Company Inc of Xiamen, China (to produce and deliver to market mid-power lighting-class LEDs in an exclusive arrangement to serve the expanding markets of North and South America, Europe and Japan).

Full-year net income has fallen from $87.5m ($0.86 per diluted share) for fiscal 2016 to $49.7m ($0.50 per diluted share) for fiscal 2017. However, despite still being down from $18.9m ($0.19 per diluted share) a year ago, quarterly net income has rebounded from just $749,000 ($0.01 per diluted share) last quarter to $3.8m ($0.04 per diluted share).

During the fourth quarter, cash generated from operations was $52.7m (down from $64.6m a year ago but up from $43.4m last quarter). In addition to patent spending of about $3.5m, spending on property, plant & equipment (PP&E) was $30m (bouncing back further, from $21.7m last quarter). So, total capital expenditure (CapEx) has risen further, from $24.7m last quarter to $33.5m. Hence, despite still being down on $40.8m a year ago, free cash flow has risen from $18.7m last quarter to $19.2m. Overall during fiscal Q4, cash and investments rose by $27m, from $439m to $466m.

For the full fiscal year, cash generated from operations has risen from $203.3m for 2016 to $215.9m for 2017. Spending on PP&E was cut from $120m to $86.9m, and patent spending from $14.4m to $12.4m, so total CapEx was cut from $124.4m to $99.3m . Free cash flow hence rose from $68.8m to $116.6m. During fiscal 2017, Cree spent $104m to repurchase 4.4 million Cree shares (with no repurchases in Q4). At the end of the fiscal year, Cree had $145m outstanding on its line of credit.

For fiscal first-quarter 2018 (ending 24 September 2017), Cree forecasts revenue of $353–367m (slightly up sequentially at the mid-point). Lighting revenue is

expected to be down slightly due to seasonally lower consumer lighting sales, but LED Product revenue should be similar sequentially, while Wolfspeed revenue should grow by 4% as some productivity gains offset near-term factory capacity constraints (Wolfspeed is fully booked for Q1 and will be capacity limited in Q2, with lead times now stretching into fiscal Q3).

Gross margin should rise to 29%, driven by both Wolfspeed and Lighting Products (due to operating improvements and a higher mix of commercial lighting sales) offset by LED Product margin falling slightly (due to product mix).

Operating expenses are expected to rise by $4m to $101m, due mainly to costs associated with the Wolfspeed factory expansion, incremental legal costs on defensive IP cases, and CEO search cost. The new joint venture has a nominal impact as Cree is just beginning to ramp its operations (although it is targeted to have a larger impact beginning in fiscal Q2).

Net income is targeted at $2–6m ($0.02–0.06 per diluted share).

"We plan to grow the LED products business by expanding our product offering with new high-power and mid-power products that leverage our market leadership to increase our share of existing LED customers, while also opening new applications for our technology," says Swoboda. "We recently started shipping to our first tier-1 automotive forward lighting customer. Our JV has started sampling the first mid-power LED products with target customers. Both the automotive and JV activities should expand the market opportunity for our LED business," he adds. "In addition, we continue to innovate with the introduction of our new RGBW lighting-class LEDs for architectural applications," Swoboda continues.

"Capital allocation priorities are focused on expanding capacity in our Wolfspeed business and possible lighting-related mergers & acquisitions (M&A) to expand our product portfolio," notes McDevitt (Cree's board has approved a fiscal 2018 stock repurchase program of not exceeding $200m). For fiscal 2018, Cree is targeting capital spending of $220m, including $150m to expand Wolfspeed's production capacity to support forecasted demand.

"We're investing in the Wolfspeed business to increase capacity and further develop the technology to support longer-term growth opportunities in silicon carbide materials, silicon carbide power devices and modules, and gallium nitride RF devices," says Swoboda.

"We're now starting to see significant growth due to our investment in these areas over the last 30 years. The combination of growth in electric vehicle systems and battery storage plus other industrial applications is quickly bringing silicon carbide power into the mainstream and putting pressure on the supply chain in the near-term," he adds.

"We target additional materials capacity to start coming online in our fiscal Q2, with a plan to double wafer capacity for external materials customers by the end of calendar 2018," notes Swoboda. "We target additional Power and RF device capacity to start coming online in fiscal Q4 due to the time required to qualify the 150mm line both internally and at our customers. This plan should double our current power device capacity by the end of calendar 2018." Nevertheless, Wolfspeed is likely going to be capacity limited through fiscal 2018.

Due to accelerating Wolfspeed capacity investments (to eliminate current capacity constraints and support the substantial growth opportunity forecasted over the next several years), Cree's free cash flow is expected to be –$20m in fiscal 2018.

www.cree.com

Lumileds expands LUXEON Stylist Series to mid-power packages for fashion retail and fresh food market

LED maker Lumileds of San Jose, CA, USA says that its LUXEON Stylist Series of LEDs for fashion retail and fresh food markets is now available as a comprehensive portfolio, which includes new mid-power packages in addition to the existing chip-on-board (CoB) products.

"Customers using our LUXEON Stylist Series LEDs are so pleased with the light quality that they want the identical look and feel in all parts of the retail shop or market regardless of fixture type," says Eric Senders, product line director for the LUXEON Stylist Series. "Lumileds enables this with our mid-power additions to the Stylist Series."

The LUXEON Stylist Series with CrispColor Technology for retail environments provides a higher color gamut, enabling richer colors, brighter whites and increased contrast between colors. Previously available in CoB packages, CrispColor Technology is now available in the LUXEON 2835 3V LED as well as on the LUXEON 3535L HE package for diffuse and linear applications, enabling the manufacture of TLEDs, troffers and other luminaires.

Also, for fresh food markets that sell fresh meat, marbled meat, produce, fish and bread & pastries, Lumileds' LUXEON Stylist Series FreshFocus Technology utilizes a higher color gamut and is now offered on either the LUXEON 2835 3V LED or LUXEON 3014 package. With FreshFocus Technology, meats, fish, baked goods and produce are highlighted in their most appealing light, says Lumileds.

www.lumileds.com/StylistSeries

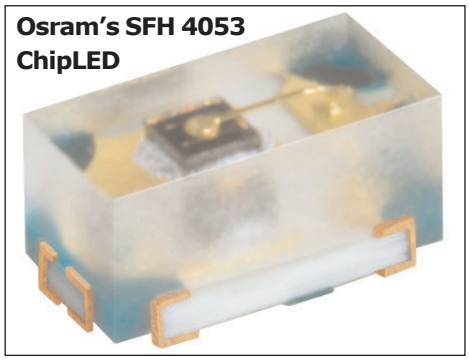
FOVE using Osram Opto's IR LEDs to make eye-tracking virtual reality headset

Japanese start-up company FOVE is offering a virtual reality (VR) headset that integrates eye tracking as a novel means of interaction. ChipLEDs made by Osram Opto Semiconductors GmbH of Regensburg, Germany provide the infrared illumination to track the user's direction of gaze and eye movements.

FOVE is a high-end VR system with enclosed headsets. To provide an authentic virtual experience, sensors keep track of users and integrate their position and movements into the virtual action.

Eye tracking now provides another, novel and highly intuitive way of interacting with virtual reality. Users can select or move an object by just looking at it. They can establish eye contact with virtual characters or trigger actions by focusing their gaze at a certain spot.

The technology also allows 'foveated rendering', a novel technique that significantly reduces demands on computing power and graphic cards. Based on the information about the user's point of gaze, VR systems can adjust the resolution and render areas in the direct field of vision in high resolution while allowing lower resolution in the periphery.



Osram's SFH 4053 ChipLED

"One of our main deciding factors [in selecting Osram's IR LEDs] was that only very little light lies outside the central emission spectrum and is therefore lost, which meant we could streamline our optical filter design process and maximize our sensor performance," says Lochlainn Wilson of FOVE.

Eye-tracking systems illuminate the user's eyes with infrared light, register the reflections with an IR-sensitive camera sensor, and employ special algorithms to determine the user's direction of gaze and eye movements. To realize the function inside a headset, several infrared LEDs are mounted around the two lenses. FOVE uses Osram's SFH 4053 ChipLEDs, which are only 0.5mm x 1.0mm x 0.45mm in size. Their emission wavelength of 850nm matches the spectral sensitivity of the camera sensor and their beam angle of ±70° ensures an even illumination of the eyes. "Through collaboration with FOVE, we are the first supplier to provide an eye-tracking solution for a VR headset," claims Hiroshi Okuma, marketing manager for ELS (Emitter, Laser, Sensors) at Osram Opto. "With its high efficiency and compact package, the SFH 4053 is ideal for this application."

Infrared LED for position sensing

FOVE also uses infrared sensor technology to track the user's position and movements in order to integrate these into the VR action. Several of Osram's SFH 4253 TOPLEDs are mounted around the headset, creating a pattern of infrared light dots that are registered and tracked by a camera to determine the user's movements. At 850nm, the emission wavelength of the SFH 4253 matches the spectral sensitivity of the photo sensor. The radiation characteristics and package geometry of the emitter also fit the requirements for the application.

www.osram.com

SDK expands IR LED range for high-output applications

Showa Denko strengthens infrared LED business, targeting growing IoT-related markets

Tokyo-based Showa Denko K.K. (SDK) has expanded its product lineup of infrared light-emitting diode (IR-LED) chips, which are mainly used as parts of photo-couplers for gate drivers in power semiconductor modules and parts of sensors for Internet of Things (IoT)-related devices.

SDK's IR-LED product lineup has three categories: conventional LEDs made by liquid phase epitaxy (LPE), and transparent-type LEDs and reflection-type LEDs made by metal-organic chemical vapor deposition (MOCVD). The firm says that, since the IR-LEDs have characteristics such as good power linearity at low electric current and a fast response time at a high speed cycle, they are widely used in equipment that require high reliability such as industrial equipment, automotive equipment, medical devices, and security systems.

Reflection-type LED comprise a chip with enhanced output via a mirror layer formed beneath the light-emission layer in order to reflect the light beam upwards. These LEDs have been used in photoelectric sensors for industrial equipment and other devices. SDK has now upgraded its technology to manufacture reflection-type LEDs, and added a double-junction reflection-type LED and a P-up reflection-type LED to its IR-LED product lineup.

The double-junction reflection-type LED chip has two light-emission layers, yielding output nearly twice that of conventional reflection-type LEDs. It is suitable for applications that require high-output LEDs, such as biometric sensors, surveillance or security cameras, virtual reality, and sensors for automotive equipment.

The P-up reflection-type LED has a polarity reversed from that of an N-up structure (the mainstream structure of conventional reflection-type LEDs). To manufacture IR-LEDs, LPE is widely used, and this method is mainly used to produce LEDs with a P-up structure. SDK has developed the new P-up reflection-type LED in response to requests from customers wanting to develop high-power modules compatible with circuit designs for conventional P-up non-reflection-type LEDs. The P-up reflection-type LED offers a greater choice of chip structures and more degrees of freedom in designing circuits for packages and modules.

With a 40-year history of manufacturing and selling aluminium gallium indium phosphide (AlGaInP), gallium arsenide (GaAs) and gallium phosphide (GaP) LEDs, SDK has in recent years expanded its IR-LED business. In addition to developing new LED chips in its main Chichibu Plant, SDK acquired Shoko Electronics Corp (SKEC) of Hioki City, Kagoshima Prefecture (which makes IR-LED chips for industrial equipment, automotive equipment and consumer appliances, as well as LED chips for displays) from Shoko Co Ltd. SDK has hence established a supply of LED chips with two production bases, integrated the two companies' technologies and quality-control expertise, and established the supply of a wide variety of LED chips to a diversified LED market.

The IR-LED market is expected to expand with the emergence of IoT-related device markets. SDK hence aims to continue to expand its LED lineup in response to demand.

www.sdk.co.jp

CST Global and University of Glasgow join forces to install and operate MOCVD system

Optoelectronic foundry Compound Semiconductor Technologies Global (CST Global) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK (a subsidiary of Sweden-based Sivers IMA Holding AB) has announced a collaboration with the University of Glasgow to run a metal-organic chemical vapour deposition (MOCVD) reactor within its foundry facility. The university will own the system, which CST Global will install and operate. Usage and operating costs will be shared.

"This MOCVD machine facilitates research projects in advanced semiconductor materials and devices, in both electronics and photonics," says CST Global's CEO Neil Martin. "It is increasingly critical to successful photonics research to consider the needs of volume production. Our collaboration provides a route for research projects to reach commercially viable volumes, leveraging CST Global's worldwide customer base. Installing the MOCVD machine at CST Global also means our foundry services are readily available for projects, when required and safely managed within an ISO 9001:2015 quality environment," he adds.

"Our agreement with the University of Glasgow means we can use the MOCVD to provide epitaxial 'overgrowth' services to customers, when it is not being used for research projects. It brings this process in-house and within our control, reducing our laser production cost-base and improving delivery times," Martin continues.

"Joint academic and commercial partnerships of this type are new in the photonics industry, providing a lower-risk alternative to conventional commercialization routes. Additionally, students have the opportunity to gain experience of working within a commercial environment, learning about adjacent technologies and rubbing shoulders with our expert team. It also provides CST Global with a potential, specialist, post-graduate recruitment pool of exceptional staff.

Martin reckons that the MOCVD collaboration will pave the way for further academic commercial partnerships.

www.CSTGlobal.uk

Glasgow photonics professor leads MOCVD partnership with CST

CST Global says that Richard Hogg, professor of photonics at the University of Glasgow, will lead the project to commission and operate its new MOCVD system.

Hogg's research spans device physics and engineering, epitaxial processes, fabrication technologies and developing diverse applications for semiconductor devices. "This unique MOCVD collaboration ensures that electronic and photonic research projects in advanced semiconductor materials and devices can be taken seamlessly from the laboratory to commercial volume production," says Hogg.

Richard Hogg.

Hogg has over 20 years of post-doctoral experience in both industrial and university research. He has worked at NTT Basic Research Laboratories in Japan, and in professor Arakawa's laboratory at the University of Tokyo as an EU-Japan Fellow. He held a research position at Toshiba in Cambridge, UK and a foundry management role at Agilent in Ipswich (then Europe's highest-volume III-V facility).

CST increases silicon photonic laser production by 500%

III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global, a subsidiary of Sweden-based Sivers IMA Holding AB) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK says that its silicon photonic laser production has increased by 500% year on year.

"CST Global supplies lasers for use in silicon waveguides. These are an integrated, optic and electronic, microchip-based components and are used to increase the optical signal processing capability, and therefore the data rate capacity, of existing fiber-optic networks," says Euan Livingston, VP sales & marketing. "The silicon waveguide technology enables the data transfer rate to increase by 10 times and represents a highly cost-effective method of upgrading existing, fiber-optic network infrastructures," he adds.

CST Global's silicon photonic lasers operate in the infrared, 1.3μm and 1.55μm wavelength used by most fiber-optic systems.

"The silicon photonic lasers that CST Global makes are most commonly used for data-center and metropolitan area network upgrades," Livingston continues. "A 500% increase in dedicated device production clearly shows that the silicon photonic-enabled network upgrade market is firmly established and rapidly deploying," he adds.

www.CSTGlobal.uk

CST Global leading Innovate UK's DiLaN project

'Diode Laser manufacturing process using Nano-imprint lithography' project targets low-cost, high-volume 25G DFB laser production

III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global, a subsidiary of Sweden-based Sivers IMA Holding AB) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK says that it is leading the government-funded 'Diode Laser manufacturing process using Nano-imprint lithography' (DiLaN) project, which aims to produce high-speed distributed feedback (DFB) lasers with significantly larger broadband line rates than currently available, while using a new manufacturing process aimed at cutting laser costs by a third.

CST Global is the project leader, with support from academic partners Cardiff University and the University College of Swansea & West Wales with additional commercial partner Compound Semiconductor Centre Limited, Cardiff.

Running from February 2017 to January 2019, the DiLaN project grant is valued at £821,319.00, with CST Global receiving £268,094.00. The funding organization is Innovate UK, a UK government research funding agency for engineering and the physical sciences.

Andrew McKee.

"The massive growth in broadband communications for the fibre-to-the-premises (FTTP) market has two key driving factors," notes director of engineering Andrew McKee. "The first is a rapid increase in demand for single-mode semiconductor laser solutions, currently exceeding 100 million new units per year. The second is that the data rate capability of lasers using current passive optical networking (PON) technology, at around 1.25–2.5Gb/s, is not enough to satisfy the ever-increasing bandwidth demands of next-generation networks," he adds.

The DiLaN project is seeking to implement a commercially viable nano-imprint lithography production process for high-volume DFB lasers. This would deliver the increased data rates of 25Gbps and the required cost saving, estimated at up to 30% per laser.

"Nano-imprint lithography is widely recognized as the most credible method of producing high-throughput, high-resolution, single-mode semiconductor lasers at low cost," McKee continues. "The lasers also operate in the 1310–1550nm wavelength spectrum, which is known to support the increased line rates necessary for next-generation networks."

www.CSTGlobal.uk

CST's sales of lasers into PON and GPON markets exceed 25 million

CST says that its indium phosphide laser sales have exceeded 25 million and that its sales of distributed feedback (DFB) lasers into Chinese and Indian GPON (Gigabit passive optical network) markets are approaching 2 million.

"It shows that PON and GPON markets are growing worldwide and that GPON sales into developing markets offer massive potential," says CEO Neil Martin. "We identified the potential and, in the last year alone, have invested in the staff, machinery and processes necessary to meet this growth."

CST Global is now qualified to process 4" wafers. "We invested in a new MOCVD capability and an automatic bar stacker machine for 4" wafers, increasing our volume capability by 50%," notes Martin. "The automatic bar stacker also increases yield, by reducing human error and making the process auditable, repeatable and totally consistent." The firm also introduced a new automatic visual inspection machine, trebling laser throughput and increasing test accuracy (boosting capacity from 10,000 to 30,000 lasers per shift).

CST Global's bar stacker machine.

"The appointment of Gary Palmer, VP operations, has seen improvements to foundry services, from epitaxial growth and fabrication, through to assembly and packaging," comments Martin. "The appointment of Euan Livingston, VP sales & marketing, has allowed us to identify and engage with the right customers, in key markets around the world, alongside a consistent promotion and communications strategy," he adds.

"We also now operate in an ISO 9001:2015 quality environment. Not only has this helped streamline production, but the accreditation itself allows us to supply market-leading companies in the data-center, cloud and telecommunications markets, who expect this level of quality control," Martin concludes.

Luna selling High-Speed Optical Receivers business to MACOM for $33.5m

Terahertz operations retained, while Luna to expand fiber-optic sensing product range

Luna Innovations Inc of Roanoke, VA, USA (which makes high-speed optoelectronics and fiber-optic test products for the telecoms industry and distributed fiber-optic sensing for the aerospace & defense and automotive industries) has agreed to sell its high-speed optical receivers (HSOR) business for $33.5m to MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications).

The purchase price includes $29.5m paid-in cash at closing plus $4m held in escrow until 15 December 2018 for possible working capital adjustments to the purchase price and potential satisfaction of certain post-closing indemnification obligations. Luna intends to use part of the proceeds to expand its fiber-optic sensing product range.

The sale includes the operations associated with Luna's development, manufacturing and sales of products such as high-speed integrated coherent receivers and photodiodes. Luna originally acquired these operations as part of its merger with Advanced Photonix Inc (API) of Ann Arbor, MI, USA in May 2015. The assets and employees associated with Luna's Terahertz operations are not transferred in this transaction.

"Since the merger with API, we have invested substantial time and resources into the HSOR business as a significant growth area," notes Luna's president & CEO My Chung. "As a result of that investment, we have developed leading products and technologies in that marketplace. MACOM has recognized the value that we have created in this space, and earlier this year approached us with this transaction opportunity," he adds. "With their larger scale of operations, broader suite of product offerings and global footprint, we believe that MACOM provides a greater opportunity to drive long-term growth for the HSOR business, and the completion of this sale maximizes the value we would receive from the HSOR business."

Employees associated with the HSOR operations and administration in in Ann Arbor will transfer to MACOM. The Picometrix line of high-speed optical receivers and optical-to-electrical converters serve the telecoms, data-center and manufacturing testing industries.

"Similar to our High Performance Analog and 25G laser products, Luna's industry-leading high-speed optical receiver products and technology are well aligned with MACOM's previously announced growth strategy in Cloud data centers and other high-speed networking markets, and we are excited to be able to add these products to our growing portfolio through this tuck-in acquisition," says MACOM's president & CEO John Croteau. "We expect the transaction to be neutral to accretive in the first year of combined operations, and to contribute meaningfully to growth in our fiscal year 2018," he adds.

"We are especially grateful to the dedicated employees in the HSOR business whose skills and efforts have resulted in building this valuable business," says Chung.

www.lunainc.com
www.macom.com

POET's Q2 product revenue up 39% year-on-year

Focus on developing InP-based hybrid dielectric photonics platform and securing partner for developing and commercializing monolithic GaAs optical engine

For second-quarter 2017, POET Technologies Inc of San Jose, CA, USA — which has developed the proprietary planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — has reported revenue of US$648,382, down on US$712,550 last quarter but up on US$576,741 a year ago.

However, excluding non-recurring engineering (NRE) revenue, POET's product revenue rose 39% year-on-year, due to continued shipment of DenseLight photonic sensors (primarily for test & measurement applications).

Gross margin was 50.5%, down from 59.6% last quarter and 51.4% a year ago. However, this was after management performed a detailed review of the firm's cost structure and determined that certain product costs historically included in cost of sales should be more appropriately categorized in selling, marketing & administration expenses. As a result, gross margin for comparative periods have been adjusted to reflect this determination.

"We continued to diligently manage operating expenses," says CEO Dr Suresh Venkatesan. "Our collective reductions in wages, professional fees, as well as management and consulting fees, resulted in a meaningful year-over-year improvement in net loss," he adds.

Net loss was cut from US$3.4m ($0.02 per share) a year ago and US$3.5m ($0.01 per share) last quarter to US$2.8m ($0.01 per share).

POET ended the quarter with cash and short-term investments of US$9.8m, down from US$14.9m at the end of 2016.

"As outlined at the 2017 annual general meeting (AGM) in July, we are focusing our design and engineering resources on further development of our indium phosphide (InP)-based hybrid dielectric photonics platform to introduce disruptive new solutions with lower cost and higher performance. Also, as discussed at the AGM, we are focused on securing a strategic partner to assist with further developing and commercializing our monolithic gallium arsenide (GaAs) optical engine," says Venkatesan.

"InP-based solutions for 100G applications have emerged as one of the largest and fastest-growing segments in the data communications market. We believe our recently introduced hybrid dielectric photonics platform based on InP, which leverages a combination of POET's integrated photonics expertise and proprietary dielectric waveguide technology, provides a compelling and differentiated solution in the multi-billion-dollar transceiver market. Reinforcing our strategic decision to focus on an InP-based hybrid platform is the ability to leverage the company's established InP fabrication and manufacturing facility in Singapore, which provides a number of operational and economic benefits," continues Venkatesan.

We also expect to introduce distributed feedback lasers with wavelengths spanning the O-band and C-band, with delivery of engineering samples to customers expected during the third quarter

"As we make progress toward developing a transceiver optical engine, we also expect to introduce photonic transceiver components for the data communications market. As an example, we recently introduced multiplexing and de-multiplexing devices that are based on our proprietary dielectric waveguide technology. We also expect to introduce distributed feedback (DFB) lasers with wavelengths spanning the O-band and C-band, with delivery of engineering samples to customers expected during the third quarter. Additionally, we are making solid progress on incorporating our Hybrid Integrated Photonics Packaging (HiPP) into new high-performance packaged solutions, such as narrow linewidth lasers, that will expand DenseLight's existing line of sensor products beginning in 2018," he adds.

"Our fundamental vision continues to be enabling disruptive solutions by leveraging innovative photonics integration to lower cost and increase performance for the data communications and sensing markets. POET's strategic direction fully capitalizes on our core competencies and assets and is also well aligned with the trends and substantial growth opportunities within our targeted end markets, which is critical to realizing the highest return on investment," Venkatesan believes.

Grant of options

POET also announced that, under its stock option plan (and subject to the TSX Venture Exchange policies and applicable securities laws), it has granted Kevin Barnes previously approved incentive stock options, consisting of the right to purchase up to 150,000 common shares and a four-year vesting schedule beginning on 13 July 2018. The options are exercisable at CAD$0.28 per share.

www.poet-technologies.com
www.denselight.com

Applied Optoelectronics' sales up 22% in Q2, driven by ninth quarter of record data-center revenue

Q3 revenue to fall as soft 40G demand from large customer to offset 100G growth

For second-quarter 2017, Applied Optoelectronics Inc (AOI) of Sugar Land, near Houston, TX, USA, a manufacturer of broadband fiber-optic access network products (including components, modules and equipment) for the Internet datacenter, CATV broadband, fiber-to-the-home (FTTH) and telecom markets, has reported record revenue of $117.4m, up 22% on $96.2m last quarter and up 112% on $55.3m a year ago.

Growth was driven by the ninth consecutive quarter of record revenue for data-center products: $99.3m (more than doubling from $41.3m a year ago), while CATV revenue rose by 51% from $9.5m to $14.4m, and FTTH revenue fell from $436,000 to $125,000.

On a non-GAAP basis, gross margin increased to a record 45.5%, up from 43.2% last quarter and 31.4% a year ago, driven by continued improvement in manufacturing costs and capacity expansion. Operating expenses have risen from $15.3m a year ago to $19m.

Net income has risen further, from $2.8m ($0.16 per diluted share) a year ago and $21.8m ($1.10 per diluted share) last quarter to a record $31.3m ($1.54 per diluted share).

During the quarter, cash, cash equivalents and short-term investments rose from $60.6m to $75.9m.

"Our ability to leverage our vertical integration and proprietary manufacturing processes to drive greater efficiencies and shorten our production cycle times sets AOI apart from others in the industry," believes founder, president & CEO Dr Thompson Lin.

"As we look into the third quarter, we see softer-than-expected demand for our 40G solutions with one of our large customers that will offset the sequential growth and increased demand we expect in 100G," says Lin.

For third-quarter 2017, Applied Optoelectronics expects drops in revenue to $107–115m, gross margin to 43–44.5%, and net income to $26.6–29.4m ($1.30–1.43 per fully diluted share).

"We believe AOI has a leading position in the advanced optics market and we continue to expand within our existing customer base as well as engage with new customers for 100G technologies and beyond," says Lin.

AOI produces 1.4 million 25G lasers

Applied Optoelectronics Inc has produced over 1.4 million 25Gbps distributed feedback (DFB) laser diodes since first shipping the products in late 2015.

AOI utilizes the overwhelming majority of the diodes produced in its 100G QSFP-28 transceiver products that are primarily deployed in hyperscale datacenters. The 1.4 million 25Gbps laser diodes have passed all production testing and are fully qualified for use in AOI's transceiver products and have either been shipped to customers or are in the process of transceiver manufacture.

"We are currently on track to achieve our production ramp goal of producing approximately one million fully-qualified lasers per month by the end of the year. In May, we produced nearly 600,000 such laser diodes," says Dr Fred Chang, senior VP & head of the Optical Component BU. "Additionally, the expansion of our fab capabilities in Sugar Land last year have enabled the ramp in production and we continue to build out capacity in the fab in order to reach our production goals."

www.ao-inc.com

Applied Optoelectronics unveils 50Gbps PAM-4 directly modulated lasers

Applied Optoelectronics Inc (AOI) of Sugar Land, near Houston, TX, USA — a manufacturer of fiber-optic access network products (including components, modules and equipment) for the Internet datacenter, cable broadband, fiber-to-the-home (FTTH) and telecom markets — has developed uncooled 50Gbps PAM-4 directly modulated lasers (DMLs) for its 200Gbps and 400Gbps optical transceivers.

The 50Gbps-per-channel lasers are produced using AOI's in-house combination of metal-organic chemical vapor deposition (MOCVD) and molecular beam epitaxy (MBE) crystal growth techniques. The lasers feature high bandwidth, high linearity, and low noise (all critical for demanding applications like 200Gbps and 400Gbps transceivers). The new lasers have demonstrated a high extinction ratio of up to 6dB and a highly desirable transmitter dispersion eye closure quaternary (TDECQ) value of less than 2.5dB. All four standard coarse wavelength division multiplexing (CWDM) channels (including 1270nm, 1290nm, 1310nm and 1330nm wavelengths) have achieved data transmission over single-mode fiber lengths of 10km. The lasers are suitable in the production of 200G and 400G FR8 transceivers that meet the IEEE 802.3 200G/400G Ethernet transceiver standards.

"Transceivers based on directly modulated lasers are preferable in datacenters due to their low power consumption and low cost," says Dr Fred Chang, senior VP & general manager of North America. "The high linearity and low noise of our 25 GBaud DML is the key to make 50Gbps per channel possible," he adds. "With this laser, leveraging our high-volume, high-yield 100G transceiver platform, AOI is able to continue the technological and cost leadership that is of paramount importance to our hyperscale datacenter customers."

AOI will present more details on the lasers in a presentation on 20 September at the 43rd European Conference on Optical Communication (ECOC 2017) in Gothenburg, Sweden (17–21 September), where the firm is exhibiting in booth #538.

www.ecocexhibition.com
www.ao-inc.com

Applied Optoelectronics announces 100G PIN photodiode array

Applied Optoelectronics Inc has developed 100Gbps (4x25Gbps) PIN photodiode (PD) arrays for high-speed optical receivers.

The indium gallium arsenide (InGaAs) PIN PD is a front-illuminated photodiode with a large modulation bandwidth, high responsivity, and low dark current. Designed specifically for 100Gbps transceiver modules for datacenter and 100G EPON transceivers for FTTH applications, the PIN photodiode can also be used for PAM4 receivers in the firm's 200G and 400G data-center transceivers.

Besides the 1x4 array, the 25Gbps singlet photodiode can also be used in 25G SFP28 transceivers for 5G wireless and 25G EPON applications.

"High-speed photodiodes require high-quality epitaxial crystal material with very high purity in order to operate with low noise," says Dr Jun Zheng, VP & head of AOI's R&D division. "In addition, such high-performance photodiodes require very small aperture to achieve high bandwidth. Both of these requirements were achieved by our advanced metal-organic chemical vapor deposition (MOCVD) growth capability and mature wafer processing technology," he adds.

"With in-house manufacturing for both our 100Gbps PIN PD array and 25Gbps laser diodes, AOI now controls the two key optical components for its 100G transceivers, which will greatly improve our lead time, cost, and quality," Zheng reckons. "This product line deepens our vertical integration for our current 100G and 200G products, and opens exciting possibilities for 400G and beyond."

NeoPhotonics' revenue grows in Q2 despite sale of Low-Speed Transceiver product assets

China revenue stabilizing despite inventory overhang at Huawei

For its second quarter 2017, NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated opto-electronic modules and subsystems for high-speed communications networks) has reported revenue of $73.2m (towards the upper end of the $68–74m guidance range). This is down 26% on $99.1m a year ago but up 2% on $71.7m last quarter (or up 4% on $70.2m after excluding $1.5m from the Low-Speed Transceiver product line, which was divested in January). Growth was driven by strength in 100G-and-above shipments to North America as well as modest sequential growth in China despite the inventory overhang there.

Sales of High-Speed Products rose slightly from $58.7m last quarter to $59.4m (81% of revenue, up from 66% a year ago).

Sales of Networking Products & Solutions rose from $13m last quarter to $13.8m (19% of revenue, down from 34% a year ago).

There were again two 10%-or-greater customers: US-based Ciena (the largest customer outside China) grew by $3m from 14% to 19% of total revenue, while China's Huawei Technologies and its affiliate HiSilicon Technologies collectively fell by $1.4m from 41% to 37% of total revenue as they continued working through their inventory build-up.

However, apart from Huawei, NeoPhotonics saw growth at each of its Chinese network equipment customers, resulting in China revenue growing by $1.6m (4%) sequentially. Consequently, of total revenue (excluding Low-Speed Transceiver product revenue from Q1), China fell only slightly overall from 54% last quarter to 53%, as the Americas rose from 17% to 20%. Japan fell from 5% to 3%, and the rest of the world from 25% to 24%.

On a non-GAAP basis, gross margin has fallen further, from 29.3% a year ago and 26.3% last quarter to 23.9%, reflecting excess and obsolescence charges on discontinued products plus continued under-absorption in NeoPhotonics' manufacturing facilities (given the softness in China and hence the lower-than-planned shipments).

In light of both the disposal of the Low-Speed Transceiver assets and the soft business levels in China, NeoPhotonics implemented cost-saving measures including limited restructuring actions, reducing sales, general & administrative (SG&A) expenses, and thinning some R&D spending and manufacturing overheads for legacy products. Although still up on $21.8m a year ago, operating expenses have been cut by nearly 20% from $30.2m (42.1% of revenue) last quarter to $24.2m (33.1% of revenue) — beyond the targeted $26–27m — driven by the cost savings plus a reduction in audit-related costs (which were more than usual in Q1).

Net loss was $6.6m ($0.15 per diluted share), cut from $10.7m ($0.25 per diluted share) last quarter (and better than the targeted $0.19-0.26 per diluted share), although this compares with net income of $6.9m ($0.15 per diluted share) a year ago.

Adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) was breakeven, an improvement from a loss of $5.2m last quarter but down on +$12m a year ago.

During the quarter, cash and cash equivalents, short-term investments and restricted cash fell from $91.5m to $79m.

Over the last two years NeoPhotonics has been adding significant capacity to its production facilities, and these projects are nearing completion. Total capex was planned to be about $100m over two years. Cash capital expenditure in 2017 is estimated to total $57m. "On an operating level, we have scaled our production levels to reflect current demand forecasts, and we continue to closely monitor our operating expense levels," says interim chief financial officer Sandra Waechter.

NeoPhotonics' existing $30m credit facility with Comerica Bank (under which it borrowed $20m) expires on 31 August and a $39.2m credit line with China's CITIC Bank (under which it borrowed $17m) expires on 30 September. NeoPhotonics also has additional capacity of about $17.7m from Shanghai Pudong in China. "We are currently working through the due diligence process with a potential new lender that would provide increased flexibility in borrowing, and we are hopeful this will come to completion this quarter," says Waechter. "We have mitigation plans in place to conserve our cash including a combination of expense and inventory controls. However, without any recovery in China, there would be doubt that our existing cash would be adequate for the next full year if we did not extend at least one of these credit lines or secure equivalent financing," she adds. "In line with this effort, we borrowed $17m in China subsequent to the end of the second quarter that will remain in place until early Q1/2018," she adds. "In the near term, while we continue to deal with this softer China market, we are tightening expenses as we closely manage inventory and production levels, and drive further cost savings measures."

For Q3/2017, NeoPhotonics expects revenue of $70–76m. "While China softness has contin-

ued into the third quarter, we believe we are seeing relative stability in demand," says Waechter. "However, there is limited visibility, given the inventory overhang, the move to provincial deployments and customer inventory management changes. As a result, we anticipate only modest changes in existing inventories and in gross margins, and our factory underabsorption will continue through the remainder of this year," she adds.

"We continue to operate our production facilities with a focus on efficiency and with lower overhead, and we expect to be able to expand gross margins as finished goods inventory depletes with higher production and shipment volumes," says chairman & CEO Tim Jenks. Gross margin should rise to 24–27% in Q3, with operating expenses of $23–25m. Net loss should be $17–0.07 per diluted share.

Cash used in operations should be about $18m, inclusive of changes in working capital. Cash capital expenditure is targeted to be down to $12m. "We anticipate financing these cash requirements with debt, inclusive of our $17m debt financing in China," says Waechter.

"While we believe the business is on a good footing to realize increased operating leverage when demand levels return, we continue to see near-term challenges with China visibility and forecasts," says Jenks. "Within China, it is too early to predict how the full year will unfold with the transition from primarily national backbone to primarily provincial deployments. Our near-term growth may continue to be restricted by the China inventory overhang, as certain customers are driving their inventories lower across the board. In addition, the inventory situation may impact some of our customers who also sell to customers in China as they are similarly pressured by the inventory-related actions," he adds. "While these issues may overshadow metro growth and 400G wins and related early shipments in the near term, we believe that the mid- and long-term market drivers for our business remain compelling. China is committed, through the China Broadband 2020 and newer initiatives, to continue to build out the national backbone network and expand buildouts of 100G provincial and metro networks. Our OEM customers in China expect these actions to increase the number of 100G ports in China in 2017 and again in 2018," notes Jenks.

"We continue to see strong demand in regions outside of China driven by North American carriers," says Jenks. "We anticipate robust growth in the medium and long term, driven by metro, data-center interconnect, a normalized China market, and the emergence of 400G and above."

NeoPhotonics expects to be positive on an adjusted EBITDA basis for both Q3 and Q4/2017, concludes Waechter.

www.neophotonics.com

LioniX & Heinrich Hertz Institute intensify collaboration

Engineering resources to integrate TriPleX and InP PIC platforms

LioniX International BV (LXI) of Enschede, The Netherlands (which provides customized integrated photonics-based microsystems) and Fraunhofer HHI (Heinrich Hertz Institute) in Berlin, Germany (a research center for mobile and stationary communication networks) are strengthening their collaboration by actively supporting the integration of their respective photonic integrated circuit (PIC) platforms. Combining the functionalities of both platforms enables new applications, ranging from telecoms and datacoms to bio-photonics, sensing and metrology. Both platforms have their own unique properties that are complementary, as was demonstrated in the recent realization of record ultra-low-linewidth lasers (290Hz linewidth).

HHI and LXI will both actively supply engineering resources to support combining the two platforms.

Branded TriPleX, LioniX's PIC platform is based on stoichiometric silicon nitride proprietary waveguide technology realized by low-pressure chemical vapor deposition (LPCVD). The platform is complementary to HHI's indium phosphide (InP) platform, as it is ultra low loss (from 405nm to 2350nm) and has the ability to create spot size converters, enabling optimized conversion between the mode profiles in, for example, HHI's InP chips as well as many types of fibers.

"Our unique hybrid integration capabilities support our customers that demand fully assembled photonic integrated circuit modules," says LXI's CEO Hans van den Vlekkert. "With HHI we have found a supplier that supports our vertical integrated approach to our photonic IC module manufacturing".

HHI's PIC platform relies on InP, offering a wide range of optical functionalities such as light sources, detection, amplification and phase control in the wavelength region 1200–1650nm. Its portfolio of commercial products includes: high-speed photodiodes and balanced detectors, high-speed Mach–Zehnder and other modulators, as well as a wide variety of laser products. In addition, HHI's platform for customer-specific PICs, enhanced by LXI's low-loss PICs, allows a large range of products targeting a wide range of applications.

"Developing a standard interface between active and passive PICs allows for experience accumulation over many different designs and thus benefits hybrid integration and its industrial and academic users," comments HHI's director Martin Schell.

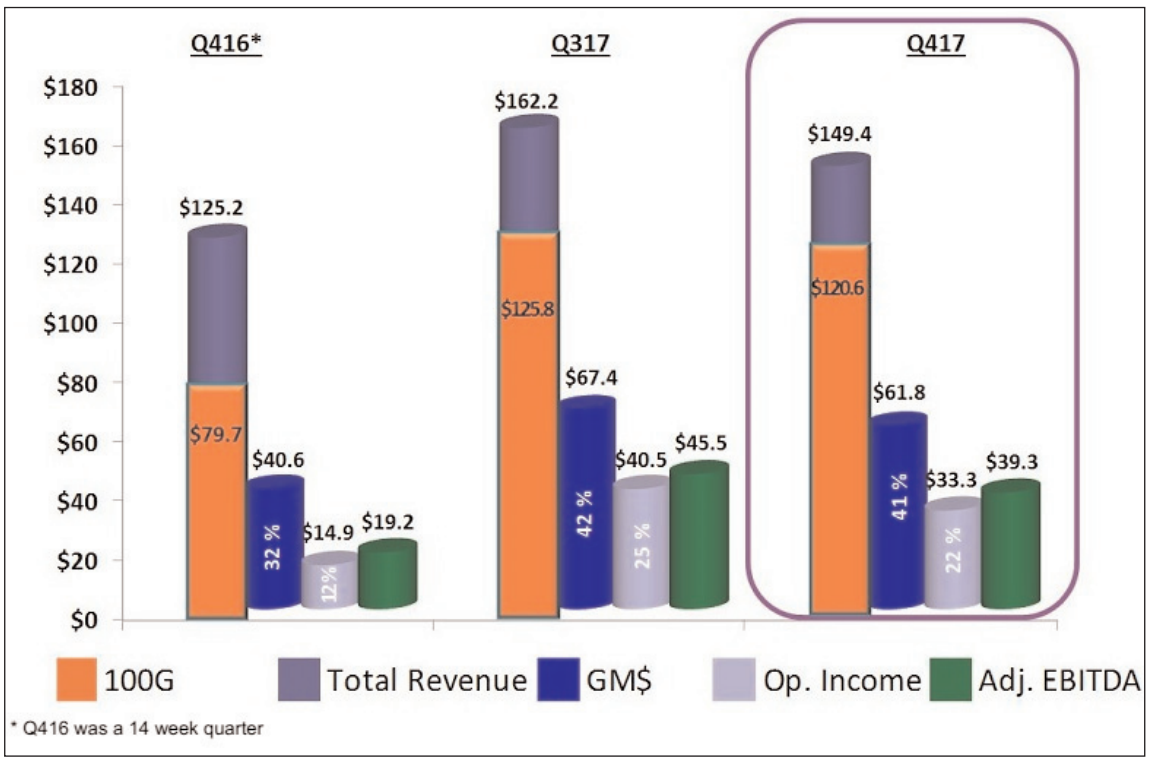
www.lionix-international.com
www.hhi.fraunhofer.de

Oclaro's quarterly revenue up 28% year-on-year, despite 10G softness in China

Full-year growth of 47% driven by QSFP28 and CFP2-ACO transceivers

For fiscal fourth-quarter 2017 (ended 1 July), Oclaro Inc of San Jose, CA, USA (which provides components, modules and sub-systems for optical communications) has reported revenue of $149.4m (split about 50:50 between client-side/datacoms and line-side/telecoms).

This is up 28% on $125.2m a year ago, with a greater-than-expected 32% drop for 40G-and-below products from $45.5m to $28.8m (falling from 36% to 19% of total revenue) being offset by 100G-and-above products growing 63% from $79.7m to $120.6m (rising from 64% to 81% of total revenue). The latter includes including QSFP28 sales doubling (together, the QSFP28 and CFP2-ACO transceiver product families comprised over 40% of total revenue, compared with just 15% a year ago). However, revenue is down 8% on $162.2m last quarter, due to 40G-and-below products falling by 21% following expected softness in 10G product sales into China (falling by $11m, mainly in the client-side CFP family) plus the planned end-of-life for the 40G line-card product line.



Oclaro's revenue, gross margin, operating income and adjusted EBITDA for fiscal Q4/2017.

Full-year revenue was $601m in fiscal 2017, up 47% on $407.9m in fiscal 2016, driven by 100G-and-beyond product revenue doubling (growing by $230m). "The most significant growth came from the CFP2-ACO and QSFP28 product family," says CEO Greg Dougherty. The top customers were Cisco (18% of total revenue), ZTE (18%), Huawei (15%) and Nokia (12%).

Of total revenue, China comprised 32% (down further, from 36% last quarter, as sales fell by %), Southeast Asia 18% (down further, from 22%) and Europe, Middle East & Africa (EMEA) 10% (falling back from 12%), while the Americas surpassed China to become the largest region at 39% (up from 28%), driven by strong growth in both data-center and metro sales. The customer base diversified further, with the top four customers falling to 55% of revenue (compared with 68% two quarters ago). For full-year fiscal 2017, Cisco was the largest customer (replacing Huawei).

Despite quarterly revenue declining, non-GAAP gross margin fell only slightly, from 41.6% last quarter to 41.4%. This is up on 32.4% a year ago, driven by a richer 100G product mix and great scale as Oclaro further leveraged its manufacturing overhead. Full-year gross margin has grown from 29% in fiscal 2016 to 39.5% in fiscal 2017.

Operating expenses have risen further, from $25.7m a year ago and $27m last quarter to $28.6m (19% of sales), due mainly to R&D expenses.

Operating income was $33.3m (22% of revenue), down from $40.5m (25% of revenue) last quarter but more than doubling from $14.9m (12% of revenue) a year ago. Full-year operating income has risen from just $25.1m in fiscal 2016 to $130.9m (20% of revenue) in fiscal 2017.

Net income was $33.9m ($0.20 per diluted share), down from $39.9m ($0.23 per diluted share) last quarter but more than doubling from $14.4m ($0.11 per diluted share) a year ago. Full-year net income was $130.1m ($0.79 per diluted share) for fiscal 2017, up from just $19.2m ($0.17 per diluted share) in fiscal 2016.

Adjusted EBITDA was $39.3m, down on $45.5m last quarter but more than doubling from $19.2m a

year ago (boosting full-year adjusted EBITDA from $40.9m in fiscal 2016 to $151.6m in fiscal 2017).

Hence, after subtracting capital expenditure (CapEx) of $18.4m (cut from $21.7m last quarter) and working capital (mostly related to inventory) of $15m, overall cash, cash equivalents, restricted cash and short-term investments rose during the fourth quarter by just $2.7m, from $254.8m to $257.5m.

For fiscal first-quarter 2018 (to end-September 2017), Oclaro expects revenue to grow to $151–159m, despite China revenue expected to be down by about 15% sequentially (then flat to down in fiscal Q2 — "We expect revenue from our 40G-and-below product to be relatively flat in the range of high 20s to $30m per quarter throughout fiscal year 2018," says Dougherty). Gross margin should fall slightly to 38–41%, due to the proportion of new products in the mix, plus bringing on extra depreciation of about $1m per quarter. Operating income is expected to be $30–34m (falling to 20–21% of sales).

"As we enter fiscal year 2018, we expect to see continued high demand for our 100G-and-beyond products [specifically QSFP28 and ACO] in the data-center and metro markets," says Dougherty. "We will be able to maintain our gross margins in the high 30s below 40 percentage range. This margin translates into operating income in the high-teens to 20% range," he adds. "We also expect to continue to generate cash throughout the year."

Going forward, operating expenses are expect to be steady at 19–20% of sales. CapEx for full-year fiscal 2018 should be $65–75m (similar to fiscal 2017). "For the year we expect spending to be front-end loaded and to add about $1m per quarter in depreciation," says chief financial officer Pete Mangan.

Despite two strong headwinds (the market in China and the ramp-down of the client-side CFP platform as the market transitions to the QSFP28 form factor), for calendar full-year 2017 Oclaro still expects revenue growth of about 20%

Despite two strong headwinds (the market in China — which is expect to be flat to down in the December quarter — and the ramp-down of the client-side CFP platform as the market transitions to the QSFP28 form factor), for calendar full-year 2017 Oclaro still expects revenue growth of about 20% on 2016. This implies that second-half calendar 2017 will be relatively flat on the first half (with growth for QSFP28 and CFP2-ACO again compensating for China being flat to down).

We expect revenue from our 40G-and-below product to be relatively flat in the range of high 20s to $30m per quarter

"While we continue to expect the healthy market in the Americas and a slower China market for us over the next couple of quarters, we still believe the fundamental demand drivers in China remain intact," comments Dougherty. "We anticipate growth from the region to return again later this fiscal year, driven by new metro and prudential network deployment."

Growth in China should be further aided by an increase in demand for 25G and 100G optical transceivers used in 5G front-haul deployment. "We are well position to serve what could be a very significant new market for Oclaro due to these transceivers requiring industrial operating temperature ranging. Our laser chip and packaging technologies enable us to address this requirement and differentiate ourselves in this market," says Dougherty. "While we will likely see most of the growth over the next few quarters from the ACO and QSFP28 product family as both the metro and data-center market upgrades to 100G and beyond, we expect both of these markets to stay strong throughout fiscal year 2018, particularly in North America and gradually building in China," he adds.

Oclaro appoints global communications services executive to board

Oclaro has appointed Ian Small to its board of directors (effective 1 September).

"Ian's extensive global experience as an executive and technology strategist with leading communications services companies is expected to further strengthen our board as Oclaro looks to the future," says board chair Marissa Peterson.

As a global executive with 25 years of professional experience, Small has competencies in communications services, digital services, technology innovation and strategy. Most recently, he served as chief data officer of Telefónica S.A. and a member of its global executive committee. He is also chairman of TokBox, a platform-as-a-service provider of embedded video communications that was acquired by Telefónica. Prior to TokBox, he held executive technology and strategy positions at MarkLogic, marchFIRST and USWeb/CKS. Small began his career at Apple. A holder of nine US patents, he has an M.Sc. in Computer Science and a B.A.Sc. in Engineering Science from the University of Toronto.

On 27 July, Oclaro's board increased its size from seven to eight. Small will serve as a Class II director and his current term will expire at the firm's 2018 Annual Stockholders Meeting.

www.oclaro.com

Emcore's quarterly revenue up 38% year-on-year to $31m as DOCSIS 3.1 growth continues

China plant relocation and shift of satcom manufacturing to US EMS partner to cut quarterly revenue breakeven point by $1–1.5m by the start of fiscal 2018

For fiscal third-quarter 2017 (ended 30 June), Emcore Corp of Alhambra, CA, USA — which provides indium phosphide (InP)-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets — has reported revenue of $30.9m (at the high end of the $29–31m guidance). This is down 5% on $32.6m last quarter but up 38% on $22.4m a year ago, driven by strengthening demand across most product lines, offset by a return-to-normalized RF-over-glass (RfoG) volumes (following the fiscal Q2 product transition to OBI-mitigated products). However, adjusting for the $3m of revenue shift in fiscal Q2 of low-margin RFoG products, revenue grew 5% sequentially.

Of total revenue, cable TV comprised 75–80% (down from 80–85% last quarter), chips 7.5–12.5% (up from 5–10%), satcom video 7.5–12.5% (up from 5–10%), and fiber-optic gyro products (FOG) 2.5% (roughly level with last quarter).

Cable TV revenue grew 2% quarter-on quarter (excluding the low-margin RFoG shipments) and 38% year-on-year, with continued strong demand for DOCSIS 3.1 products.

Merchant chip revenue grew further, by 21% quarter-on-quarter, due to a combination of GPON customer orders (which were received in Q2 and began shipping in Q3) as well as a small but increasing number of 10G parts.

Satcom video revenue grew more than normal sequentially, as a large project shipped during the quarter.

Fiber-optic gyro sales grew normally (receiving a small order for MTS-B fiber-optic gyros from Raytheon, while contract negotiations for the multi-year opportunity continue).

On a non-GAAP basis, gross margin has risen further, from 33.6% a year ago and 34.4% last quarter to 35.4%, benefitting from a positive mix shift to higher-margin products, partially offset by relocation and redundancy expenses for the Beijing facility of about $300,000 (slightly lower than last quarter).

Operating income was $3.6m (operating margin of 11.5% of sales), down slightly from $3.7m last quarter but up from just $0.6m a year ago, despite higher-than-planned expenses caused by heavy R&D investments and the relocation of the China manufacturing operations. Adjusting for the Beijing facility transition expenses, operating income would have been closer to $3.9m (12.5% of revenue, hitting the fiscal Q4 target).

Net income was $3.64m ($0.13 per diluted share), down from $3.75m ($0.14 per diluted share) last quarter but up from $0.6m ($0.02 per diluted share) a year ago.

Capital expenditure was $2.7m, offset by $0.3m cash collected from the sale of fully depreciated assets. Emcore again recognized about $0.9m in depreciation. Overall, free cash flow was –$2.4m. During the quarter, cash and cash equivalents hence fell by $2.5m to $66.1m.

Work on new chip products such as our 6.5GHz wireless product and data-center products continues, with the goal of broadening our chip portfolio and the number of markets we serve. Growth will drive revenue as well as higher blended margin both for our chip business and for the company overall

"Emcore completed important operational transition milestones and delivered a solid quarter financially," says president & CEO Jeffrey Rittichier. "We made strong investments in R&D in the quarter and announced the new Emcore Orion family of inertial navigation systems." In addition, Emcore received major design wins from its CATV customers for new linear transmission products based on its L-EML [linear externally modulated laser] technology, positioning the firm for future growth.

"Looking into fiscal Q4 and the recent comments made by MSOs [multi-service operators] regarding their capital spending plan, we expect to see strong demand on the infrastructure side of CATV in general and DOCSIS 3.1 in particular," says Rittichier. For fiscal fourth-quarter 2017 (to end-September), Emcore expects revenue of $29-31m, with operating margin growing to hit the targeted 12.5%.

"Development work on new chip products such as our 6.5GHz wireless product and data-center products continues, with the goal of broadening our chip portfolio and the number of markets we serve," says Rittichier. "This growth will drive revenue as well as higher blended margin both for our chip business and for the company overall."

During fiscal Q3, Emcore completed the transition of its satcom manufacturing operations to its US-based electronics manufacturing services (EMS) partner and discontinued its non-core video products. "Keeping our EMS operations in the US allows us to meet the TAA [Trade Adjustment Assistance] and ITAR [International Traffic in Arms

Regulations] requirements from our military customers," notes Rittichier. "This transition paced away towards incremental operating leverage, as we continue to grow the volume of our satcom product lines through the introduction of new low-cost L-band links and technologies for 5G radio-over-fiber DAS [distributor antenna system] and, of course, focused on larger systems," he adds.

"With our new automated facility inside the 5th Ring of Beijing now in production, we are working hard to complete the qualification of the remaining automation equipment," reports Rittichier. "We've reduced our direct headcount from a peak of 370 in December 2016 to about 160 people, and we'll conclude this stage with 100 directs by the end of August for a total headcount — including all functions such as manufacturing and engineering, supply chain, etc — of 150 people in Emcore Asia, down from 430," he adds. "We stopped production at the facility in Langfang two months ago, and we have moved out nearly all of the equipment and inventory. We'll return the buildings to the landlord this month. While this work has been finalized in Q4, we expect to incur a decline in transition costs," Rittichier continues.

Emcore expects these actions in China, combined with the transformation of the US manufacturing operation, to result in a breakeven revenue point of $1–1.5m less per quarter. "While we expect to realize some of the benefit in Q4, we should fully realize the benefit at the start of fiscal 2018," forecasts Rittichier.

Looking into fiscal Q4... we expect to see strong demand on the infrastructure side of CATV in general and DOCSIS 3.1 in particular

"This manufacturing transformation is not the endpoint. For example, we expect to add fully automated material management systems to our newly automated transmitter line in Q1 and Q2 of fiscal 2018. This will complete the move of the entire transmitter build process, improving our working capital and costs," says Rittichier.

"Over the next year, we expect to devote the majority of our Six Sigma Green Belt and Black Belt projects to wafer fab operations, where we will not only improve the standard process controls but build process nodes that will launch new generations of chip products for captive and merchant markets. We see the fab as a key area for investment both in terms of capital and world-class technologies as we work to improve our ability to execute and invent," Rittichier concludes.

www.emcore.com

II-VI Inc buys Kaiam's 6" fab in UK for $80m

Newton Aycliffe fab expands capacity for VCSELs plus other GaAs-, SiC- and InP-based devices

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has acquired Kaiam Laser Ltd, a 6-inch wafer fabrication plant in Newton Aycliffe, UK, for $80m in cash reserves. The acquisition is expected to be breakeven at the EBITDA level within 12 months.

The 300,000ft^2 facility has a 100,000ft^2 cleanroom designed for high-volume manufacturing of compound semiconductor devices based on gallium arsenide (GaAs), silicon carbide (SiC) and indium phosphide (InP) materials.

"This facility hosts one of the best cleanrooms in the entire compound semiconductor industry and augments our capabilities at a time when industry capacity is rapidly becoming fully subscribed," notes II-VI's president & CEO Dr Chuck Mattera. "Given the demand we anticipate, this acquisition will allow us faster time to market than building a proprietary green-field site," he adds. "It adds to our in-house capacity for VCSELs [vertical-cavity surface-emitting lasers], and is also as part of a broader strategic move to provide a versatile 6" wafer fab for GaAs-, SiC- and InP-based devices. This acquisition will significantly expand our capacity and is expected to enable us over time to penetrate high-growth markets driven by, for example, 3D sensing, 5G wireless, the electrification of the car, and data-center communications," he adds.

Kaiam Laser's parent firm Kaiam Corp of Newark, CA, USA – which is commercializing hybrid photonic integrated circuit (PIC) technology for pluggable optical transceivers in data-centers — acquired the fab from Compound Photonics Group Ltd in early May. "II-VI will be using this fab more effectively by leveraging its full capacity and multi-purpose use," comments Kaiam's CEO Dr Bardia Peseshki. "I am looking forward to working with II-VI to establish a commercial relationship that includes having II-VI provide InP-based epitaxial wafers and wafer fabrication services for our products as we continue to expand our transceiver business in the rapidly growing 100G and impending 400G datacenter markets."

II-VI says that, as a part of its vertical integration strategy, it is expanding its VCSEL product family and leveraging its broad engineered materials and optoelectronic device technology platforms and manufacturing capabilities around the globe to drive scale and innovation through the development of compound semiconductor devices.

www.kaiam.com
www.ii-vi-photonics.com

Audi and Alta Devices to co-develop solar cells integrated into car roof

First joint prototype to be completed by end 2017

Audi and Alta Devices of Sunnyvale, CA, USA (a subsidiary of solar-cell specialist Hanergy Thin Film Power) plan to cooperate on integrating solar cells into the panoramic glass roofs of cars, aiming to generate solar energy to increase the range of Audi electric vehicles. The first prototype will be developed by the end of 2017.

Audi and Alta Devices will integrate solar cells into a panoramic glass roof as a first step. In the future, because Alta's gallium arsenide (GaAs) solar cell technology is flexible, thin and efficient, almost the entire roof surface will be covered with solar cells. The electricity generated from the cells will flow into the car's electric system and can supply, for example, the air-conditioning system and seat heaters – a gain in efficiency that has a direct benefit to electric vehicle range.

"The range of electric cars plays a decisive role for our customers," says Dr Bernd Martens, Audi board member for Procurement. "Together with Alta Devices and Hanergy, we plan to install innovative solar technology in our electric cars that will extend their range and is also sustainable," he adds.

At a later stage, solar energy could directly charge the traction battery of Audi electric vehicles. "That would be a milestone along the way to achieving sustainable, emission-free mobility," says Martens. Alta Devices' solar cells are very thin and flexible, hold the record for solar energy conversion efficiency, and perform well in low-light and high-temperature environments," he adds.

"This partnership with Audi is Alta Devices' first cooperation with a high-end auto brand," notes Dr Jian Ding, senior VP of Hanergy Thin Film Power Group Ltd., CEO of Alta Devices Inc and co-leader of the Audi/Hanergy Thin Film Solar Cell Research and Development Project.

www.altadevices.com

Twiggs Space Lab, Nearspace Launch and Virginia Space using Alta Devices' modular and lightweight GaAs solar cells

At the 31st Annual AIAA/USU Conference on Small Satellites (SmallSat) in Logan, Utah (5–10 August), satellites powered by solar cells made by Alta Devices of Sunnyvale, CA, USA (a subsidiary of solar-cell specialist Hanergy Thin Film Power) were displayed by Twiggs Space Lab LLC (TSL), NearSpace Launch Inc (NSL) of Upland, IN, USA and Virginia Commercial Space Flight Authority (VCSFA), which are pioneering new models of satellites that are smaller, simpler and more affordable. Their focus is to broaden access to space for educational and commercial participants. Alta Devices says that its gallium arsenide solar technology was chosen due to its unique modular, lightweight and high-efficiency characteristics.

"Our goal is to inspire future generations of engineers and scientists through innovation in the field of space," says TSL founder Bob Twiggs (a former consulting professor at Stanford University Department of Aeronautics and Astronautics, where he established the Space Systems Development Laboratory). "Alta Devices technology is easy to integrate, and its modular form factor is well suited to the standardized dimensions of CubeSats [which he co-developed in 1999]."

CubeSats (built around a 10cm x 10cm x 10cm building block) were originally developed for university students to participate in space research. The standard has now been adopted worldwide and has helped to ignite a small satellite revolution. Typically placed into low-earth orbits, they often have standardized or off-the-shelf components and have facilitated more affordable and easier access to space. CubeSats are driving new industries via the explosion of big data accessible from space.

All small satellites need solar cells to generate electrical power. Alta Devices says that, until now, no commercial solar technologies could match the improvement in cost, weight and ease of use that other components of small-satellite technology have achieved: solar cells are traditionally expensive, fragile, rigid, and difficult to encapsulate and robustly attach to spacecraft.

Alta Devices says that its solar cells overcome these challenges because they are flexible, easy to encapsulate and mount, and provide high power conversion efficiencies, providing mechanical and design flexibility for the small-satellite industry (e.g. they can be mounted to low-mass deployable structures including coiled carbon-fiber booms, flat-packed, polymer-based accordioned arrays, and even inflatable structures, allowing creative design approaches to maximizing onboard solar power).

"Innovation in solar is essential to the continued evolution of small-satellite technology," says CEO Jian Ding. "Our thin-film GaAs solar technology uniquely meets the challenge of limited surface area; it can be wrapped around curved surfaces yet is highly robust. Our small cell size enables high packing density," he adds.

www.smallsat.org

CSEM, NREL and EPFL raise silicon-based multi-junction solar cell efficiency record

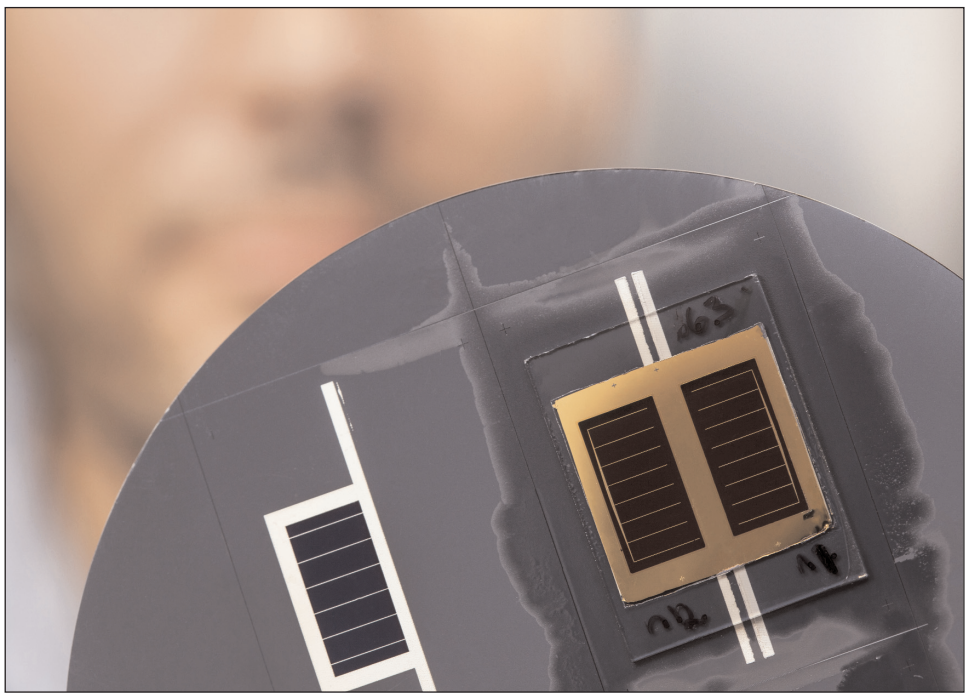
Tandem cells use CSEM silicon heterojunction bottom cell with NREL GaAs and GaInP/GaAs top cells, respectively, for 32.8 % dual-junction and 35.9% triple-junction efficiencies

The US Department of Energy's National Renewable Energy Laboratory (NREL), the Swiss Center for Electronics and Microtechnology CSEM (Centre Suisse d'Electronique et de Microtechnique) and EPFL (École Polytechnique Fédérale de Lausanne) in Switzerland have raised the record one-sun conversion efficiency of III–V/Si silicon-based multi-junction solar cells to 32.8% for two junctions and 35.9% for three junctions ('Raising the one-sun conversion efficiency of III–V/Si solar cells to 32.8% for two junctions and 35.9% for three junctions', Stephanie Essig et al, Nature Energy 6, article number 17144 (2017) doi:10.1038/nenergy.2017.144).

Efficiency rates of more than 35% have previously been reached in the laboratory, but with cells that only use expensive materials. The existing photovoltaics (PV) market is dominated by cost-effective modules made of single-junction silicon solar cells, with efficiencies of 17-22%. Like many research centers and industrial players, NREL, CSEM and EPFL are working with multi-junction cells, combining silicon with a cell that absorbs blue light from the sun more efficiently. The transition from a silicon single-junction cell to a silicon-based multi-junction solar cell has the potential to push efficiencies past 30% while still benefiting from the cost-effective manufacturing expertise in making silicon solar cells. In January 2016, the NREL/Swiss team was able to reach 29.8%, setting their first joint world record.

Potential demonstrated for new generation of solar cells

The CSEM/EPFL/NREL team has now raised their efficiency record to 32.8 % for a dual-junction cell (by combining an NREL GaAs top cell with a CSEM silicon heterojunction bottom cell) and 35.9% for a triple-junction cell (by combining an NREL GaInP/GaAs top cell with a CSEM silicon heterojunction bottom cell). "It shows, for the first time, that silicon-based tandem cells can provide efficiencies competing with more expensive multi-junction cells consisting entirely of III-V materials," says Adele Tamboli, a senior researcher at NREL. "It opens the door to develop entirely new multi-junction solar cell materials and architectures," she adds.



GaAs/Si tandem cells with efficiency up to 32.8% under 1-sun illumination.

Silicon-based tandem cells can provide efficiencies competing with more expensive multi-junction cells consisting entirely of III-V materials

Making solar more accessible

"These records show that combining crystalline silicon and other materials is the way forward if we are to improve solar power's cost/efficiency ratio," believes Christophe Ballif, director of CSEM's PV-center and EPFL Photovoltaics laboratory. "It affirms that silicon heterojunction solar cells, when integrated into the structure that we've developed, can generate multi-junction cell conversion efficiencies over 32%," adds Matthieu Despeisse, manager of crystalline silicon solar cells activities at CSEM.

CSEM is working on such silicon-based multi-junction solar cells and is also testing new materials to be used as a top cell in order to optimize the cost/efficiency ratio. For example, it is studying the potential use of perovskite material as part of the European Space Agency (ESA) CHEOPS project.

http://dx.doi.org/10.1038/nenergy.2017.144
www.nrel.gov/pv
https://pvlab.epfl.ch
www.csem.ch

First Solar awarded 241MW module supply contract for Edify Energy solar projects in Australia

Cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA has been awarded a 241MW_{DC} module supply contract by RCR Tomlinson Ltd as engineering, procurement & construction (EPC) contractor for Edify Energy's Daydream (180.7MW_{DC}) and Hayman (60.2MW_{DC}) solar projects in Queensland, Australia. The deal takes First Solar's delivery pipeline to over 500MW in the next 12 months, cementing it as the leading module supplier for large-scale solar in Australia, the firm claims.

Located across two sites north of Collinsville, the projects will utilize optimized technology that includes single-axis tracking technology from Array Technologies Inc, and over 2,026,565 First Solar modules. On completion, the projects will produce about 531,000MW-hrs per year (serving the needs of about 73,000 average Queensland homes), which is enough energy to displace 429,000 metric tons of carbon dioxide emissions per year combined (equivalent to taking about 115,000 cars off the road).

First Solar says that the Series 4 modules chosen for the projects are suited to the hot and humid environmental conditions of the Whitsunday Region, due to a superior temperature coefficient, as well as better shading and spectral response.

"First Solar's unique energy yield advantage enables our solar projects in North Queensland to produce more energy per MW installed than other available PV technology," comments Edify Energy's CEO John Cole. "This is of significant importance for asset owners and operators looking to maximize energy production," he adds.

Construction on the projects is scheduled to begin in Q3/2017, with module delivery in Q4/2017 and Q1/2018.

www.firstsolar.com

First Solar sells 40MW Cuyama Solar Project to DESRI

An affiliate of D. E. Shaw Renewable Investments LLC (DESRI) — which acquires, owns and manages long-term contracted renewable energy assets in North America — has acquired First Solar's 40MW_{AC} Cuyama Solar Project in Santa Barbara County, California.

Currently under construction (for completion by the end of 2017), output is expected to be supplied to Pacific Gas & Electric (PG&E) under a 25-year power purchase agreement (PPA) starting in January 2019. Community Choice Aggregator Peninsula Clean Energy has a one-year 'bridge' PPA for power delivered from the plant in 2018.

The plant (the first utility-scale solar installation in Santa Barbara County) should provide enough electricity annually to power about 16,000 typical California homes and displace over 30,000 metric tons of CO_2 greenhouse gas emissions each year (equivalent to taking almost 6000 cars off the road).

Cuyama is the third renewable energy project that DESRI has acquired from First Solar. In 2016, DESRI affiliates acquired the 31MW_{AC} Portal Ridge Solar Project in Los Angeles County and the 11MW_{AC} Rancho Seco Solar Project in Sacramento County.

www.deshaw.com

First Solar sells California Flats project to Capital Dynamics

First Solar has completed the sale of the 280MW_{AC} California Flats Solar Project in Monterey County, California, to global private asset manager Capital Dynamics.

Sited on about 2900 acres of ranch land within the Jack Ranch owned by the Hearst Corporation near the San Luis Obispo and Monterey County borders, California Flats comprises two phases. The 130MW first phase is expected to be commissioned in fourth-quarter 2017, and is fully contracted under a long-term power purchase agreement (PPA). The 150MW second phase (currently under construction) is expected to be commissioned by the end of 2018, and is fully contracted under a long-term PPA.

"Our Clean Energy Infrastructure (CEI) team now owns three of the 10 largest solar projects in North America and has over 3GW of projects operating or under construction," says John Breckenridge, head of Capital Dynamics Clean Energy Infrastructure. "As an investor focused on clean energy projects, we expect to continue to actively grow that portfolio in the immediate future," he adds.

"The California Flats project includes an exciting mix of utility and corporate renewable energy procurement," comments First Solar's chief commercial officer Georges Antoun.

Earlier this year, Capital Dynamics acquired cash equity in the Moapa Southern Paiute Solar Project in Nevada, which First Solar developed and constructed.

California Flats will generate enough energy to power about 100,000 average homes per year, displacing over 109,000 metric tons of CO_2 annually based on the PG&E grid (equivalent to taking about 22,000 cars off the road).

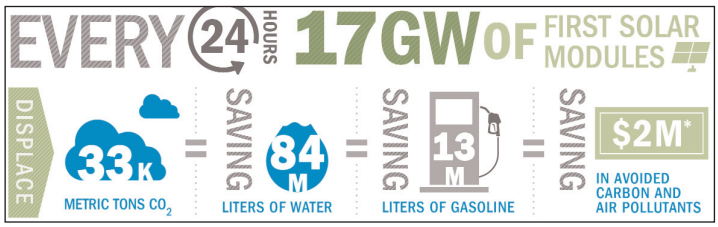
www.firstsolar.com

First Solar beats its greenhouse-gas emissions reduction target, while reducing manufacturing energy intensity

First Solar Inc of Tempe, AZ, USA, which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services, has released its annual sustainability report, which highlights its environmental and safety performance progress, utility-scale PV project development practices, and the anticipated sustainability and performance advantages of its next-generation Series 6 module technology.

Since 2008, the firm has almost halved its greenhouse gas (GHG) emissions intensity, surpassing its goal of a 35% company-wide reduction by 2016. The decline in emissions intensity was the combined result of an increase in module efficiency, manufacturing throughput and capacity utilization, decreased emissions intensity of purchased grid electricity, along with energy conservation and low-carbon initiatives.

Data released as part of the 2017 Sustainability Report shows that it has also reduced its manufacturing energy intensity by 30% from 2009 to 2016. Notably, although production volume increased by 24% in 2016, First Solar reduced its absolute water withdrawals by 4% and saved more than 185 million liters (about 49 million gallons) by recycling water at its manufacturing facility in Malaysia.



"Thanks to our thin-film technology and efficient manufacturing process, the environmental impact of a First Solar PV system is about two-thirds lower than the average PV system available in the market today," claims CEO Mark Widmar (citing a report Wyss et al, 'PEF screening report of electricity from photovoltaic panels in the context of the EU Product Environmental Footprint Category Rules (PEFCR) Pilots v.2.0', 24 April 2016). "In fact, our new Series 6 module technology is expected to further increase that gap," he adds. "We now deliver high-performance PV modules that can successfully compete against silicon panels, while also delivering the fastest energy payback time and the lowest lifecycle impact in the industry."

First Solar has also tracked a 74% reduction in manufacturing waste intensity, from 35.1 grams per watt produced in 2009 to 9.1 grams per watt in 2016. Its recycling program — claimed to be unique in the PV module manufacturing industry — recovers 90% of the semiconductor material and glass from decommissioned modules.

"The reduction in our environmental footprint is entirely by design; the result of taking a long-term view on continuously improving our environmental performance," says Alex Heard, senior VP of global technical services. "Our commitment remains stronger than ever, and we will continue to work to improve our performance."

EDF acquires 179MW Switch Station 1 & 2 projects from First Solar

EDF Renewable Energy (EDF RE) of San Diego, CA, USA (a subsidiary of EDF Energies Nouvelles, the renewable energy arm of EDF group) says that in late June it acquired the 179MW_{AC} Switch Station 1 and Switch Station 2 Solar Projects from First Solar Inc of Tempe, AZ, USA, which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services. Currently under construction, the projects will sell their combined output and environmental attributes under three power purchase agreements (PPAs) to subsidiaries of NV Energy Inc. Commercial operation dates (COD) for the two projects were scheduled for late July and late September, respectively.

Located in Clark County, Nevada on land managed by the US Bureau of Land Management (BLM) in the Dry Lake Solar Energy Zone (SEZ), the projects consist of First Solar modules on horizontal single-axis trackers. The expected electricity generated at full capacity is enough to meet the consumption of about 46,000 Nevada homes (equivalent to avoiding more than 265,000 metric tons of CO_2 emissions annually according to US EPA Greenhouse Gas Equivalencies calculations, which represents the greenhouse-gas emissions from 52,000 passenger vehicles driven over the course of one year).

"The acquisition of Switch Station 1 and Switch Station 2 marks EDF RE's entry into Nevada, a state with world-class solar resources where we plan to build additional projects in the coming years," says Ryan Pfaff, executive VP of EDF Renewable Energy.

EDF RE is one of the largest renewable energy developers in North America, with 9GW of wind, solar, biomass, and biogas projects developed throughout the USA, Canada, and Mexico.

www.edf-re.com
www.firstsolar.com

Imec boosts efficiency of 4cm² perovskite/silicon solar module to record 23.9%

Nanoelectronics and photovoltaics research centre imec of Leuven, Belgium (a partner in Solliance and EnergyVille) has improved its 4cm^2 perovskite/silicon tandem photovoltaic module, achieving record solar energy conversion efficiency of 23.9% (the first to achieve a module-on-cell stack that outperforms the standalone silicon cell).

Perovskite solar cells can achieve high power conversion efficiency, are inexpensive to produce, and have high absorption efficiency in sunlight. The material can be engineered to result in various optical and electronic properties. Additionally, perovskite solar cells or modules can also be used to boost standard silicon solar technology when engineered to absorb a spectral range that is complementary to the optical range of silicon cells. By stacking the perovskite solar cells or modules on top of silicon solar cells, power conversion efficiencies above 30% can potentially be achieved, surpassing the efficiencies of the best single-junction Si solar cells.

Developed in collaboration with Solliance — a cross-border Dutch–Flemish–German thin-film photovoltaic (TFPV) solar energy R&D consortium in the ELAT (Eindhoven–Leuven–Aachen) region — in 2016 imec presented for the first time a semi-transparent perovskite module, stacked on top of an interdigitated back-contact (IBC) crystalline silicon solar cell in a four-terminal tandem configuration. This achieved an overall power conversion efficiency of 20.2% on an aperture area of 4cm^2. Imec's improvement of this technology has now resulted in record power conversion efficiency of 23.9% for a module-on-cell stack of this size.

"Two innovations are key to this achievement," explained Tom Aernouts, group leader for thin-film photovoltaics at imec and perovskite PV program manager at Solliance. "First, a different perovskite material (CsFAPbIBr) was used, largely improving the stability and conversion efficiency of the 4cm^2 semi-transparent perovskite module to 15.3%. Second, the architecture of the stack was optimized for minimal optical losses by adding an anti-reflection texture on top of the module and a refractive-index-matching liquid between the perovskite module and the Si solar cell."

The perovskite/Si four-terminal tandem was realized with matched aperture areas as large as 4cm^2 for the perovskite module and the silicon solar cell. "Having matched areas of this size makes the fabrication technology more attractive to the solar cell industry," says Aernouts. "For reference, we have also fabricated a stack of a small perovskite cell (0.13cm^2) on top of an IBC c-Si cell (4cm^2). In this configuration, the conversion efficiency of the small semi-transparent perovskite cell is 16.7%, outperforming the larger 4cm^2 perovskite module due to better perovskite layer properties. Although less attractive from an industrial point of view, the overall power conversion efficiency of this cell-on-cell stack is as high as 25.3%."

www.imec.be

Manz orders sputtering systems from centrotherm's FHR for CIGS solar module factories in China

FHR Anlagenbau GmbH of Ottendorf-Okrilla, Germany (a subsidiary of centrotherm international AG) has won a contract from Reutlingen-based Manz AG for sputtering systems for manufacturing copper indium gallium diselenide (CIGS) thin-film solar modules, to be delivered in 2018 and commissioned in two fully integrated factories in China (as part of orders Manz received in January from partners Shanghai Electric Group and Shenhua Group).

Meanwhile, centrotherm Group, via its subsidiary FHR, is targeting a strategic partnership focused on further developing CIGS thin-film technology together with Manz.

"Since our founding in 1991 we have considered ourselves as pioneers in vacuum process technology for the deposition of a wide range of functional thin films," says FHR's general manager Torsten Winkler. "The special electrical, optical or other functional coatings are used today in many different sectors. We can contribute our core competence into the development partnership with Manz. Together we intend to further enhance the efficiency and competitiveness of thin-film solar technology in the photovoltaic market," he adds.

"In concluding this agreement, centrotherm has achieved an important milestone in its corporate strategy of further diversifying its range of services," says centrotherm's chief operating officer Gunter Fauth. "As a leading technology provider of production solutions for the manufacture of standard p-type crystalline and high-efficiency PERC [passivated emitter rear-contact] solar cells, we have again delivered proof throughout the group with FHR of our strong competence in thin-film vacuum coating."

www.centrotherm.de
www.manz.com

Solar-Tectic granted US patent for tin perovskite/c-Si thin-film tandem solar cell

Solar-Tectic LLC of Briarcliff Manor, NY, USA says that a patent application for a tin perovskite/crystalline silicon (c-Si) thin-film tandem solar cell has been granted by the US Patent and Trademark Office (USPTO). US patent 15/205,233, the first for a perovskite layer on crystalline silicon thin-film (tandem cell), covers all non-toxic perovskites and inorganic materials. The inventor is Solar-Tectic's CEO Ashok Chaudhari.

Recently, perovskite materials have gained attention as a promising solution to the long-standing problem of solar cell efficiency. While there have been 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. Wafer-sized bottom poly- and monocrystalline silicon layers in PERC, PERL, HIT, HJ 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 costs of production significantly. The top perovskite layer is less than 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 — due to tariffs or otherwise — less silicon material use will be an additional cost saving, notes Solar-Tectic.

An example of a perovskite layer is $CsSnBr_3$, which has a bandgap of 1.75eV, ideally suited as a top layer on silicon thin-film (which has a bandgap of 1.12eV). Such a tandem solar cell is capable in theory of 45% efficiency, although Solar-Tectic has set a more realistic 30% efficiency goal, higher than the best silicon wafer technologies such as PERC, PERL, HIT and HJ cells with 25–26.6% efficiencies. The efficiencies of existing solar cells on the market generally range from 14–25%. 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, eliminating the need for fossil fuel generated electricity entirely, reckons Solar-Tectic, and silicon wafer technology based on polycrystalline or monocrystalline silicon (90% of today's market) would become obsolete.

Solar-Tectic says that its entire process is environmentally friendly, since non-toxic tin (Sn) is used to deposit the crystalline silicon thin-film material for the bottom layer in the tandem configuration as well as in the top, perovskite layer. The more commonly used toxic lead (Pb) is not used in the perovskite here. The processing methods are conventional and similar to those used in the existing thin-film solar cell industry, as well as in the display industry, notes the firm.

The tin perovskite/silicon thin-film tandem solar cell is part of a 'Tandem Series' of high-efficiency and cost-effective solar cells by Solar-Tectic with the potential to surpass the efficiencies of thin-film solar cell technologies such as cadmium telluride (CdTe), copper indium gallium diselenide (CIGS) and amorphous silicon (a-Si) and to replace incumbent silicon photovoltaic technology based on poly and monocrystalline wafers, says the firm. Solar-Tectic's solar cell technologies include a variety of different proven semiconductor photovoltaic materials (i.e. III-V, CZTS, a-Si, etc) for the top layer on a silicon (or germanium) bottom layer, on various substrates including flexible glass and polyimide for R2R (roll to roll) processing.

Recently, a patent for a germanium perovskite thin-film solar cell was also granted to Solar-Tectic and last year a similar patent was issued for a 'Hybrid Organic/Inorganic Eutectic Solar Cell', which is applicable to organic light-emitting diodes (OLEDs).

R&D on the new perovskite thin-film tandem technology has begun at Blue Wave Semiconductors Inc in Maryland, USA under the direction of Dr Ratnakar D. Vispute.

www.solartecticllc.com

Midsummer receives order for two DUO CIGS solar cell manufacturing systems

Midsummer AB of Järfälla, near Stockholm, Sweden — a provider of turnkey production lines for manufacturing flexible, lightweight copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) solar cells — has received a repeat order from an undisclosed customer for two compact DUO thin-film solar cell manufacturing systems (for delivery by the end of 2017) as a result of strong demand for lightweight, flexible modules.

Designed for operational stability and superior material utilization, the compact, fully automatic DUO deposition system is used for manufacturing lightweight flexible CIGS solar panels to cater for the growing demand for portable panels and roof-top installations.

"Our DUO system is now the most widely spread manufacturing tool for flexible CIGS solar cells in the world," claims Midsummer's CEO Sven Lindström.

www.midsummer.se

Smart stacking III-V on crystal silicon solar cells to boost conversion

Palladium nanoparticle array connection enables thin-film on aluminium back-surface-field silicon tandem devices to reach 25% efficiency.

Japan's National Institute of Advanced Industrial Science and Technology has used palladium nanoparticle (Pd NP) arrays to connect crystalline silicon (c-Si) and III-V tandem solar cell stacks, resulting in high conversion efficiency [Hidenori Mizuno et al, Appl. Phys. Express, vol10, p072301, 2017]. The researchers term the technique 'smart stack'.

While silicon solar cell technology offers the advantages of mature mass production and low cost, single-cell silicon devices are theoretically limited to conversion efficiencies less than ~29%. Using tandem structures with III-V thin-film subcells above c-Si cells could extend this performance.

The researchers used a simple aluminium back surface field (BSF)-type c-Si cell, based on a 400μm-thick double-side mirror polished, p-type Si (100) substrate. An n^+-Si surface layer was created using thermal diffusion of phosphoryl chloride ($POCl_3$). The p^+-Si BSF was achieved through screen-printing and firing of aluminium paste.

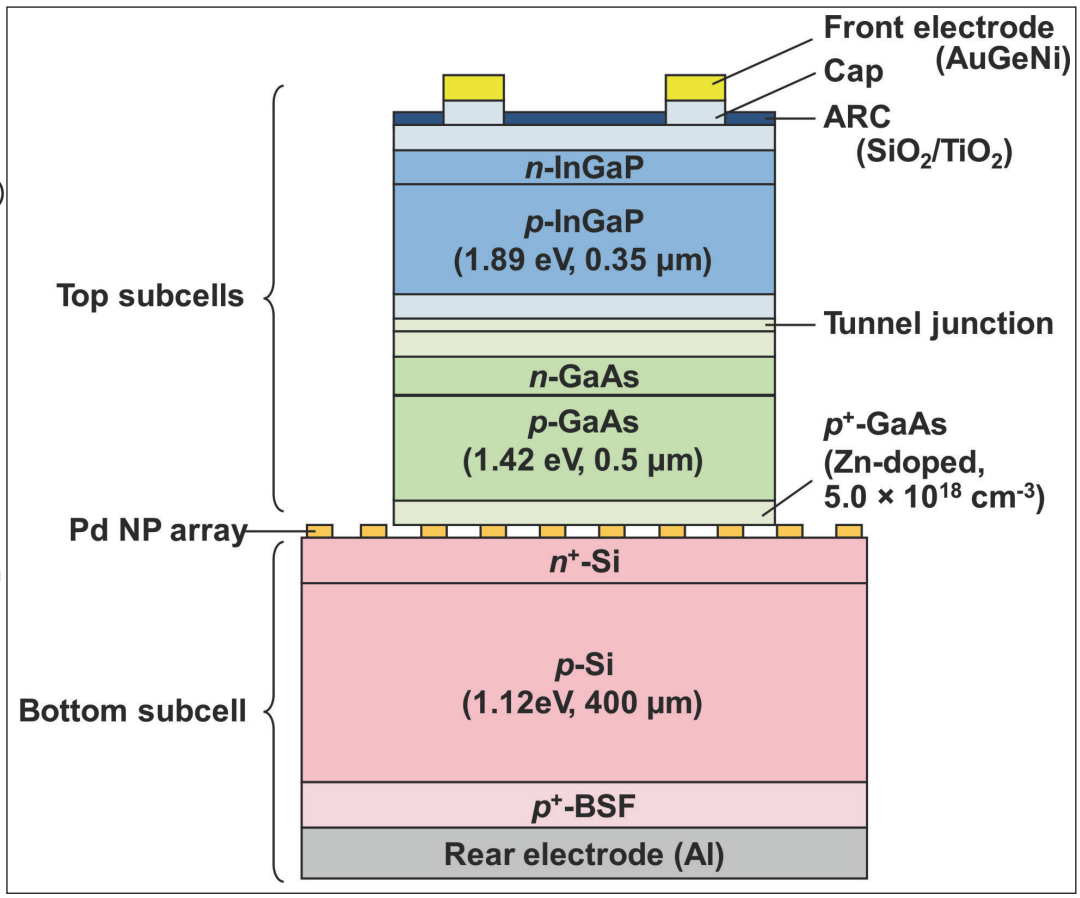


Figure 1. Schematic cross-section of InGaP/GaAs//Si ("/" is tunnel junction, "//" is Pd NP smart stack) triple-junction cell.

The structure was prepared for smart-stack bonding with the indium gallium phosphide/gallium arsenide (InGaP/GaAs) (0.35μm/0.5μm) thin-film cell by creating a Pd NP array in a self-assembled polystyrene-block-poly(2-vinylpyridine) template. The gap between the GaAs and silicon layers was found to be uniformly around 10nm.

The InGaP and GaAs absorber layer thicknesses were designed to give relatively matched currents for the three subcells from AM1.5g standard solar illumination – 10.7mA/cm^2 from InGaP, 10.7mA/cm^2 from GaAs, and 10.2mA/cm^2 from Si. Matching currents is very important for high efficiency.

The completed structure (Figure 1) included a gold-germanium-nickel (AuGeNi) front electrode plus a silicon dioxide/titanium dioxide (SiO_2/TiO_2) anti-reflective coating (ARC).

The researchers comment: "It should be emphasized that no additional heat treatment was necessary to improve the bonding quality (lower the interfacial resistance), which is usually required with other bonding-based fabrication of two-terminal tandem cells."

PV measurements with AM1.5g solar spectrum illumination (1 sun, 100mW/cm^2) showed 24.5% conversion efficiency η (Figure 2). The researchers found that the open-circuit voltage (V_{oc}) was down on what was expected from measurements on separate cells: "This could be attributed to the shading of the c-Si bottom subcell because, in this situation, unfavorable migrations of photo-generated carriers to unilluminated regions could easily occur. This would lead to an increased dark current and recombination probability, and thereby a decreased V_{oc}."

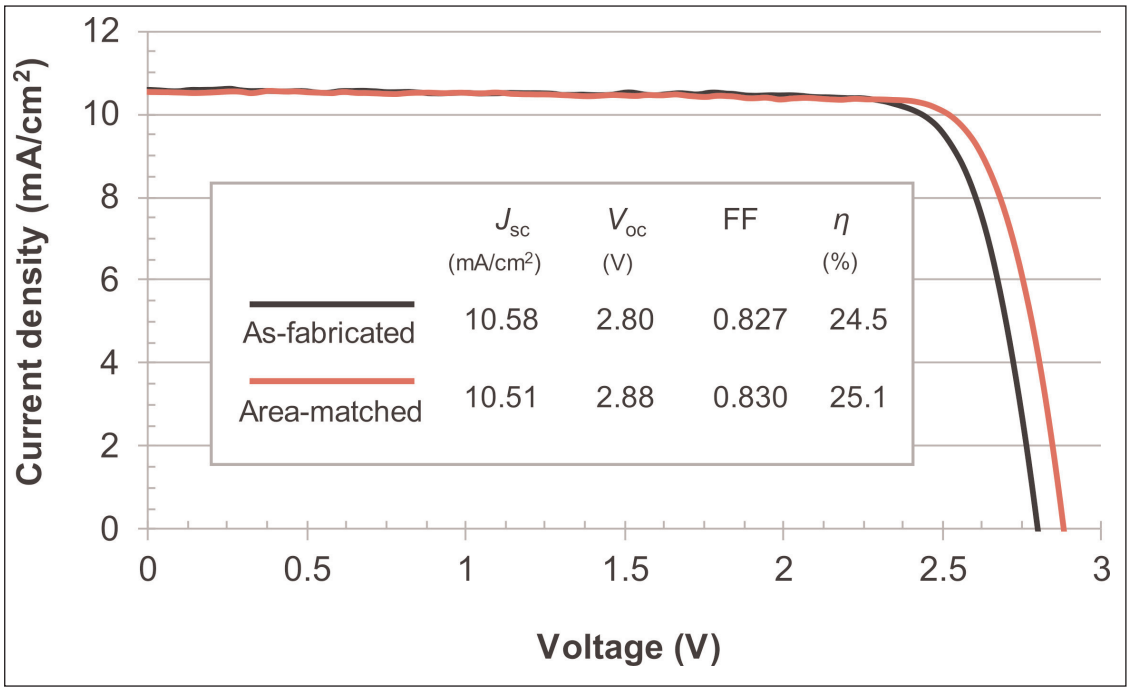


Figure 2. Current density–voltage (J–V) characteristics of as-fabricated (before-cutting, black curve) and area-matched (after-cutting, gray curve) InGaP/GaAs//Si cells.

The high fill factor (FF) of 0.827 was attributed to the low resistance interface between the silicon and GaAs given by the Pd NP array.

To improve the performance by tackling the shading issue, the researchers used a dicing saw to remove excess regions of the c-Si bottom cell. This increased V_{oc}, although it reduced the short-circuit current density (J_{sc}) somewhat. The researchers say that the current degradation was not significant — indeed, the FF increased to 0.830 and the conversion efficiency was enhanced to 25.1%. The team adds that the improved performance after using the dicing saw strongly supports "the hypothesis that smart stack cells are durable enough to withstand rather severe semiconductor processes".

The researchers say that they consider the observed performance as being close to the best achievable for the types of subcells used. "Higher-efficiency smart stack cells will require development of high-quality, thicker InGaP/GaAs cells, advanced c-Si cells, and tricks for current matching between them, which is actively underway in our group," the team adds. ■

https://doi.org/10.7567/APEX.10.072301

Author: Mike Cooke

Monolithic electrically injected microdisk lasers on silicon

Researchers in Russia claim first demonstration for a range of devices.

Researchers in Russia claim "the first demonstration of an injection quantum well microdisk laser fabricated of III-V materials monolithically grown on silicon (001) substrate" [N. V. Kryzhanovskaya et al, Optics Express, vol. 25, p16754, 2017]. Up to now, reports of microdisk lasers on silicon have used optical pumping rather than the electrical injection needed for optoelectronic applications.

Scientists and engineers are seeking to combine III–V light-generating technology with silicon photonics for many applications such as optical telecommunications. Monolithic direct growth of III-V materials on silicon is preferred over heterogeneous integration methods such as wafer bonding. Monolithic integration should reduce process complexity, cutting costs and increasing yields.

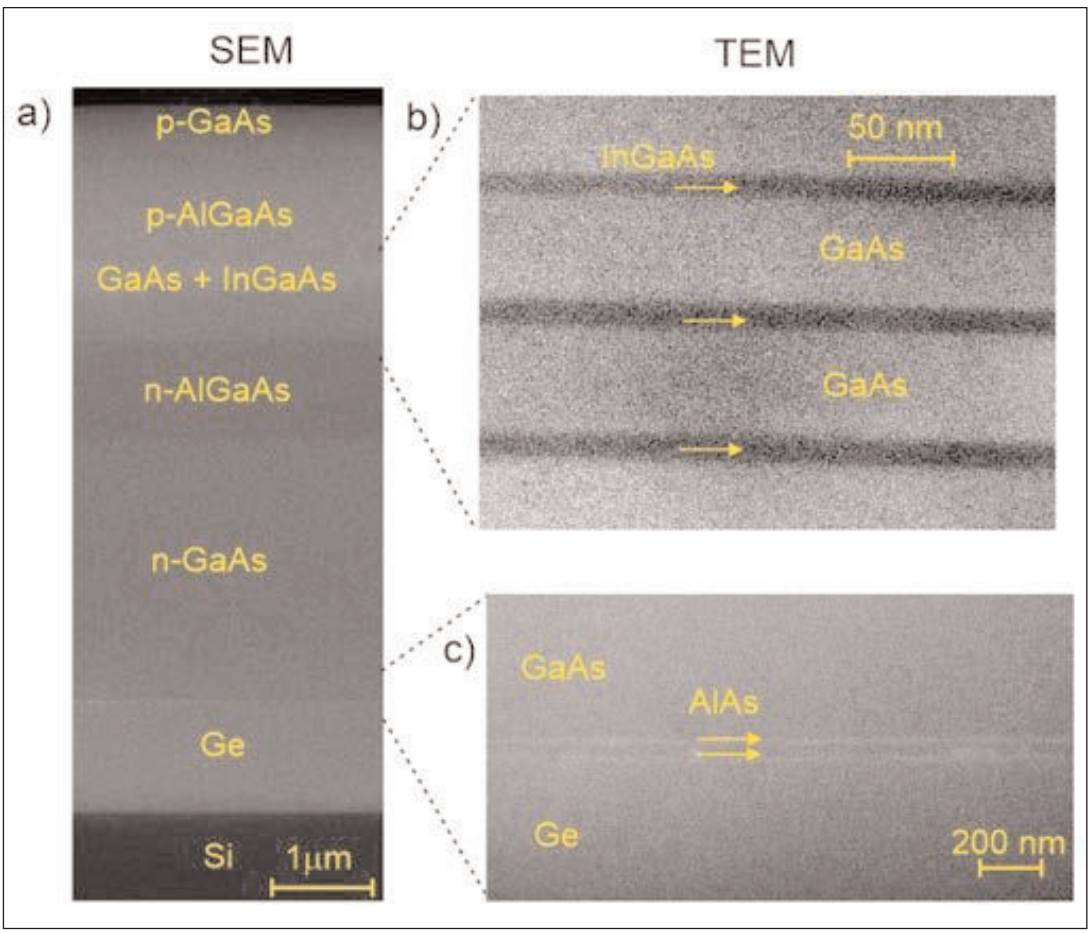


Figure 1. Cross-sectional scanning electron microscope (a) and transmission electron microscope (b,c) images of the epitaxial structure.

St Petersburg Academic University, Peter the Great St. Petersburg Polytechnic University, Ioffe Physical Technical Institute of the Russian Academy of Sciences (RAS), Institute for Physics of Microstuctures of RAS, and the Lobachevsky State University of Nizhny Novgorod, used molecular beam epitaxy (MBE) to produce templates that consisted of germanium (Ge) on exact (i.e. less than 0.5° offcut angle) (001) Si substrate.

An initial 275°C 50nm Ge layer, aimed at two-dimensional growth and island suppression, was followed by a 600°C 1µm Ge buffer. The low-temperature step allowed strain relaxation by misfit dislocation generation, while presenting a flat surface for further high-quality growth at high temperature. The template was then annealed with five cycles of 850°C/550°C for 2 minutes at each temperature.

The template was cleaned before metal-organic chemical vapor deposition (MOCVD) of III-V layers (Figure 1): 10nm AlAs, 50nm GaAs, 10nm AlAs buffer; 2.5µm n-GaAs current spreader; 0.8µm n-GaAs waveguide; 1µm n-$Al_{0.3}Ga_{0.7}As$ cladding; active region; 1µm p-$Al_{0.3}Ga_{0.7}As$ cladding; and 0.8µm p-GaAs waveguide. The active region was three 10nm InGaAs quantum wells with average InAs content of 17%. The n-type silicon doping was achieved with silane. Carbon tetra-

fluoride was used for p-type carbon doping.

Microdisk resonators were formed using photolithography and inductively coupled plasma etch to a depth of 3μm. The p-contact metal consisted of silver-manganese/nickel-gold. The diameter of the metal contact was 4μm less than that of the microdisk. The common gold-germanium/nickel/gold n-contact was deposited on the region between the microdisks.

The pulsed-injection turn-on voltage of the devices was around 1.2V, in line with the expected optical transition energy. A 31μm-diameter device had a knee in the intensity of the 988.47nm-wavelength dominant mode at 0.31A injection current, suggesting a lasing threshold (Figure 2). The linewidth was 81pm at minimal current, which reduced to 35pm at threshold. The dominant mode was an order of magnitude greater than side modes at threshold, increasing up to 20dB side-mode suppression with increasing current injection. As the current increase continued, the dominant mode was quenched and side modes began lasing.

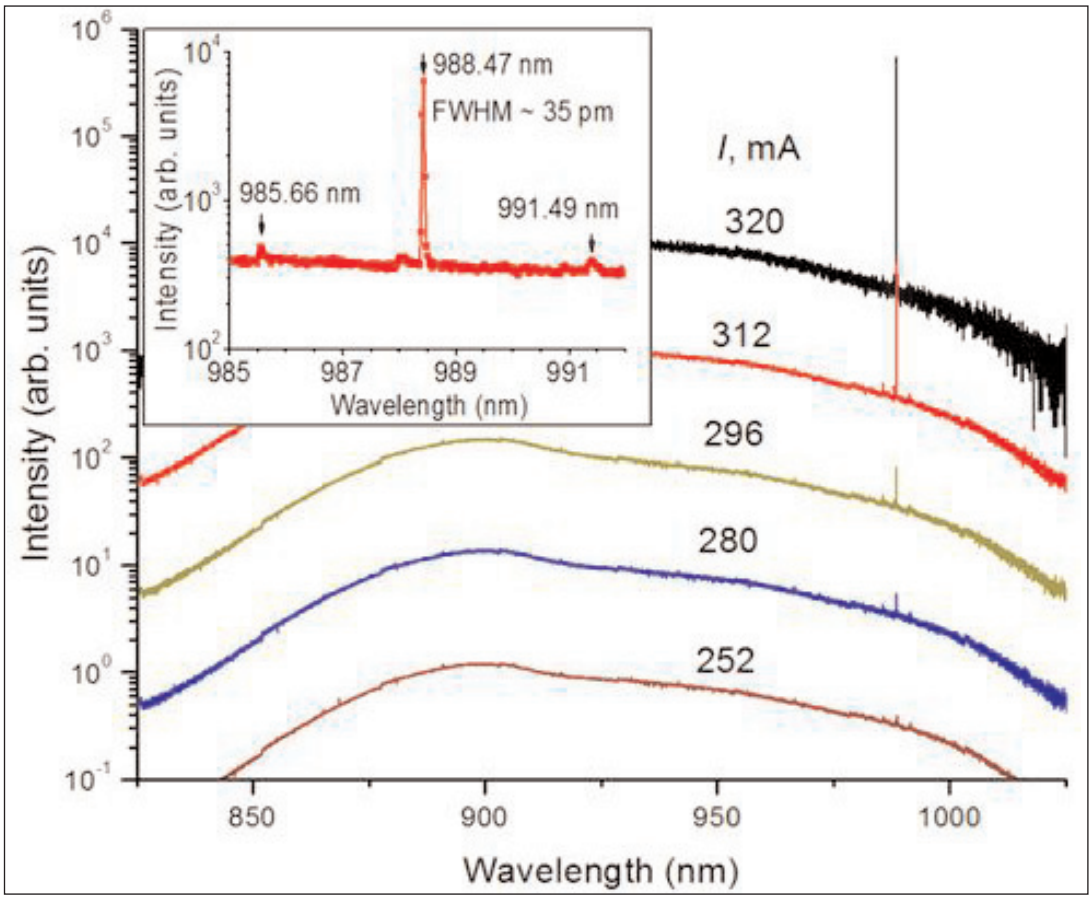


Figure 2. Electroluminescence spectra taken at different currents for 31μm-diameter microdisk laser. Spectra vertically shifted by 10dB for clarity. Inset: close-up spectrum near threshold (312mA).

Smaller 27μm- and 23μm-diameter microdisks had lasing thresholds at 160mA and 131mA, respectively. The 27μm device had the smallest threshold current density of 28kA/cm^2. This is five times higher than for edge-emitting lasers of similar III-V structures, according to the researchers. The team blames non-radiative recombination at the microdisk sidewalls, suggesting also that this factor is to blame for the lack of lasing in devices with 21μm-diameter disks and smaller. Passivation could help to reduce surface recombination. ■

https://doi.org/10.1364/OE.25.016754

Author: Mike Cooke

Indium gallium nitride light-emitting diodes on thin industry-spec silicon

Researchers find ways to tackle bowing and threading dislocation trade-offs.

Researchers in Singapore and USA have been developing ways to grow III-nitride structures on SEMI-spec 200mm-diameter silicon by metal-organic chemical vapor deposition (MOCVD) [Li Zhang et al. Semicond. Sci. Technol., vol32, p065001, 2017].

Ordinarily such structures are grown on relatively thick silicon wafers (1–1.5mm) to avoid breakage in wafer handling caused by hidden stress in indium aluminium gallium nitride (InAlGaN) layers from lattice mismatch and high-temperature growth and cooling processes. Unfortunately, 200mm silicon wafer manufacturing facilities are based on tools designed to meet specifications of the Semiconductor Equipment and Materials International (SEMI) industry organization, which specifies 725µm (0.725mm) thicknesses or thinner.

The Singapore-MIT Alliance for Research and Technology, the National University of Singapore, and the Massachusetts Institute of Technology (MIT) see the work as part of their efforts towards "integration of GaN and Si CMOS as the driver for GaN-on-Si materials and device development". GaN materials are being used and developed for both high-power, high-voltage and high-frequency electronics, along with the longer-term light-emitting (LED) and laser diode applications.

The team used MOCVD equipment with a specially shaped pocket susceptor. A flat susceptor suffers from uneven heating of the substrate. With concave bowing caused by stress, the contact is made in the center of the wafer, giving higher temperatures there. With convex bowing, the temperature is higher toward the edge. The researchers designed a concave pocket with 12 400µm-high protrusions placed radially at 30° separation so that the substrate was suspended above the susceptor, giving more even heating. Bowing of the wafer, if excessive, can cause plastic deformation of the substrate, increasing fragility.

The researchers explain: "By suspending the wafer with 12 protrusions, this design ensures that, during the entire growth run, the wafer is not in contact with the susceptor except at the protrusions. As a result, maintaining a uniform temperature across a SEMI-spec 200mm-diameter silicon wafer can be more easily achieved during the entire growth process."

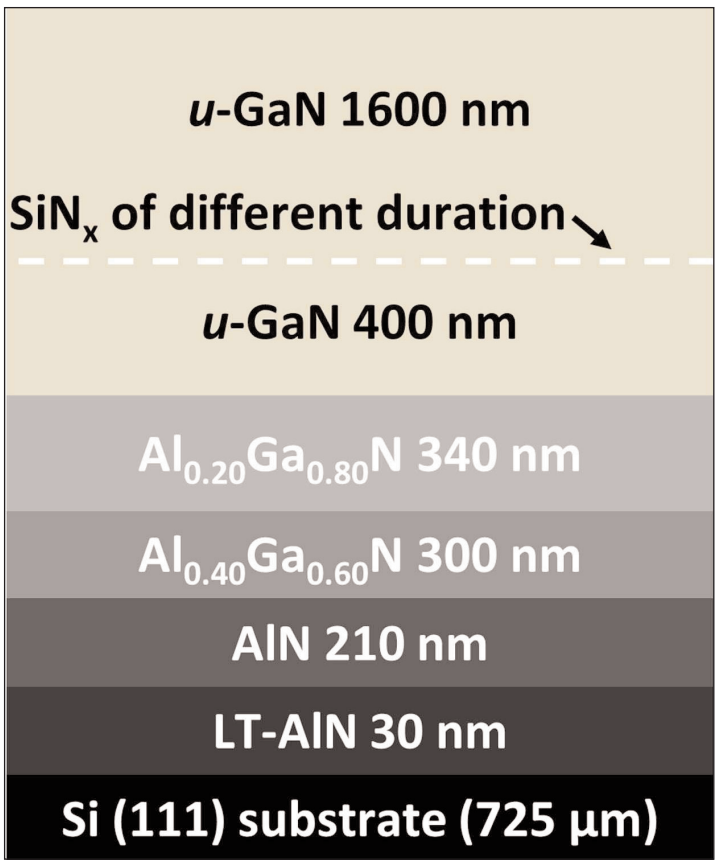


Figure 1. Schematic of optimized epitaxial structure of GaN-on-Si growth for LEDs.

After native oxide removal and pre-treatment of the 200mm-diameter SEMI-spec boron-doped silicon wafer, MOCVD began with 20nm low-temperature (980°C) AlN nucleation.

The temperature was then ramped for 240nm high-temperature AlN, followed by step-graded layers of AlGaN to bridge over to the final GaN layer (Figure 1). The AlGaN layers also introduce compressive strain that was designed to compensate for tensile strain that usually develops when GaN-on-silicon structures are cooled to room temperature.

The AlN initial part of the growth, from tensile strain due to lattice mismatch with silicon, gives a concave

wafer bow. The AlN to GaN step-grading converts this to convex bowing. The final cooling results in an approximately flat wafer due to differences in the coefficients of thermal expansion of the various layers.

LED material was grown on 0.4µm undoped GaN template on silicon with layer sequence: 2.4µm n-GaN, 3x 1.5nm InGaN/40nm GaN V-pit initiation, 10–15x 2.5nm InGaN/10nm GaN multiple quantum wells/barriers (MQWs), p-AlGaN electron blocking, and p-GaN and p^{++}-GaN for ohmic contact.

By suspending the wafer with 12 protrusions, this design ensures that, during the entire growth run, the wafer is not in contact with the susceptor except at the protrusions. As a result, maintaining a uniform temperature across a SEMI-spec 200mm-diameter silicon wafer can be more easily achieved during the entire growth process.

V-pits roughen the surface (Figure 2) and give three LED performance advantages. According to the researchers: "The thinner MQWs on the sidewall enhance the efficiency of LEDs in several ways: (i) form a potential barrier to non-radiative recombination; (ii) improve hole injection into the MQWs; (iii) reduce reverse leakage current in the LEDs."

Since the V-pits tend to nucleate on threading dislocations (TDs), the density of V-pits gives an indication of TD density (TDD). For the optimized 450nm-wavelength LED structures the V-pit density was $5.5x10^8/cm^2$. This compares with a minimum V-pit density of $2.7x10^8/cm^2$ for LEDs produced on thicker (1mm) non-SEMI silicon.

The LEDs on SEMI-spec silicon had an internal quantum efficiency of about 70%. For 300µmx300µm devices, the typical turn-on voltage was 2.5V. Reversed bias leakage was 0.2nA at –4V. Diode ideality was 2.3.

Before producing the LEDs, the researchers worked to optimize the growth processes, in particular step-graded AlGaN structure. A three-step AlGaN layer sequence — 280nm $Al_{0.8}Ga_{0.2}N$, 300nm $Al_{0.4}Ga_{0.6}N$, 310nm $Al_{0.2}Ga_{0.8}N$ — resulted in minimum concave bow of -4µm. However, the generation of edge-type threading dislocations (TDs), as indicated by x-ray analysis, increases with decreasing $Al_{0.2}Ga_{0.8}N$ layer thickness.

"Generally, edge-type dislocations are more detrimental to device performance and reliability, causing reliability issues in HEMTs [high-electron-mobility transistors] and increasing non-radiative recombination in the MQWs of LEDs," the team comments. Increasing the $Al_{0.2}Ga_{0.8}N$ layer to 395nm reduced the (102) x-ray peak to 670 arcsec, from 750 arcsec for the minimum bow 310nm layer. However, the wafer bow increased to +72µm convex.

Edge-type dislocations are more detrimental... causing reliability issues in HEMTs and increasing non-radiative recombination in the MQWs of LEDs

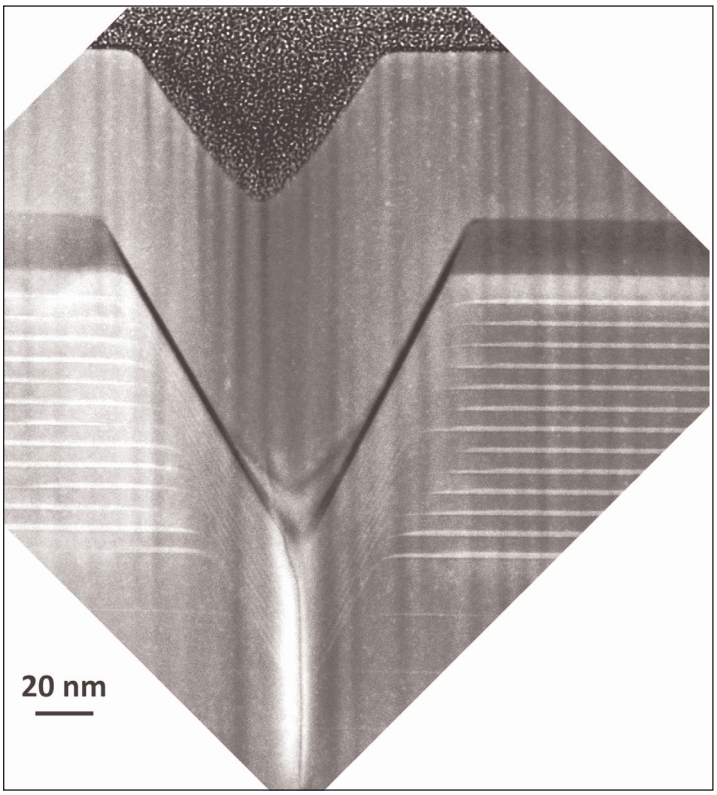


Figure 2. Cross-sectional scanning transmission electron micrograph of V-pit initiation layers and MQWs.

The researchers used a silicon nitride (SiN_x) masking layer in the middle of the u-GaN growth as a technique to balance low bowing with low TDDs. In particular applying silicon nitride on GaN can create a $SiGaN_3$ monolayer that acts as an anti-surfactant, inhibiting GaN growth. The team comments: "We use the anti-surfactant behavior of SiN_x masking to moderate the strain of the subsequently grown GaN layer from the masked GaN layer."

Further GaN growth is from uncovered regions, which reduces dislocation densities. The growth from the uncovered island regions coalesces to form laterally overgrown GaN material. The amount of coverage by $SiGaN_3$ was controlled by the duration of exposure to disilane (Si_2H_6) and ammonia (NH_3) precursors.

The researchers produced an optimized GaN template for LEDs with a 2-step AlGaN buffer combined with 150-second SiN_x masking that was used for the LED material. A 2-step buffer was found to increase the compensating compressive stress within a thinner layer to counteract bowing. ■

https://doi.org/10.1088/1361-6641/aa681c

Author: Mike Cooke

Finding the root of nanopipes in aluminium nitride on sapphire

Researchers reduce densities by treating precursor residues on reactor quartz-ware.

Researchers in the USA and Japan suggest that precursor residues on reactor quartz-ware are responsible for large variations in the quality of aluminium nitride (AlN) films grown on sapphire by metal-organic vapor phase epitaxy (MOVPE) [D. D. Koleske et al, Appl. Phys. Lett., vol110, p232102, 2017].

The team from Sandia National Laboratories and JR Creighton Consulting LLC in the USA and Taiyo Nippon Sanso Corp in Japan was particularly keen to reduce the formation of nanopipes or open-core screw dislocations. Such nanopipes form current leakage paths that can kill light-emission performance in gallium nitride and aluminium gallium nitride devices. Such devices often use material grown on AlN nucleation layers.

The AlN was grown through MOVPE on sapphire using trimethyl-aluminium (TMAl) and ammonia (NH_3) precursors in Taiyo Nippon Sanso high-temperature, high-pressure SR4000 system. The growth began with nitridation and 100nm AlN nucleation at 920°C, followed by 2.7μm AlN at 1320°C. The growth time was 50 minutes.

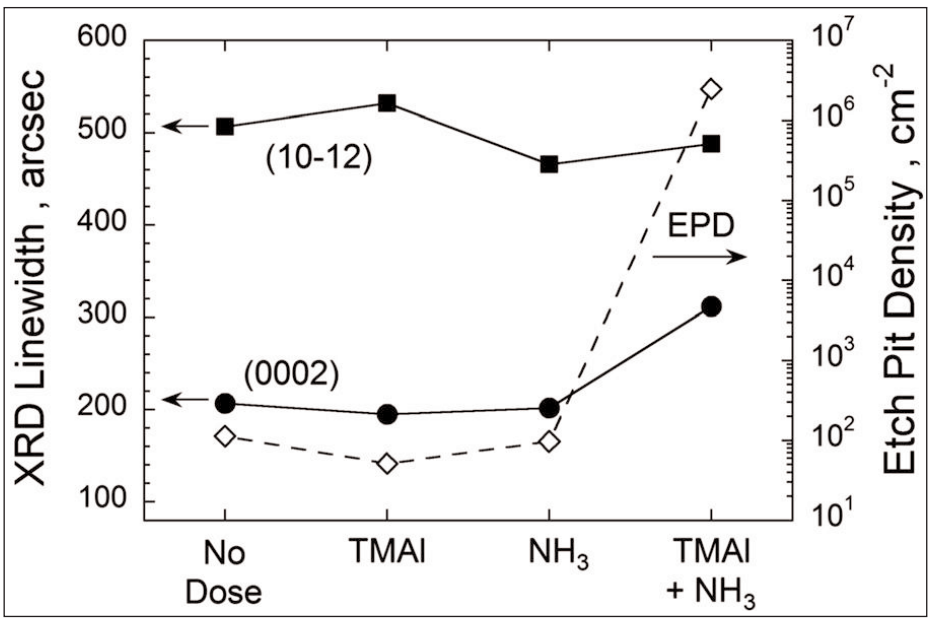


Figure 1. Plot of (0002) and (10$\bar{1}$2) XRD linewidths (solid circles and squares, left axis) and EPD (open diamonds, right axis) as function of four different bake conditions. Quartz-ware was dosed with H_2O for 30 minutes before baking to pre-condition quartz surfaces. After H_2O exposure, quartz-ware was baked in hydrogen (H_2) at 1300°C with 30-second dose of TMAl, NH_3, or TMAl + NH_3 midway during bake. For comparison, no-dosing condition is also shown.

The low-temperature AlN nucleation layer was N-polar, while that of the high-temperature AlN was Al-polar. The researchers comment: "While this polarity inversion is not entirely understood, N- to Al-polarity inversion has been reported after annealing to 1650–1700°C in N_2–CO gas mixtures. Also, recent work by Mohn et al has shown that thin oxynitride phases of $Al_xO_yN_z$ might provoke polarity inversion especially for AlN growth on oxide surfaces."

The researchers found that exposing the quartz-ware components of the reactor to room air or water (H_2O) vapor in a nitrogen-purged glovebox reduced etch pit densities (EPDs) to less than 100/cm^2. Further, the full-width at half-maximum (FWHM) of the (0002) x-ray diffraction (XRD) peak was 200 arc-seconds. These values suggest that the density of 'nanopipe' open-core screw dislocations was of the same order as for GaN growth. Without treating of the quartz-ware, the EPD increased to 1.6x10^7/cm^2 and the (0002) FWHM was 398arcsec. The (0002) reflection is affected by dislocations with a screw component.

The team comments: "Even small amounts of partly reacted TMAl and NH_3 coatings on reactor components can strongly impact the AlN nucleation during the subsequent growth run as shown in [Figure 1]. Our work suggests that these unreacted TMAl + NH_3 coatings, which should be present on the walls of other MOVPE systems, are significant factors in limiting reproducible growth of AlN on sapphire."

The removable quartz-ware components were upper and lower quartz channels, a silicon carbide (SiC) coated susceptor, and a SiC susceptor cover.

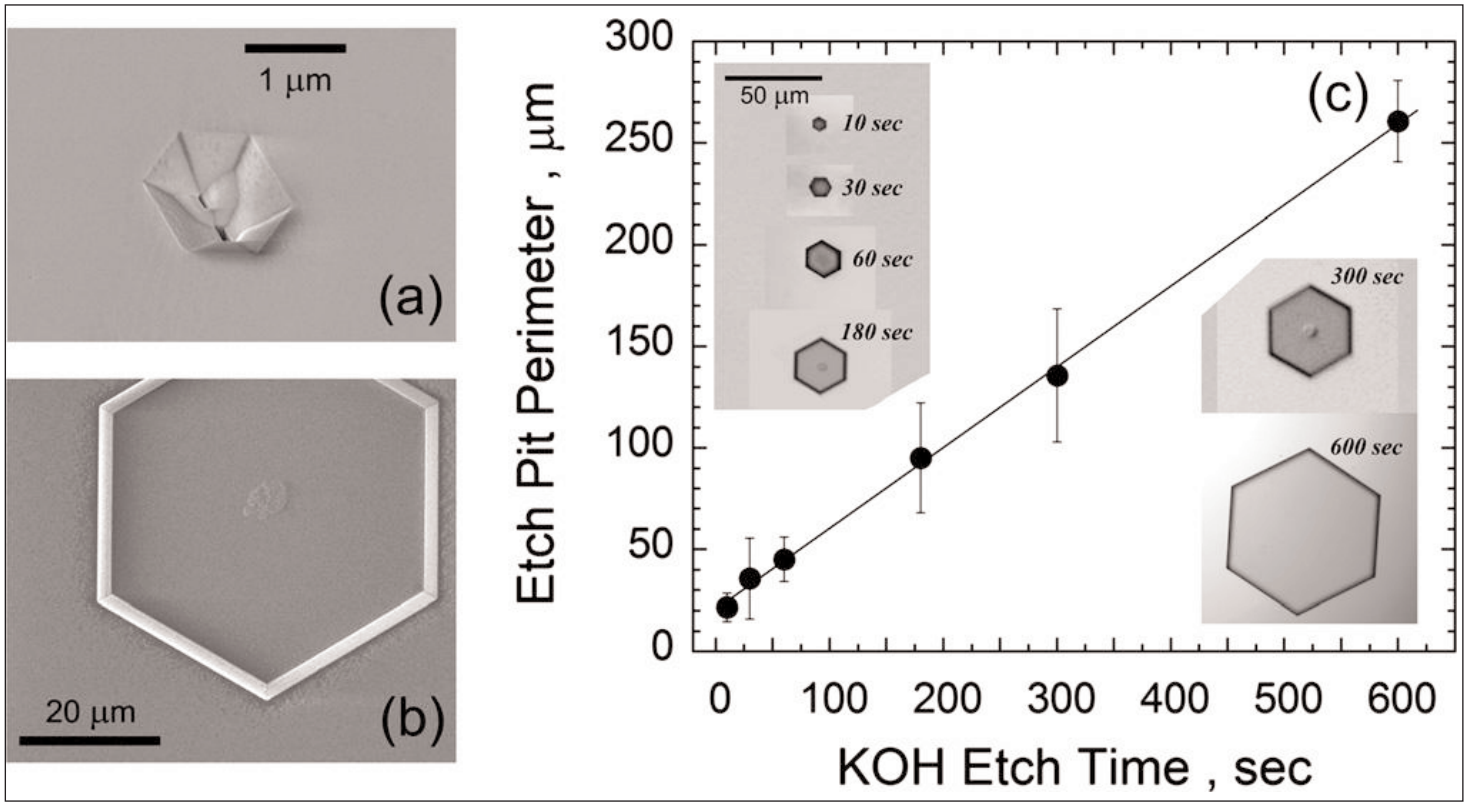


Figure 2. (a) SEM image of open core pit after AlN growth. (b) SEM image of KOH etched pit in AlN, showing hexagonal shape and possible unetched material in center. (c) Images of KOH etched pits for increasing etch times and plot of etch pit perimeter as function of KOH etch time.

The researchers did not remove a quartz gas injector or exhaust funnel, since these were fixed in the reactor.

Scanning electron microscope (SEM) analysis showed that at least some of the open-core dislocations reached down to the AlN/sapphire interface. Potassium hydroxide (KOH) etching at 70°C was used to decorate/expand the open cores to make them more visible to optical Nomarski microscopic analysis (Figure 2).

The researchers comment: "We speculate that H_2O reacts with TMAl and/or NH_3 chemical moieties adsorbed on the reactor surfaces, rendering them inert for the next growth run."

Deliberately dosing the quartz-ware with TMAl or NH_3 separately did not increase the (0002) peak or EPDs. However, a combined dose gave AlN layers with 300arcsec FWHM and $1x10^6/cm^2$ EPDs. "These results suggest that the combined reaction of TMAl and NH_3 results in a reactor coating that negatively impacts the subsequent AlN growth," the team writes. ■

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Author: Mike Cooke

Indium tin oxide metal-organic chemical vapor deposition for UV LEDs

Using MOCVD for the deposition of indium tin oxide transparent conductive electrodes increases 368nm-wavelength ultraviolet LED output power by 11.4% under 350mA current injection and 14.8% under 600mA current injection, it is found.

Sun Yat-Sen University in China has been developing a metal-organic chemical vapor deposition (MOCVD) indium tin oxide (ITO) process with a view to creating ultraviolet transparent conductive electrodes for aluminium gallium nitride (AlGaN) light-emitting diodes (LEDs) [Zimin Chen et al, Appl. Phys. Lett., vol110, p242101, 2017].

Although ITO is one among many possibilities for visible light transparent conductive layers, these materials, including ITO, tend to become less transparent at shorter ultraviolet wavelengths. The Sun Yat-Sen team has managed to widen the optical bandgap to 4.7eV through MOCVD growth. A photon of 4.7eV has an ultraviolet wavelength of 364nm.

Ultraviolet semiconductor devices are being developed with a view to water purification, biological detection, medical diagnostics, UV curing and other applications.

The Sun Yat-Sen researchers first used MOCVD to grow 90nm ITO layers on sapphire at ~500°C (Figure 1). The precursors were trimethyl indium (TMIn), tetrakis-dimethylamino tin (TDMASn), and oxygen carried in argon. The resulting material was textured with pyramid-like shape (100) and triangle or truncated-triangle plate-like shape (111) grains.

The increase of tin content to 350 standard cubic centimeters per minute of precursor resulted in the highest free electron density (2.15×10^{21}/cm^3) and an

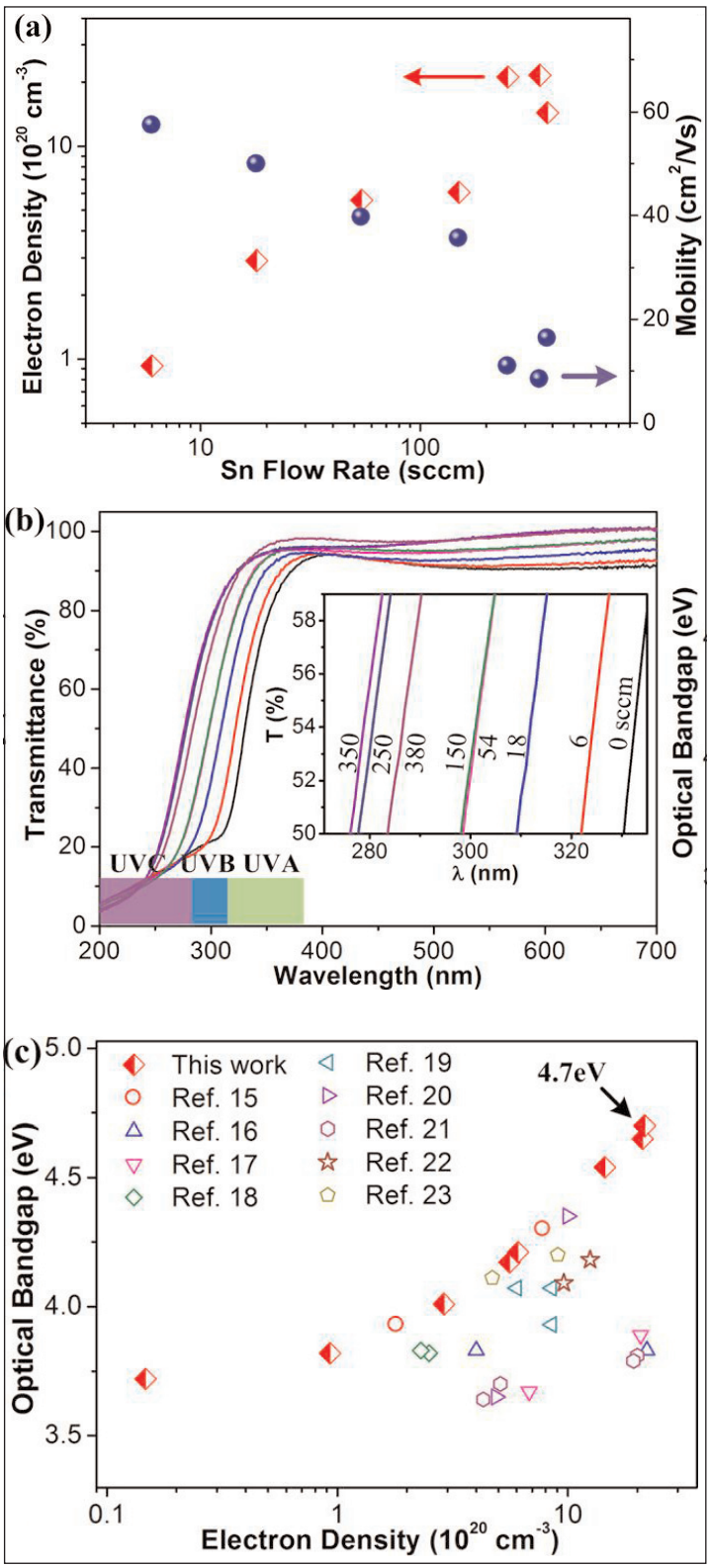

Figure 1. Electrical and optical properties of 90nm-thick MOCVD-ITOs. (a) Dependence of electron density and mobility on Sn flow rate. (b) UV–visible transmittance of MOCVD-ITO with different Sn flow rates. Inset: blue-shift of absorption edge. (c) Comparison of optical bandgap of ITO grown by different techniques.

Contact	p-GaN	100nm
Electron blocking	AlGaN	40nm
Multiple quantum well	9x(AlGaInN/AlGaN)	
Contact	n-AlGaN	2.5µm
Template	AlGaN	2µm
Substrate	c-plane sapphire	

Figure 2. Epitaxial structure of LED.

increase in the optical bandgap to 4.70eV. The free electron density in indium oxide (In_2O_3, zero TDMASn precursor) was $1.47x10^{19}/cm^3$, giving a bandgap of 3.72eV. The impact of free electrons on the bandgap was attributed to the Burstein–Moss effect, where electrons fill the lower conduction band states and hence increase the photon energy needed to excite electrons from the valence band. "The widening of bandgap as large as ΔE_g = 0.98eV is rarely reported to date," the team comments.

The team also believes MOCVD avoids lattice distortion by improving crystal quality. Lattice distortion can be a factor that narrows optical bandgaps in ITO.

UV LEDs were also produced using MOCVD (Figure 2). Magneto-sputtering ITO was compared with MOCVD-ITO for use as a 120nm-thick transparent conducting p-electrode. The target tin/indium oxide (SnO_2:In_2O_3) ratio was 1:9 by weight. The magneto-sputtered material was annealed at 550°C for 5 minutes in nitrogen. The ITO thickness was designed to improve current spreading. The 1143µmx1143µm LEDs were completed with chromium/palladium/gold contact pads.

The LED wavelength was 368nm. At this wavelength, the sputtered-ITO had 86% transmittance, while the MOCVD-ITO managed 95%. While the resistivity of the sputtered-ITO was less than that of the MOCVD-ITO, the sputtered contact resistance was greater.

The result of using MOCVD-ITO was an increase in output power of 11.4% at 350mA and 14.8% under 600mA injection (Figure 3). The 350mA operating voltage was 3.45V, averaged over 2000 devices. The voltage–current behavior of the two devices was basically the same over the operating range. ■

Although ITO is one among many possibilities for visible light transparent conductive layers, these materials, including ITO, tend to become less transparent at shorter ultraviolet wavelengths

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Author: Mike Cooke

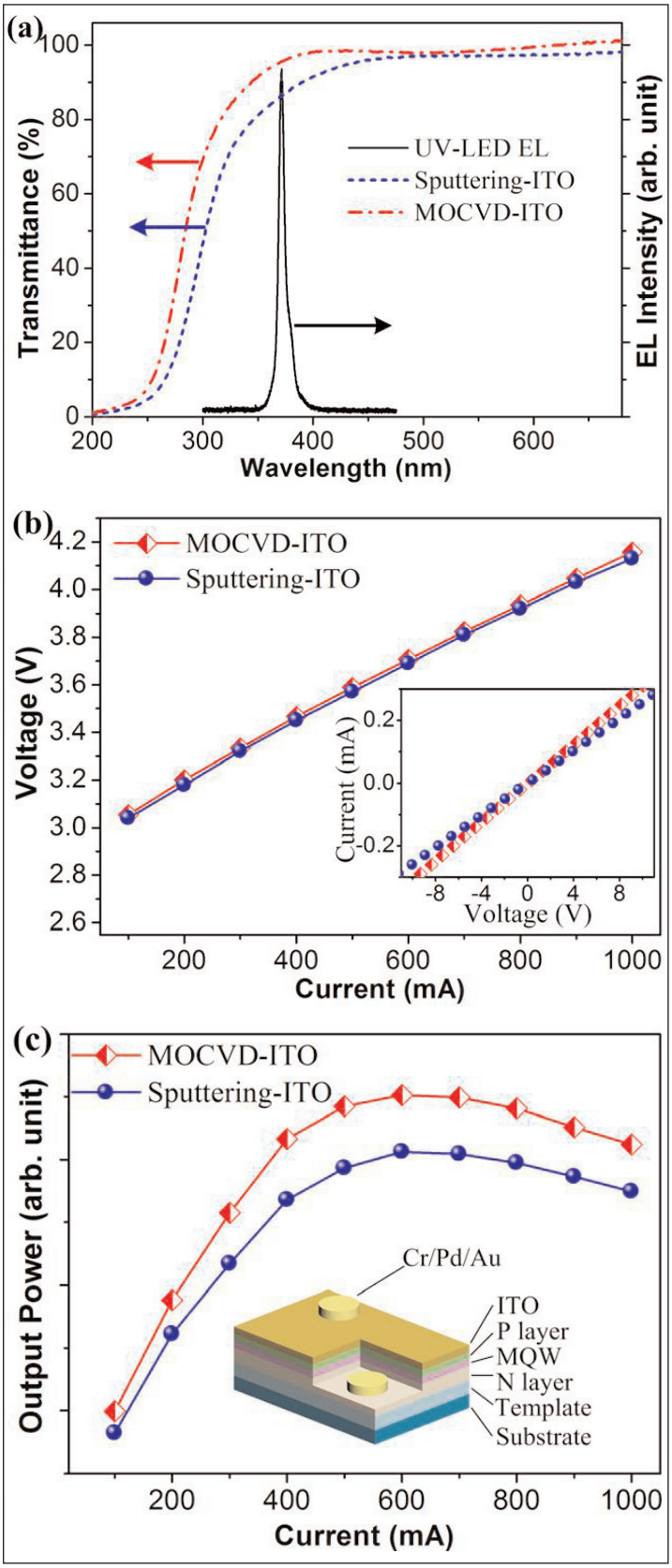

Figure 3. (a) Transmittance of 120nm-thick MOCVD-ITO and sputtering-ITO grown on sapphire. Electroluminescence spectrum of LEDs with MOCVD-ITO electrodes is also shown. (b) Voltage–current (V–I) characteristics of LEDs. Inset: I–V characteristics of ITO/LED contact. (c) Output power versus current characteristics. Inset: LED schematic.

Amber quantum wells on InGaN pseudo-substrate

Layer transfer techniques enable strong long-wavelength photoluminescence.

University Grenoble Alpes and Soitec S.A. in France have used layer transfer techniques to create indium gallium nitride on oxide/sapphire (InGaNOS) pseudo-substrates [A. Even et al, Appl. Phys. Lett., vol110, p262103, p2017]. The pseudo-substrates enabled the researchers to grow high-indium-content InGaN multiple quantum wells (MQWs) with strong long-wavelength photoluminescence in the amber part of the spectrum (594nm). Similar MQWs produced on conventional GaN/sapphire templates generally only produce weak photoluminescence. The hope is to apply such techniques in creating high-efficiency green and even amber light-emitting diodes (LEDs) from III-nitride semiconductor materials.

The researchers comment: "The reduced strain, due to a relaxed InGaN substrate, leads to a reduction in the compositional pulling effect and therefore to an enhancement in the indium incorporation rate. Also, as the a-lattice mismatch between the well and the buffer layer is decreased, the internal electric field should be reduced for the same emission wavelength compared to a conventional LED. This gives the possibility of increasing the well width in order to reduce the efficiency droop of LEDs with a long emission wavelength."

The donor material consisted of metal-organic vapor phase epitaxy (MOVPE) InGaN grown on a GaN/sapphire template. Three InGaN compositions were produced with varying a-lattice parameters: 3.190Å, 3.200Å, and 3.205Å, as determined by x-ray diffraction (Figure 1). The indium content for the largest lattice parameter is estimated at around 8%. Sample A's lattice parameter was comparable to that of free-standing GaN. The researchers comment: "As it is difficult to incorporate a large amount of indium into a thick continuous layer on a GaN template, the maximum InGaNOS average In content is limited to 8%."

The InGaN layer was transferred to sapphire using SOITEC's Smart Cut technology. Hydrogen ion implantation creates a weakened region inside the donor material. The donor wafer was then bonded to sapphire using silicon dioxide layers on the donor and target substrates. Heat treatment then splits away the donor GaN/sapphire template at the hydrogen implantation region.

The process resulted in an InGaN layer on buried oxide and sapphire handle, giving an InGaNOS pseudo-substrate. The InGaN layer was patterned and etched into 800μmx800μm or 500μmx500μm square mesas, and then subjected to successive thermal treatments in an effort to relax the strained InGaN crystal structure. "The challenge of this process is to get a uniform relaxed InGaN layer while keeping a flat surface," the team reports.

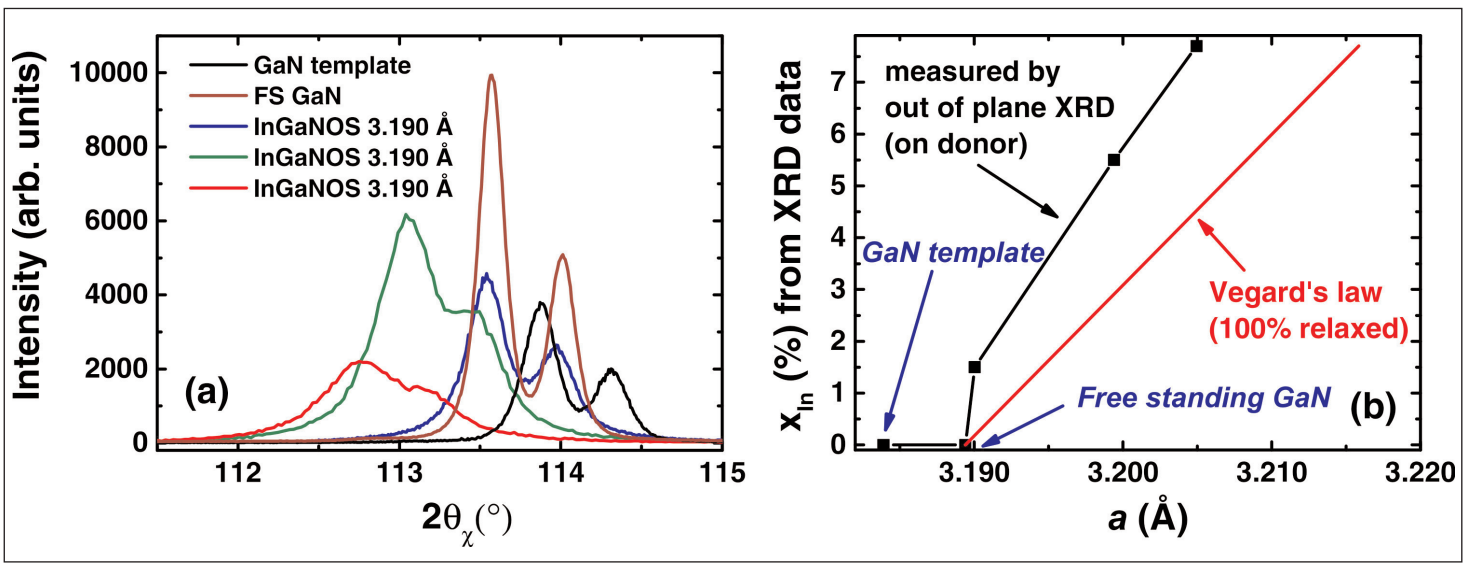

Figure 1. (a) In-plane XRD spectra [2θχ–ϕ scan on the (300) reflection] of three InGaNOS substrates [3.190Å (blue curve), 3.200Å (green curve), and 3.205Å (red curve)] and with GaN references [GaN free-standing substrate (brown curve) and GaN template on sapphire (black curve)]. (b) Indium content measured by out-of-plane XRD as a function of the a-lattice parameter inferred from (a) spectra (black curve) and corresponding Vegard's law (red curve).

Multiple quantum wells (MQWs) were grown by MOVPE on a further 150nm metal-polarity InGaN buffer: 5x 3nm InGaN wells separated by 8nm InGaN barriers. Photoluminescence measurements suggested indium contents in the buffer layers of between 6% and 7%, depending on the indium content of the InGaNOS pseudo-substrate. Using the same buffer growth conditions resulted in 4%-indium-content InGaN on GaN templates. The barriers were designed to have the same composition as the buffer.

A further aspect of buffer growth on InGaNOS pseudo-substrate was narrowing of x-ray diffraction rock-curve peaks (395 arcsec) compared with material grown on GaN templates (414 arcsec). The researchers suggest that this is associated with a reduction in the density of V-pits that tend to form at high indium concentrations.

The quantum wells were produced with varying growth conditions designed to achieve different emission wavelengths. 'Sample A' had standard blue-emitting wells grown at 750°C with 0.1μm/hour growth rate. 'Sample B' was grown at 20°C lower temperature, increasing indium incorporation. For 'Sample C', the growth rate was increased by a factor of three in addition to lower temperature.

Photoluminescence from the three types of MQW structure (A–C) on the three types of InGaNOS pseudo-substrate showed red-shifts compared with MQWs on GaN templates (Figure 2). Sample A gave blue to green emissions, sample B green, and sample C green to amber.

The sample C series does not include MQWs grown on GaN templates since such growth conditions do result in significant photoluminescence.

The Sample C MQW spectra seem to contain separate green and amber components. With the 3.190Å InGaNOS pseudo-substrate, the green component dominates, while for the other pseudo-substrates the amber light becomes more prominent.

The researchers suggest that the high-indium-content InGaN in the wells may suffer phase separation, with regions of high and low concentration giving, respectively, amber and green emission. The largest-lattice-parameter InGaNOS pseudo-substrate gave roughly twice the photoluminescence intensity of the middle parameter sample at 594nm wavelength.

The photoluminescence spectra of all the samples were relatively broad. The researchers suggest this is due to thickness fluctuations of the wells, as seen in high-resolution transmission electron microscopy.

Internal quantum efficiency (IQE) was estimated, based on measurements at 10K and 300K. The researchers report that B samples on 3.200Å InGaNOS without optimization had 31% IQE at 536nm and 10% at 566nm. ■

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Author: Mike Cooke

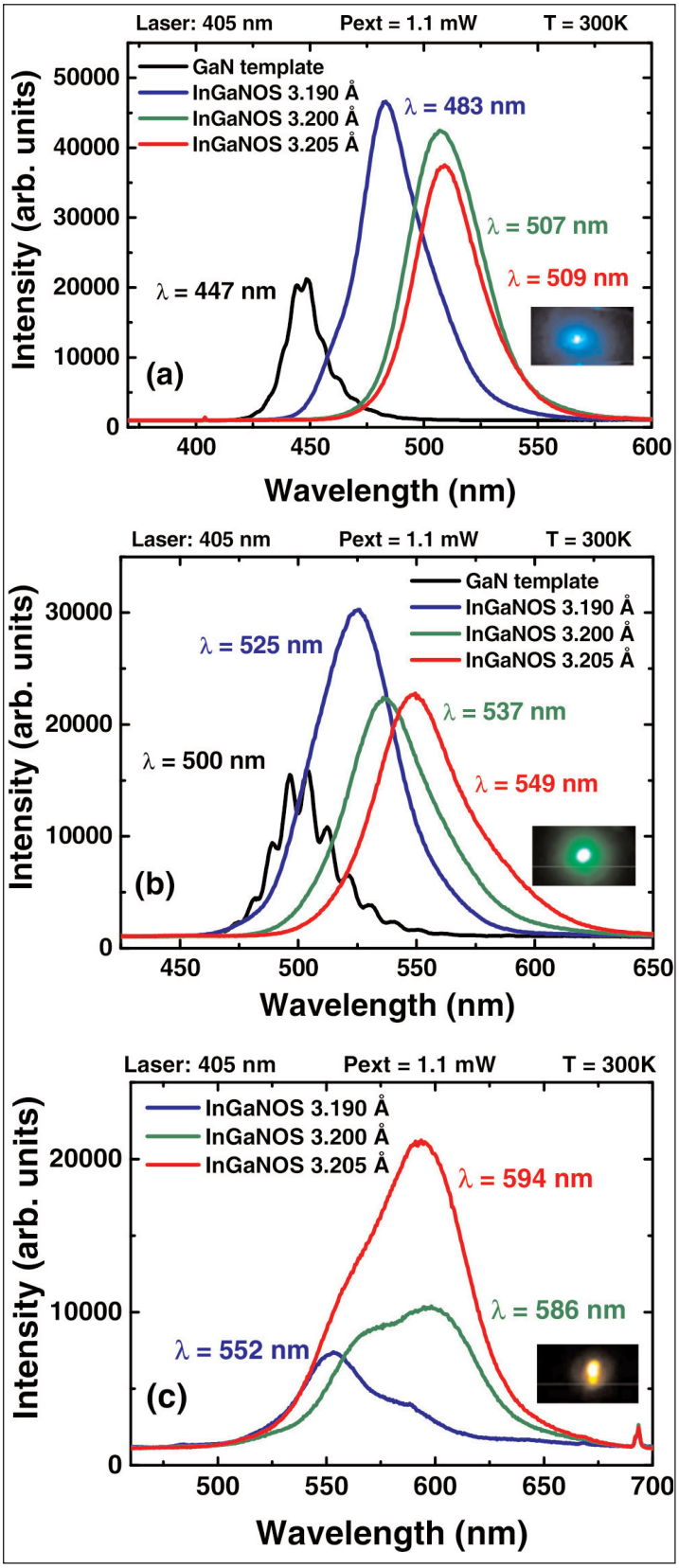


Figure 2. PL spectra at 300K of full InGaN heterostructures on InGaNOS (a) samples A, (b) samples B, and (c) samples C (blue curve is related to InGaNOS 3.190Å, green curve to 3.200Å, red curve to 3.205Å, and black curve to reference sample). Insets: pictures of emission under laser excitation from InGaNOS samples of (a) 3.190Å blue luminescence, (b) 3.200Å green luminescence, (c) 3.205Å amber luminescence.

Pushing forward with compound semiconductor technologies

Mike Cooke reports on research presented at the Symposium on VLSI Technology.

The development of III–V devices is progressing rapidly, with many new achievements and records reported by research groups at the 2017 Symposium on VLSI Technology and Circuits in Kyoto, Japan (5–9 June). Most of the reported work involved indium gallium arsenide (InGaAs), particularly integrated with silicon (Si) substrates aiming for low-cost mass production. We report here on those sessions, along with research aimed at gallium nitride (GaN) devices for high-power switching applications.

Transistor/laser integration on silicon

The National University of Singapore (NUS), Nanyang Technological University (NTU) in Singapore and Massachusetts Institute of Technology (MIT) in the USA claim the first monolithic integration of InGaAs field-effect transistors (FETs) and gallium arsenide/aluminium gallium arsenide (GaAs/AlGaAs) quantum well (QW) laser diodes (LDs) on silicon substrate through direct epitaxial growth [Session T5-2].

The researchers targeted a low sub-400ºC thermal budget process and see the achievement as a milestone towards enabling low-power and high-speed complex optoelectronic integrated circuits. On-chip and inter-chip optical communications would enable low-power and high-bandwidth computer and data transmission systems.

Molecular beam epitaxy (MBE) was used to grow III–V material on a 6º-offcut Ge-on-Si (100) substrate (Figure 1).

Laser structures contained graded-index separate-confinement heterostructure AlGaAs, with the aluminium content varying between 30% and 60%. The graded material bridged between 1mm $Al_{0.6}Ga_{0.4}As$ cladding and $Al_{0.3}Ga_{0.7}As$ barriers in which a single GaAs quantum well formed the active light emitter for the laser.

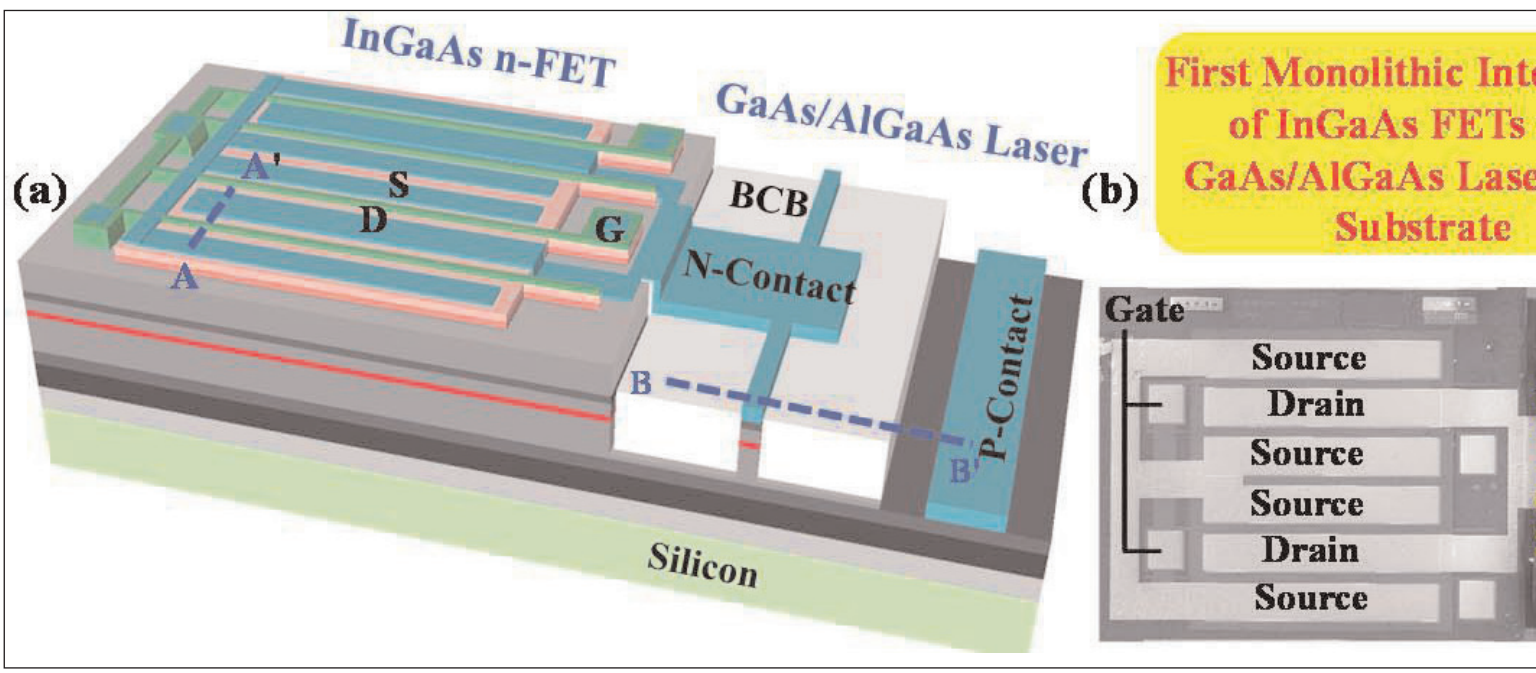


Figure 1. (a) Three-dimensional schematic of monolithic integration of InGaAs n-FETs with lasers on silicon substra finger InGaAs FETs driving laser. (c) Cross-sectional schematic along A–A' in (a). (d) Cross-sectional schematic alo

Transistor layers were grown on top of the laser structure: 800nm InAlAs graded buffer (indium content 10–52%), 15nm $In_{0.53}Ga_{0.47}As$ channel, 1nm $In_{0.52}Al_{0.48}As$ etch stop, and 25nm n^+-$In_{0.53}Ga_{0.47}As$ cap.

FET fabrication began with the blanket metal deposition of tungsten (W) and molybdenum (Mo). Fluorine-based reactive ion etch removed metal from the channel region. Wet etch removed III–V material down to the InAlAs etch-stop layer. The gate insulator consisted of atomic layer deposition (ALD) 2nm/5nm aluminium oxide/hafnium dioxide (Al_2O_3/HfO_2). The gate metals were then deposited and etched. The devices were completed with wet etch to give mesa device isolation.

Plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide (SiO_2) was used as a mask for etching the laser region. Wet etch was used to form the waveguide, and then dry etch formed the vertical/smooth laser facets. Surfaces were passivated with benzocyclobutene (BCB) before deposition of the metal contacts and interconnects.

A 500nm-channel-length n-FET achieved an on/off current ratio of 10^6 and subthreshold swing of 83mV/decade. The current was 400μA/μm with 1.5V drain bias and 1.5V overdrive (gate potential above threshold). The source-drain resistance is described as being large (~1.8kΩ-μm).

The subthreshold swing (SS) reduced to 75mV/decade after laser diode fabrication. The researchers explain: "This indicates excellent electrostatic gate control and gate stack quality of the InGaAs n-FETs. Improvement in subthreshold swing after laser diode fabrication is attributed to the reduction of interface traps at Al_2O_3/InGaAs interface during SiO_2 deposition at 350ºC using PECVD."

Laser diode fabrication also reduced the spread in threshold voltage. The team comments: "This positive shift in V_T can be explained by reduction of fixed positive charges in high-k layer during SiO_2 deposition at 350ºC."

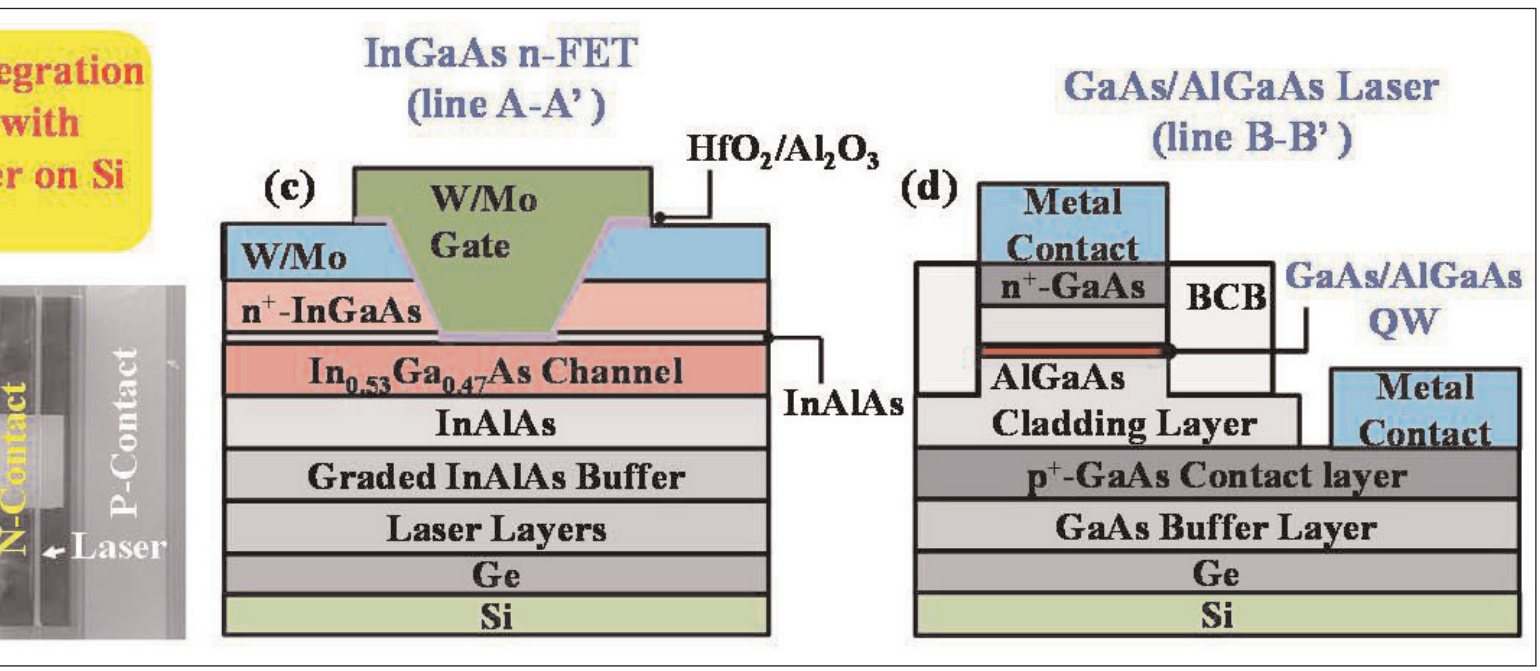
The peak effective mobility was 1920cm^2/V-s.

The laser diode had an on/off current ratio of 10^3. Threshold at 5ºC came at ~5kA/cm^2 pulsed current density with ~790nm wavelength. Above threshold, the linewidth reduced to less than 0.5nm The output power dropped with increasing temperature. The researchers also showed successful modulation of laser diode voltage and injection current by varying the FET's gate voltage.

InGaAs FETs

Lund University in Sweden reports the achievement of record on-current and optimal transconductance and subthreshold swing for vertical metal-oxide-semiconductor FETs (MOSFETs) [Session T3-2]. The researchers point out that vertical MOSFETs could give advantages over the traditional planar devices at the 5nm node. The vertical format decouples device area from gate length scaling. Off current is reduced by restricting substrate leakage.

The n^+-InAs source contact layer of the FETs was grown on silicon by metal-organic vapor phase epitaxy (MOVPE). The nanowires were defined by gold particles that formed the seed of vapor-liquid-solid growth. The core diameter corresponded to that of the gold seed. The nanowire was covered by a ~5nm shell of InGaAs.



te. (b) Top-view scanning electron microscope (SEM) image of optoelectronic integrated circuit with multiple-ng B–B' in (a).

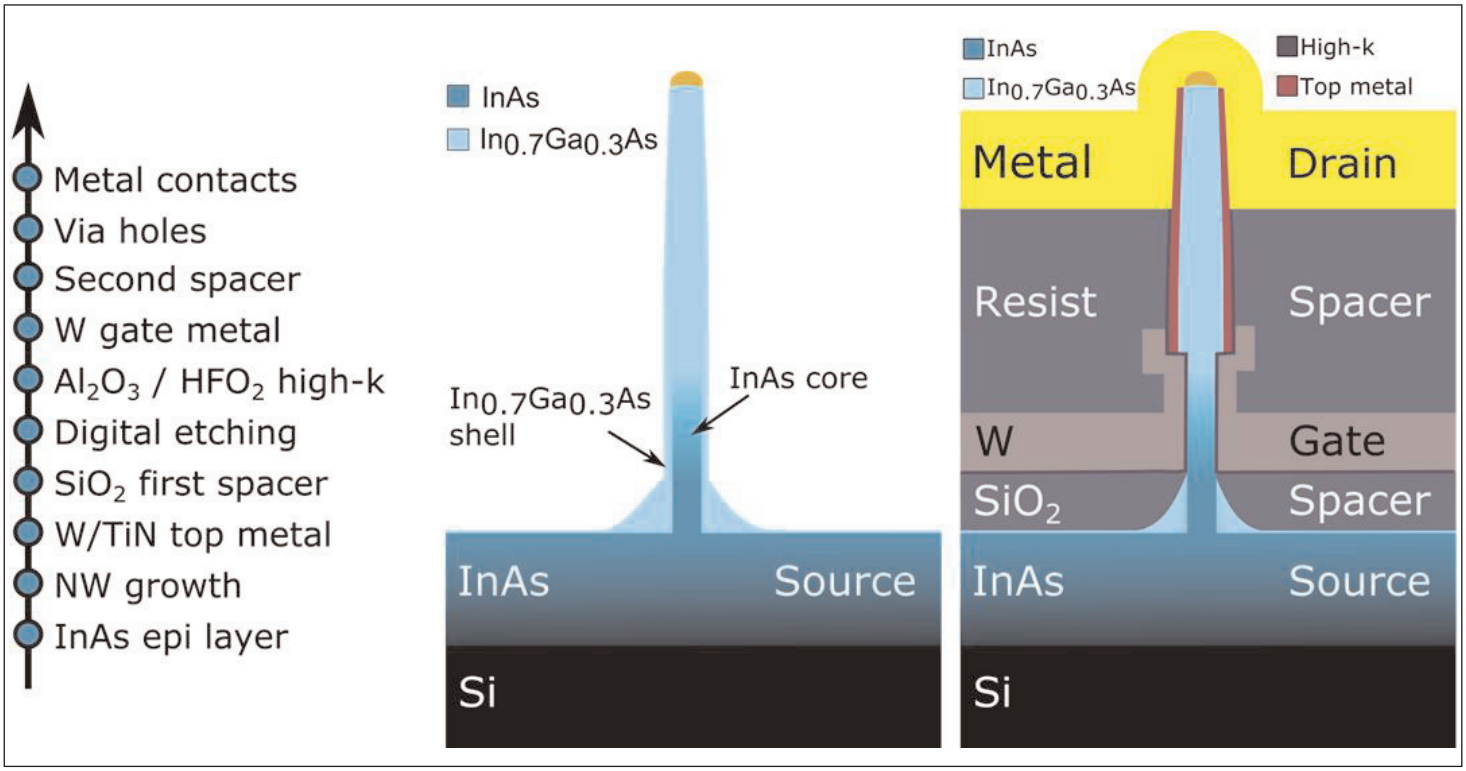


Figure 2. Illustrations of process flow (a), cross-section schematic of device after growth (b), cross-sectional schematic of finalized device (c) and SEM of the completed device.

The transistors were fabricated with a self-aligned gate-last process with the aim of reduced access resistance (Figure 2). Tungsten and titanium nitride (W/TiN) were used for the top metal. Digital etching of the channel region was achieved using ozone oxidation and hydrochloric acid wet steps to remove the shell layers. The Al_2O_3/HfO_2 gate insulator had an equivalent oxide thickness (EOT) of 1.5nm.

A device with 260nm channel length (160nm effective with contact overlap) and 28nm diameter had a peak transconductance (g_m) of 1.4mS/μm and SS of 85mV/decade with 330μA/μm on-current and 100nA/μm off-current at 0.5V drain. The researchers claim records for the on-current and Q-factor (g_m/SS) of 16 (1400/85). A lower off-current of 1nA/μm corresponded with a somewhat lower on-current of 46μA\μm at 0.5V drain.

"This is the first demonstration of a non-planar, III–V MOSFET on Si achieving I_{off} = 1nA/μm," the team adds.

A lower SS of 68mV/decade was achieved with an effective channel length of 145nm and 35nm diameter. The g_m was 0.58mS/μm. On-currents of 170μA/μm and 88μA/μm corresponded to 100nA/μm and 1nA/μm, respectively.

"Our devices show clear improvement compared to vertical MOSFETs, although state-of-the-art planar/lateral MOSFETs still have higher I_{on}," the researchers

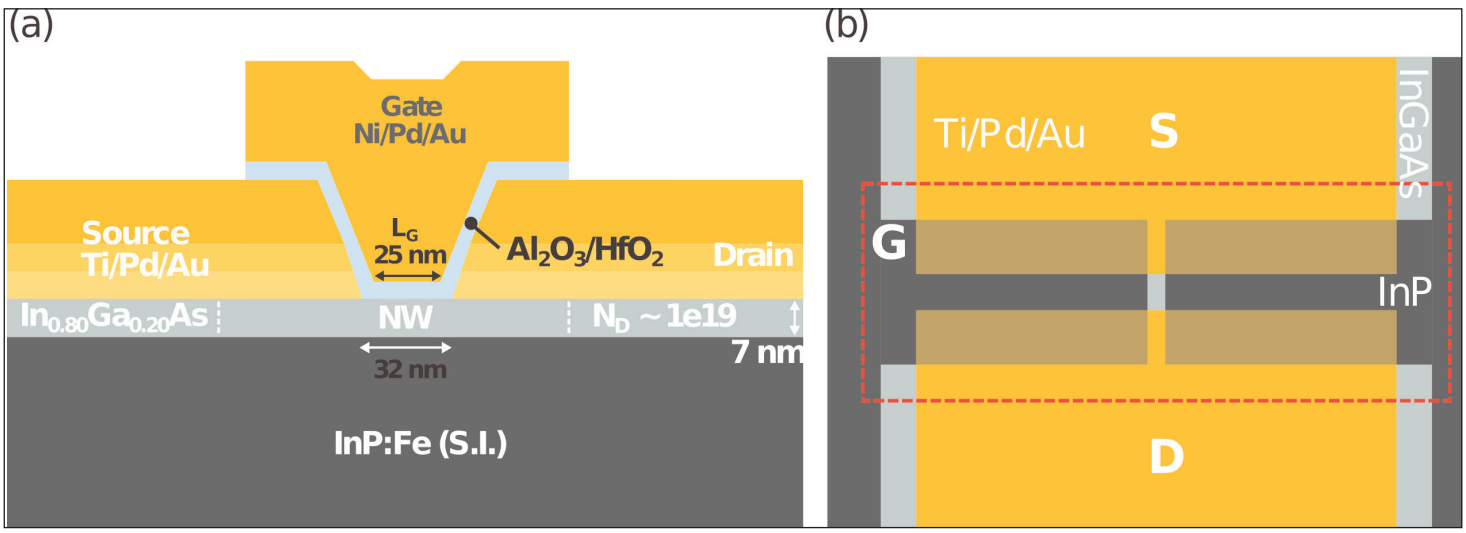


Figure 3. Schematic figures of single-layer junctionless device in (a) side and (b) top views.

report. The barrier to higher on-current seems to be high contact resistance in the vertical devices.

Another group from Sweden's Lund University claims record performance for junctionless field-effect transistors (JLFETs) based on InGaAs nanowires (NWs) [Session T3-1]. Junctionless transistors have uniform high doping in the channel region without oppositely doped source/drain regions, avoiding re-growth or implantation processes.

Nanowires were grown by metal-organic chemical vapor deposition (MOCVD) on semi-insulating iron-doped indium phosphide (Figure 3). A hydrogen silsesquioxane (HSQ) mask was used for selective area growth of the 14nm-high n-$In_{0.2}Ga_{0.8}As$ nanowires.

Etching was carried out to create 700nm-wide device mesas. The InGaAs height was reduced to 7nm by a digital etch. The etch also reduced the NW width by 14nm. Source/drain electrodes were deposited, followed by 1nm/4nm Al_2O_3/HfO_2 gate oxide. The effective gate length was 25nm.

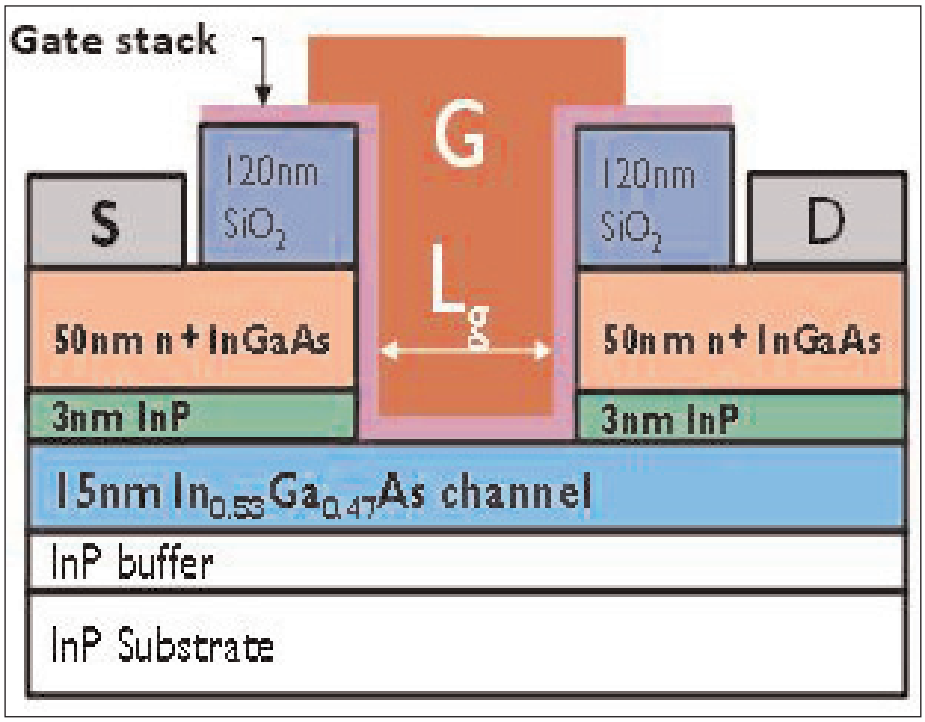


Figure 4. Implant-free InGaAs n-MOSFET.

Devices with 16nm NW width had low subthreshold swing of 76mV/decade and drain-induced barrier lowering (DIBL) of 33mV/V. A drain current of 160μA/μm (220μA/μm normalized according to chip surface width) is claimed as a record for JLFETs. The drain bias was 0.5V and the off-current was 100nA/μm. With a lower off-current of 10nA/μm, the on-current was 80μA/μm, also claimed as a record for JLFETs. The SS increased with NW width to 120mV/decade for 60nm.

The researchers also claim the peak transconductance of 1.6mS/μm at 0.5V drain as a JLFET record. The team reports that performance is presently limited by access resistance from the thin contacts, rather than degradation of electron mobility in the doped channel.

IMEC in Belgium claims the first demonstration of implant-free $In_{0.53}Ga_{0.47}As$ n-MOSFETs meeting reliability targets for advanced technology nodes of maximum overdrive voltage (gate-threshold) of 0.6V with equivalent oxide thickness (EOT) of 1.15nm [Session T3-3]. Key to the development was a new gate insulation structure with an unspecified interlayer (IL), lanthanum silicon oxide ($LaSiO_x$) and HfO_2. One suspects that the interlayer is being kept secret so that collaborators from the Belgium and USA sections of toolmaker ASM can help their company gain competitive advantage.

The researchers also claim record mobility of 3531cm^2/V-s and low SS (71mV/decade) at 1.15nm EOT.

The MOSFET III–V layers were grown on 2-inch semi-insulating InP (Figure 4). The gate-insulation structure of 1nm/1nm/3nm interlayer/$LaSiO_x/HfO_2$ was compared with various alternatives — IL/Al_2O_3/HfO_2 (1nm/1nm/3nm), $LaSiO_x/HfO_2$ (1nm/3nm), and IL/HfO_2 (1nm/3nm). The gate metal was titanium nitride (TiN). The gate insulator was applied using atomic layer deposition.

Capacitance–voltage measurements showed reduced interface trap density and capacitive equivalent thickness (CET) of the IL/$LaSiO_x/HfO_2$ gate stack. The CET was 1.55nm and equivalent oxide thickness was 1.15nm. Oxide charge traps were reduced to ~$10^{10}/cm^2$ for 3.5MV/cm field — "meeting the target for 10 years operation", according to the IMEC team.

Time-of-flight secondary-ion mass spectrometry suggested that the $LaSiO_x$ stabilizes the underlying interlayer, limiting diffusion down into the substrate.

Reducing the HfO_2 layer of the new gate stack to 2nm gave a CET of 1.46nm and an EOT of 1.06nm. This allowed the reduction of subthreshold swing to 68mV/decade.

The team comments: "As the processing of this gate stack is ALD based, it shows high potential for transfer to advanced device architectures such as horizontal and vertical nanowires."

Three-dimensional monolithic (3DM) integration of InGaAs n-FETs on fully depleted silicon-on-insulator (FDSOI) complementary MOS (CMOS) has been achieved by IBM Research GmbH Zürich Laboratory in Switzerland and CEA-Leti, MINATEC Campus, in France [Session T6-4]. A benefit of the 3DM approach is it allows specific processes with different thermal budgets to be carried out.

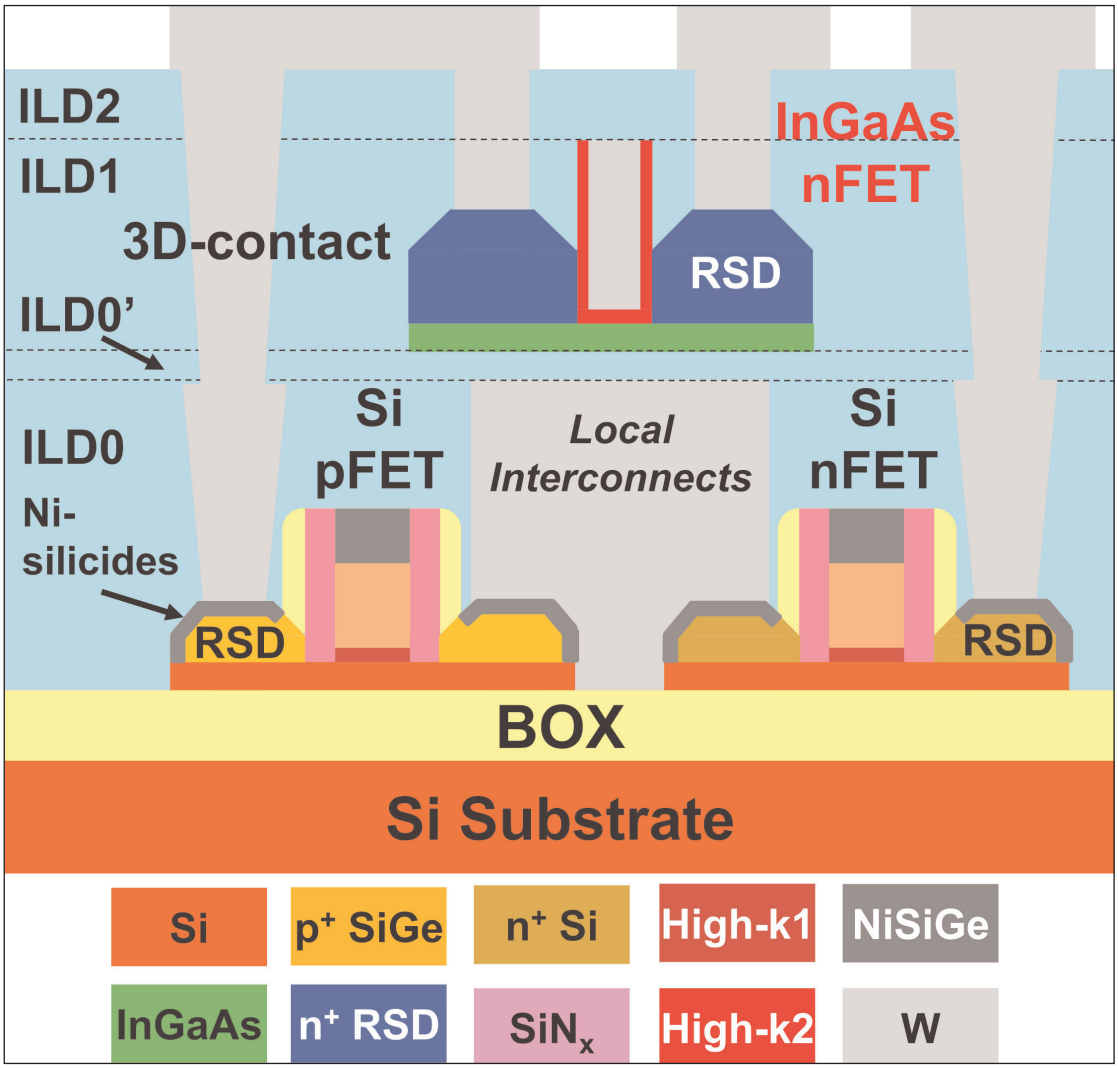


Figure 5. Schematic showing 3D monolithic stack of RMG InGaAs n-FET layer on FDSOI silicon CMOS layer.

The structure (Figure 5) combined a replacement metal gate (RMG) InGaAs n-FET and fully depleted SOI CMOS. The ~20nm InGaAs material was transferred to the SOI CMOS structure by direct wafer bonding on a thin interlayer dielectric (ILD0') before fabrication of the InGaAs n-FET. InGaAs n-FET devices managed ~70mV/decade SS down to 25nm gate length.

The researchers used the technology to fabricate 6-transistor SRAM circuits with 60nm-gate InGaAs n-FETs and 30nm-gate Si p-finFETs. "This is the first demonstration of a hybrid 3D 6T-SRAM utilizing 3DM integration of InGaAs nFETs over Si CMOS," the researchers claim. The team also says that its technology offers denser packing compared with 2D layouts. Apart from dense digital circuits, the researchers believe that functional integration of RF-on-Si could be forthcoming.

IBM T. J. Watson Research Center in the USA and Samsung and its Texas-based Advanced Logic Lab have used aspect ratio trapping (ART) to reduce defects in InGaAs buffers grown on silicon [Session T3-4]. An optimized ART process reduced junction leakage by six orders of magnitude. The fabrication of FinFETs used a gate-first process.

The device structure avoided parasitic bipolar effects (PBEs) that have been seen in III–V on insulator transistors. PBEs amplify leakage current due to the accumulation of holes injected by band-to-band tunneling at the drain end of the n-FET through a bipolar junction transistor action. Also, the researchers successfully thinned the fins to 9nm, improving short-channel control.

Using a drain bias of 0.5V and fixed off-current of 100nA/μm, the researchers claim a record high on-current for III–V-FETs on-Si of 250μA/μm with 32nm gate length. With 20nm gates, the on-current was still respectable at ~200μA/μm.

Gallium nitride

Taiwan's National Chiao Tung University, Japan's Tokyo Institute of Technology and the USA's University of California Berkeley (UCB) have developed a gallium nitride (GaN) metal-insulator-semiconductor high-electron-mobility transistor (MIS-HEMT) with high threshold voltage for enhancement-mode operation [Session T5-4]. This was enabled by using a ferroelectric material in the gate stack. The team comments that this could be a promising candidate for next-generation GaN HEMT power devices after device and process optimization for long-term reliability.

High-power switching device applications need normally-off enhancement-mode operation transistors for fail-safe performance. An added benefit is lower power consumption. Unfortunately, without special processing, GaN devices tend to be normally-on (at 0V gate), i.e. 'depletion-mode', as it is termed. GaN is of interest for power applications due to its high critical field for breakdown, enabled by its wide bandgap. Further, the electron saturation velocity is high, allowing faster switching.

AlGaN/GaN was grown on silicon by MOCVD. ALD was used to grow ferroelectric hafnium zirconium dioxide

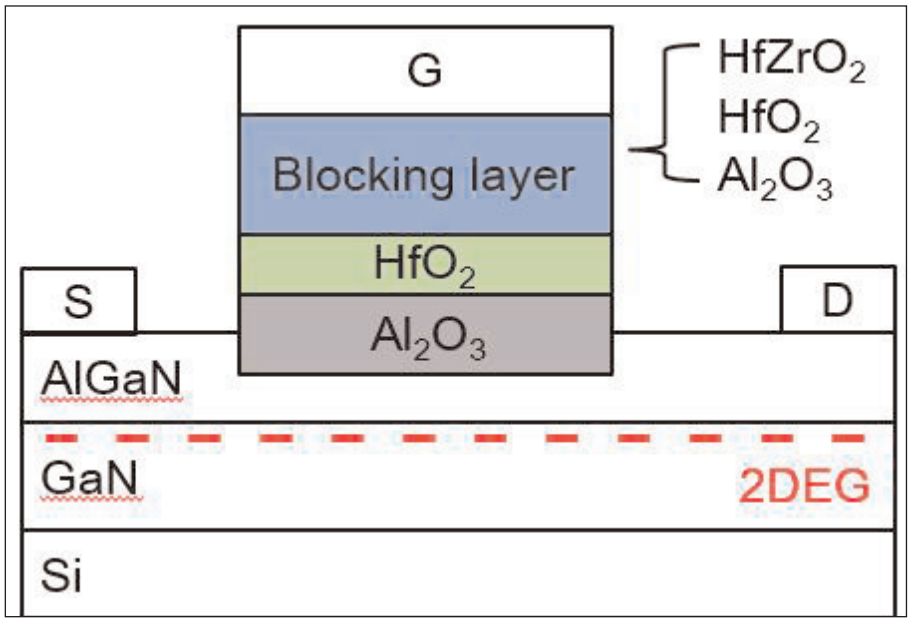


Figure 6. Schematic cross section of GaN MIS-HEMT.

($HfZrO_2$) blocking and ZrO_2 charge trap layers (Figure 6). The gate length was 2μm. The source–gate and drain–gate distances were 3μm and 15μm, respectively.

The threshold voltage was increased by applying 16V to the gate as an initialization step, causing polarization of the ferroelectric layer and charge trapping in the ZrO_2. The initialization step was less than 1ms.

This enabled a threshold voltage of +6V with a maximum drain current of 720mA/mm. The transconductance and on/off current ratio were 142mS/mm and $3x10^9$, respectively. Breakdown was at 1138V at 10μA/mm leakage. The threshold voltage shifted ~500mV at 0V drain bias after 10,000 seconds. The shift under 10V drain bias was ~300mV for the same time period.

Dynamic on-resistance under switching conditions was 1.6x the static on-resistance. The relatively modest current collapse is attributed to nitrogen passivation being applied before silicon nitride on the AlGaN barrier layer. An increase in the threshold voltage was seen in devices with a recessed gate — unfortunately the recessing also reduced the maximum drain current.

The $HfZrO_2$ blocking layer delivered both high threshold voltage and maximum drain current, compared with other enhancement-mode GaN devices. ■

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

Gallium nitride implanted current-aperture vertical electron transistor

Researchers claim first demonstration of a device with 450V blocking voltage and respectable on-state characteristics.

University of California Davis (UC Davis) and University of California Santa Barbara (UCSB) in the USA have claimed the first demonstration of an implantation-based current-aperture vertical electron transistor (CAVET), grown on sapphire, blocking 450V with respectable on-state characteristics [Saptarshi Mandal et al, IEEE Electron Device Letters, published online 30 May 2017].

Vertical devices are probably needed for higher power handling beyond 15kW, while the more widely developed lateral power devices seem to be economical up to 10kW.

The CAVET's 1µm n^+-GaN drain, 6µm n^--GaN drift and 300nm lightly doped n-GaN aperture layers (see Figure 1) were grown by metal-organic chemical vapor deposition (MOCVD). The current-blocking layer (CBL) aperture was defined by magnesium ion implantation with a photoresist mask. The aperture area (AAP) was 394µm^2 and the CBL area (ACBL) was 2490µm^2. The ion implant energy was varied to give a box profile.

The channel region was grown using ammonia-based molecular beam epitaxy (MBE). The advantage of this is a lower growth temperature, which reduces loss of magnesium doping through out-diffusion from the CBL into the channel layer.

The channel consisted of 15nm carbon-doped GaN and 300nm silicon-doped n-GaN. The aim of the carbon-doping was to compensate for a silicon excess on the growth surface which could not be removed by photoresist cleaning processes involving hydrogen fluoride, oxygen plasma clean and heated n-methyl-2- pyrrolidone.

The material structure was completed with 100nm of p-GaN, which became the gate insulator in the CAVET. The p-GaN gate-aperture overlap (L_{GO}) was 5µm. Such p-GaN gates are expected to have reduced leakage compared with the AlGaN/GaN Schottky barrier often used in lateral devices.

The CAVET fabrication used inductively coupled etching of the access regions. Electrical isolation was achieved through forming 1µm deep mesas.

The drain consisted of an etched 1µm-deep 2.4mm-diameter circle. The source and drain contact metals

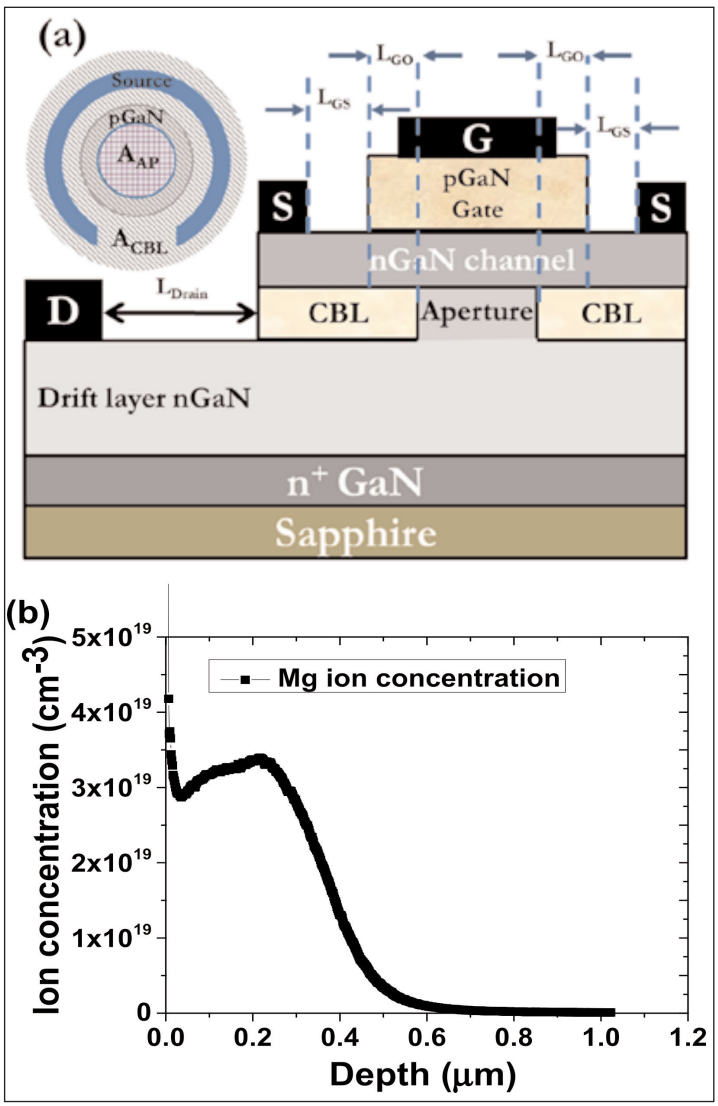

Figure 1. (a) Device structure of CAVET. Inset: top-view. The inner shaded area is the aperture and the outer shaded area is the CBL; p-GaN covers the entire aperture area. (b) Magnesium (Mg) ion distribution of implanted profile, as obtained from secondary-ion mass-spectrometry (SIMS).

were titanium/aluminium/nickel/gold. The metal stack was annealed at low temperature (735°C) to avoid the source metals spiking into the CBL. The p-GaN-source

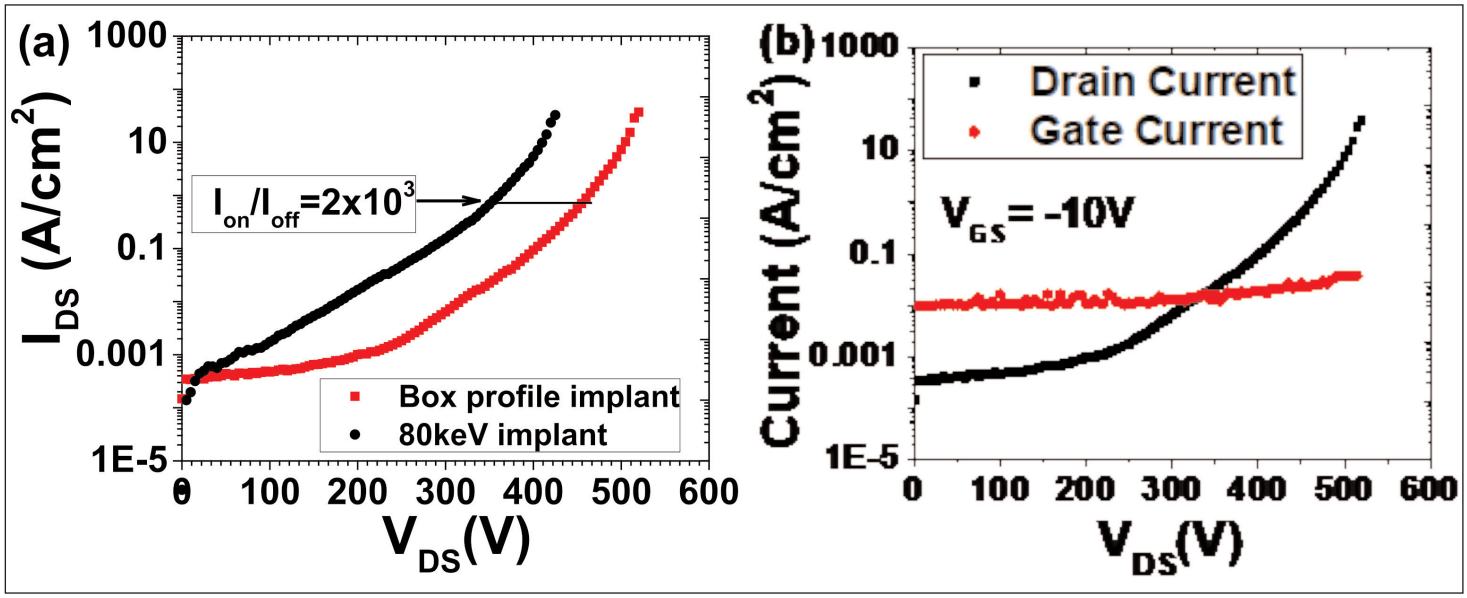

Figure 2. (a) Three-terminal breakdown of CAVET with box profile and single-energy (80keV) implanted CBL. (b) Gate and drain leakage current during breakdown measurement.

distance (L_{GS}) was 4μm. The drain contact to device distance (L_{Drain}) was 20mm.

The gate metal stack was palladium/nickel/gold. A 500nm layer of plasma-enhance chemical vapor deposition (PECVD) silicon nitride was used as passivation.

The maximum drain current density was 600A/cm^2 with 30V drain bias and +4V gate potential. The density was relative to the area enclosed by the source electrode. The device pinched off at −10V gate potential with 30V drain bias.

Pulsed operation saw no reduced current ('collapse') or dispersion from the static DC results. The researchers attribute this to the CAVET structure with the high-electric-field region buried in the drift region, away from the surface, unlike in lateral devices such as high-electron-mobility transistors (HEMTs). In fact, the researchers add: "The DC characteristics showed a reduction in current, which could be attributed to self-heating effects due to longer bias times." Sapphire is thermally insulating, reducing heat dissipation.

The three-terminal breakdown in the pinch-off state was estimated at 450V for 1mA maximum current, and on/off current ratio of 2x10^3 (Figure 2). In fact, the devices were able to withstand 520V. The researchers comment: "This is the highest reported breakdown for CAVETs with implanted CBL. The off-state leakage at a given voltage is also two orders of magnitude lower than existing state-of-art AlGaN/GaN CAVETs with ion-implanted CBL."

The source–gate leakage was initially higher than the source–drain leakage. However, at 350V drain bias the source–drain leakage begins to dominate up until breakdown. The gate–source leakage was tentatively attributed to current flow along the etched p-GaN sidewall. The drain–source leakage was attributed to breakdown/shorting of the CBL. ■

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Tel: +32-14 24 53 67
Fax: +32-14 24 58 00
www.substrates.umicore.com

Wafer World Inc
1100 Technology Place, Suite 104,
West Palm Beach, FL 33407,
USA
Tel: +1-561-842-4441
Fax: +1-561-842-2677
E-mail: sales@waferworld.com
www.waferworld.com

4 Epiwafer foundry

Spire Semiconductor LLC
25 Sagamore Park Drive,
Hudson, NH 03051,
USA
Tel: +1 603 595 8900
Fax: +1 603 595 0975
www.spirecorp.com

Albemarle Cambridge Chemical Ltd
Unit 5 Chesterton Mills,
French's Road, Cambridge CB4 3NP,
UK
Tel: +44 (0)1223 352244
Fax: +44 (0)1223 352444
www.camchem.co.uk

Intelligent Epitaxy Technology Inc
1250 E Collins Blvd,
Richardson,
TX 75081-2401,
USA
Tel: +1 972 234 0068
Fax: +1 972 234 0069
www.intelliepi.com

IQE
Cypress Drive,
St Mellons, Cardiff
CF3 0EG,
UK
Tel: +44 29 2083 9400
Fax: +44 29 2083 9401
www.iqep.com
IQE is a leading global supplier of advanced epiwafers, with products covering a diverse range of applications within the wireless, optoelectronic, photovoltaic and electronic markets.

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France
Tel: +33 1 45 10 67 31
Fax: +33 1 45 10 69 53
www.ommic.fr

Soitec
Place Marcel Rebuffat, Parc de Villejust, 91971 Courtabouef, France
Tel: +33 (0)1 69 31 61 30
Fax: +33 (0)1 69 31 61 79
www.picogiga.com

5 Deposition materials

Akzo Nobel High Purity Metalorganics
www.akzonobel.com/hpmo
Asia Pacific:
Akzo Nobel (Asia) Co Ltd,
Shanghai,
China
Tel. +86 21 2216 3600
Fax: +86 21 3360 7739
metalorganicsAP@akzonobel.com
Americas:
AkzoNobel Functional Chemicals,
Chicago,
USA
Tel. +31 800 828 7929 (US only)
Tel: +1 312 544 7000
Fax: +1 312 544 7188
metalorganicsNA@akzonobel.com
Europe, Middle East and Africa:
AkzoNobel Functional Chemicals,
Amersfoort, The Netherlands
Tel. +31 33 467 6656
Fax: +31 33 467 6101
metalorganicsEU@akzonobel.com

Cambridge Chemical Company Ltd
Unit 5 Chesterton Mills,
French's Road,
Cambridge CB4 3NP,
UK
Tel: +44 (0)1223 352244
Fax: +44 (0)1223 352444
www.camchem.co.uk

Dow Electronic Materials
60 Willow Street,
North Andover, MA 01845,
USA
Tel: +1 978 557 1700
Fax: +1 978 557 1701
www.metalorganics.com

Matheson Tri-Gas
6775 Central Avenue,
Newark, CA 94560,
USA

Tel: +1 510 793 2559
Fax: +1 510 790 6241
www.mathesontrigas.com

Mining & Chemical Products Ltd
(see section 1 for full contact details)

Praxair Electronics
542 Route 303, Orangeburg,
NY 10962,
USA
Tel: +1 845 398 8242
Fax: +1 845 398 8304
www.praxair.com/electronics

SAFC Hitech
Power Road, Bromborough,
Wirral, Merseyside CH62 3QF,
UK
Tel: +44 151 334 2774
Fax: +44 151 334 6422
www.safchitech.com

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

6 Deposition equipment

AIXTRON SE
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52134 Herzogenrath,
Germany
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Fax: +49 2407 9030 40
www.aixtron.com

AIXTRON is a leading provider of deposition equipment to the semiconductor industry. The company's technology solutions are used by a diverse range of customers worldwide to build advanced components for electronic and optoelectronic applications (photonic) based on compound, silicon, or organic semiconductor materials and, more recently, carbon nanotubes (CNT), graphene and other nanomaterials.

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CH-9477 Trübbach, Switzerland
Tel: +41 81 403 8000
Fax: +41 81 403 8001
www.evatecnet.com

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Fax: +1 925 449-4096
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www.riber.com

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

Veeco Instruments Inc
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7 Wafer processing materials

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

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

Praxair Electronics
(see section 5 for full contact details)

8 Wafer processing equipment

EV Group
DI Erich Thallner Strasse 1,
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Fax: +43 7712 5311 4600
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Fax: +44 (0) 1389 879 042
www.logitech.uk.com

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

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

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

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

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

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

9 Materials & metals

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

10 Gas and liquid handling equipment

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

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

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

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

11 Process monitoring and control

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

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

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Fax: +1 408 875 4144
www.kla-tencor.com

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

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

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

12 Inspection equipment

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

13 Characterization equipment

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

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

14 Chip test equipment

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

15 Assembly/packaging materials

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

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

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

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

16 Assembly/packaging equipment

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

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

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

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

17 Assembly/packaging foundry

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

18 Chip foundry

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

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

19 Facility equipment

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

20 Facility consumables

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

21 Computer hardware & software

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

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

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

22 Used equipment

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

23 Services

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

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Stuttgart,
Germany
Tel: +49 711 8804 1141
Fax: +49 711 8804 1950
www.mw-zander.com

24 Consulting

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

25 Resources

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

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

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

event calendar

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

6–9 September 2017
19th China International Optoelectronic Exposition (CIOE 2017)
Shenzhen Convention & Exhibition Center, China
E-mail: Shirly.Yi@cioe.cn
www.cioe.cn/en

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

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

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

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

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

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

26 September 2017
Photonic Integration Conference 2017
High Tech Campus Eindhoven, The Netherlands
E-mail: info@jakajima.eu
www.phiconference.com

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

13–17 May 2018
IEEE 30th International Symposium on Power Semiconductor Devices and ICs (ISPSD 2018)
Chicago, IL USA
E-mail: info@ispsd.org
www.ispsd2018.org

5–7 June 2018
PCIM Europe (Power conversion and Intelligent Motion) 2018
Nuremberg Messe, Germany
E-mail: daniela.kaeser@mesago.com
www.mesago.de/en/PCIM/main.htm

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